EFFECT OF RECYCLED TYRE STEEL FIBRES ON STRUCTURAL PERFORMANCE AND IMPACT RESISTANCE OF RUBBERIZED CONCRETE

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April 2018

DECLARATION

I declare that this Thesis is my original work and has not been presented for award of a degree in any other university.

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DEDICATION

To PAUSTI Administrations

JKUAT Administration

To my Supervisors

To my family

To my colleagues

To my friends

ACKNOWLEDGEMENT

My first acknowledgement is addressed to the almighty God, for all he has done for me, keeping me healthy during my education and the time for this research project. I would Particularly like to express my sincere appreciation to my supervisors **Prof. Walter Odhiambo Oyawa**, **Prof. Richard Onchiri and Prof. Stanley M. Shitote** for their advices on the achievement of this research project. I also give thanks to my classmates for their moral support, motivations, and inspiration.

ABSTRACT

The disposal of waste tyres continues to raise an environmental concern on the world. The dumping of used tyres is a serious environmental problem mostly in urban areas of Kenya and other urbanized areas of African countries. Many researches have been done on the use of waste tyre rubbers in concrete, but most of the tyre rubbers are only being used for production of non-structural Concrete, as filling materials, which in turn reduce its potential use in Civil Engineering Construction industry. The major cause, is the reduction in mechanical strengths of rubber concrete which makes it unsuitable for structural component subjected to heavy static or dynamic forces. In this research, Recycled tyre steel fibres(RTSF) were used to investigate their effect on structural performance of rubber concrete.

Crumb Rubber ranging of (0.15mm-2.36mm) was used for partial replacement of natural fine aggregates by 5,10,12.5,15 and 20% volume to evaluate the effect of Crumb Rubber volume on concrete mechanical properties. For investigating the effect of the recycled tyre steel fibres on rubber concrete, a resulted optimum value of 12.5% Crumb Rubber volume was mixed with different percentages of RTSF by 0.3,0.6, 0.9 and 1.2% of mass of the concrete with the fibres having different lengths which are 60,40 and 20mm. Three different mix groups: (CR0, CR5, CR10, CR12.5, CR15, CR20); (CR12.5-V0.3L60, CR12.5-V0.6L60, CR12.5-V0.9L60, CR12.5-V1.2L60); and (R12.5-V1.2L60, CR12.5-V1.2L40, CR12.5-V1.2L20) were casted and tested at 7 and 28 days of curing. The first group were tested to assess the effect of Crumb Rubber volume on compressive and tensile strength of concrete. The second group were tested to evaluate the effect of RTSF content on properties of Rubberized concrete. The third group were casted and tested to investigate the effect of the RTSF aspect ratio on properties of rubberized concrete.

The results showed that, at 12.5% of rubber content, Compressive, tensile and flexural strength reduced by 21.51, 17.44 and 17.4% respectively at 28 days; and Flexural toughness and Impact strength increased by 5.9 and 58.82% respectively at 28 days. The addition of RTSF volume up 1.2%, the compressive, tensile and flexural strength of Recycled tyre steel fibre reinforced rubber concrete(RTSFRC) reduced by 10.38, 0.27 and 4.3% respectively at 28 days; and flexural toughness and Impact strength increased by 258.75% and 741.18% respectively compared to plain concrete at 28 days. The results further indicated that, the increase in aspect ratio of RTSF resulted in increase of mechanical properties, toughness and impact resistance, but limitation should be put to avoid balling effect of RTSF caused by higher value of aspect ratio, in this regard 60mm fibre length was adopted as the maximum. The interesting results confirm the promising application of recycled tyre steel fibres and crumb rubber in construction industry.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACI	American concrete Institute
AR	Alkali Resistant
ASTM	American Standard Testing Method
BS	British standard
BSI	British Standard Institute
ES	European Standard
FC	First Crack
FRC	Fibre Reinforced Concrete
GFRC	Glass Fibre Reinforced Concrete
GGBS	Ground Granulated Blast Slag
HRWR	High Range Water Reducer
ISF	Industrial Steel Fibre
ISFRC	Industrial Steel Fibre Reinforced Concrete
J	Joule
JKUAT	Jomo Kenyatta University of Agriculture and Technology
JSCE	Japan Society of Civil engineers
KN	Kilo Newton
LVDT	Linear Variable Differential Transformer
MPa	Mega pascal
MSF	Manufactured steel Fibre
NEMA	National Environmental Management Authority

PAUSTI	Pan African University Institute for Basic Science Technology and Innovation
PFA	Pulverized Fuel ash
PPC	Portland Pozzolana cement
PPF	Polypropylene Steel Fibre
PRSF	Pyrolyzed recycled Steel Fibre
RSF	Recycled Steel Fibre
RTPF	Recycled Tyre Polymer Fibre
RTSF	Recycled Tyre Steel Fibre
RTSFRC	Recycled Tyre Steel Fibre Reinforced Rubber Concrete
SCRC	Self-Consolidated Rubberized Concrete
SEM	Scanning Electron Microscopy
SFCR	Steel Fibre Reinforced concrete
SNFRC	Synthetic Steel Fibre reinforced Concrete
SRSF	Shredded Recycled Steel Fibre
UTM	Universal testing Machine

LIST OF APPENDICES

PUBLICATIONS

1. "Combined Effect of Recycled Tyre Steel Fibre and Crumb Rubber on Flexural Toughness of Concrete "published in International Journal of Innovative Science and Modern Engineering (IJISME): http://ijisme.org/download/volume-5-issue-1/

2. "Cumulative effect of Recycled Tyre Steel Fibre and crumb rubber on impact resistance of concrete" Published in European International Journal of Science and Technology (EIJST): http://eijst.org.uk/

CHAPTER ONE: INTRODUCTION

1.1 Background to the study

The overall global development has required Construction of great numbers of roads and the increase of population has raised the vehicular density from last few decades. For a Country like Kenya, an increase of roads construction is still necessary for national integration, industrial development as well as socio-economic development. Due to improvement in living standards of the people, the use of vehicles has increased over a last few years, giving rise in the vehicular density on roads. As vehicles are frequently used the wear and tear of their tyres is obvious. Due to wear and tear of tyres the life of tyre reduces and at last it becomes useless (Scrap tyres). The disposal of these used tyres has become a serious problem. These waste tyres are disposed mostly by either burning or by dumping. Disposal by burning causes air pollution and dumping causes valuable land to be wasted for stacking up the tyres. So, it is required to dispose them safely and economically (NOOR, 2014).

It has been reported that, the most commonly potential environmental impacts associated with tyre storage are: compounds leaching from the tyres and contaminating soil, groundwater and surface water, uncontrolled open air burning of tyres which releases pyro lytic oils and other compounds into the soil and groundwater as well as large plumes of black smoke and other contaminants into the air. In addition to this, water used to extinguish tyre fires is likely to become contaminated with tyre compounds. Tyre piles may become breeding grounds for insects, rodents and other animals. Mosquitoes are a concern in tropical and subtropical countries because they are capable of transmitting diseases to humans (BMZ, 2014)**.**

Many Countries of EU and USA have been aware of this problem and many researches have been done on the use of tyre rubbers in civil engineering application. Tyre rubbers were used to partially replace normal aggregates and the resulted Rubber concrete showed advantages and disadvantages. The most disadvantages are the significant decrease of mechanical properties of the concrete which are important properties of concrete for structural application purpose. The reason for this decrease was reported to be the weak bond between rubber aggregates and cement paste, and low modulus of elasticity of rubber particles compared to conventional aggregate particles. Different inorganic compounds such as NaOH, H2SO4, Anhydrous ethanol were used to treat the Rubber aggregates surface to increase the bond between Rubber aggregates and cement matrix but, the resulted strengths were still much lower than those of normal concrete which still hinders the use of this rubber concrete in civil engineering applications (NOOR, 2014)

Based on many researches it was proven that industrial steel fibres increase the strengths and other properties of concretes. In 1,500,000,000 tons of waste tyres that are produced in world each year, 360, 000,000 tones are steel fibres/wire which are mostly deposed in land fill (Angelakopoulos, 2008)**,** (Martinez Juan Danial, 2013)**.**

Material recovery from used tyres is undertaken either mechanically or thermal degradation process. The former reduces tyres to steel fibres and granulated rubbers and the latter process breaks down the tyres into steels, char, and liquids and gases.

The recovered steel fibres (RSF) are currently either used as scrap feed in steel manufacturing or end up being deposed into landfill (Pilakoutas K. N., 2004)

Recently, researchers have developed methodology to extract used tyre steel cord and use in Concrete. The concrete obtained by adding randomly distributed of steel fibres showed a satisfactory improvement of fragile concrete matrix in terms of toughness and post-crack behaviour, ductility, impact energy resistance and flexural strength (ACI committee 544.R5-10, 2010) (Carpenteri.A,Bringheti.R, 2010).In addition to that , it was proven that mechanical behaviour of concrete reinforced with fibres extracted from waste tyres is comparable to that of conventional steel fibre reinforced concrete. As consequence, Recycled tyre steel fibre reinforced rubber concrete (RTSFRC) appears to be a promising candidate for both structural and non-structural concrete (Alieo M, 2008)**.**

Concrete with the above mentioned enhanced properties is preferred in construction of airport runaway pavements, Industrial flooring, bridges, military buildings, hydraulic structures, earthquake resisting structures and heavy machinery foundations, where dynamic loading is enormous. Under dynamic loading, plain concrete exhibits excessive cracking and undergoes brittle failure mode with a relatively low impact energy absorption capacity. Fibre reinforced concrete is best candidate for concrete structures resisting impact loads and limiting initiation and propagation of plastic shrinkage cracks which usually affect durability of concrete structures (ACI committee 544.R5-10, 2010).

This research studies the effect on structural performance of Rubber concrete reinforced with Recycled tyre steel cord extracted from waste tyres. The increase in mechanical properties of Rubber Concrete will increase potential use of waste tyre rubber in civil structural constructions, solving the disposal problem of waste tyres and same way saving the cost.

1.2 Problem statement

At present the disposal of waste tyres is becoming a major waste management problem in the world. It is estimated that 1.5 million tons of used tyres are produced annually, and out of these tons of waste tyres only 4% is being used for civil engineering application. It was reported by NEMA in 2012 that Kenya generates almost over 2 million waste tyres with majority of them being disposed hazardously in the environment, GIZ, (2012). Concrete is the most widely used as structural material in the world, due to its easy preparation and low cost. For this reason, many researches have been done on the use of waste tyre rubber as an aggregate in production of rubberized concrete as one of safe and effective disposal of waste tyres. Based on many researches, Rubber concrete exhibits a decrease in mechanical properties due to weak bond between rubber aggregates and cement paste, as well as low modulus of elasticity of rubber particles.

To improve bond property of Rubber aggregate, rubber surface was treated with inorganic compounds; though an increase in strength was observed on rubber concrete with treated rubber aggregates, still the strengths were much lower than that of normal concrete, as result, tyre rubber is still being used as filling material. As structural concrete is widely used in Civil engineering industry, the decrease in strengths has reduced the potential use of rubber concrete in civil engineering application. Recycled tyre steel fibre has been tested and showed good property as that of industrial steel fibres. For this reason, an attempt is to be made on the use of recycled tyre steel fibre (RTSF) as reinforcement to improve Structural performance of Rubberized concrete. Industrial Steel Fibre Reinforced concrete (ISFRC) has shown Improved ductility, impact resistance, toughness, crack control and energy absorption capacity. Once the inclusion of RTSF improve structural performance of rubber concrete, it will ultimately induce the potential use of waste tyre in structural construction industry which will be environmentally beneficial and technically sound.

1.3 Objectives of the research

1.3.1 General objective:

To investigate effect on structural performance, Flexural toughness and impact resistance of rubberized concrete by incorporating Recycled tyre steel cords as reinforcement.

1.3.2 Specific Objectives:

1. To evaluate the effect of recycled tyre steel fibres on Compressive, tensile and Flexural strengths of rubberized concrete
2. To determine the impact of combined Crumb Rubber and recycled tyre steel fibres on Flexural toughness of concrete
3. To assess cumulative effect of the recycled tyre steel fibres and Crumb Rubber on impact resistance of concrete

1.4 Research questions and hypothesis

1.4.1 Research question

1. Do recycled tyre steel fibres affect Compressive, tensile and Flexural strengths of Rubberized concrete?
2. Do combined recycled tyre steel fibre and Crumb Rubber in concrete affect the flexural toughness of concrete?
3. Do recycled tyre steel fibre and Crumb Rubber in concrete affect the impact resistance of concrete?

1.4.2 Research hypothesis

1. **$H_0$1**: Recycled steel fibres do not affect compressive, tensile and Flexural strength of Rubber concrete
2. **$H_0$2**: Combined Recycled tyre steel fibre and Crumb Rubber in concrete do not affect flexural toughness of concrete
3. **$H_0$3:** adding Recycled tyre steel fibre and Crumb Rubber in concrete do not affect impact resistance of concrete

1.5 Research justification

As reported in many researches, waste tyres will continue to be increasing as roads increase. Country like Kenya will face the problem of waste tyre disposal as million tons of waste tyres are produced at increasing rate each year and yet there is no defined safe environmental management of waste tyres (NOOR, 2014). Using waste Tyre Rubber as an aggregate material and recycled tyre steel fibres as reinforcement in concrete will significantly reduce a great amount of waste tyres which affects environment causing atmospheric contamination. The efforts of using waste tyre in concrete production will not only be beneficial to the government in reduction of providing land for disposal, but also will contribute to the growth of economy in various sectors especially in construction industry.

Since rubber concrete was reported to have good properties such as impact resistance, good ductility index, and energy absorption capacity; Once the mechanical properties of rubber concrete are improved by using recycled tyre steel fibres, RTSFRC will be beneficial for the design of concrete pavement subjected to dynamic forces, Concrete structures susceptible to earthquake loads, heavy machinery foundations to minimize damage caused by vibration and also design of industrial floors to reduce damage due to abrasion forces.

1.6 Scope of the study

The Proposed research is limited to the determination of effect on combination of Recycled tyre steel fibre and Crumb Rubber on Compressive, Tensile and flexural strengths, Flexural Toughness and Impact energy of Concrete, by incorporating waste tyre steel cord as reinforcement and Crumb rubber as an aggregate. Crumb Rubber of size of (0.15mm-2.36mm) from Rubber company and recycled tyre steel cord from Pyrolysis plant (acqualine distributor company) were used in this research. Experimental tests were conducted in JKAUT structural and Materials laboratory.

1.7 Organisation of the thesis

This Thesis is structured into 5 main chapters, each chapter is divided in number of sections and further subsections. Chapter One describes, the background to the study, Objectives of the research and its significance inclusive of the methodology.

In Chapter Two, a comprehensive review on the use of steel fibre reinforced concrete is discussed. The type of application and design consideration of Rubber concrete is addressed in this chapter. The types and, properties and current application of fibres are also described. Recycled tyre steel fibre recycling, its properties and area of applications have been given more focus in this chapter.

Chapter Three deals with Materials and Methods used for the current study. Properties of Materials used, mix proportioning of the materials, Mixing, casting and curing procedures have been broadly covered in this chapter. All the procedures performed to conduct different tests are also explained in detail in this chapter.

Chapter Four focuses on the results, analysis, discussion and presentation of the test results. The results are presented in different forms such as Graph and tables. Graphs have been used to show a possible relationship of the variables considered in this research. Tables have also employed in the presentation of the results to statistically analyse the data collected during experimentation.

Chapter Five focus on conclusions drawn and recommendation given to further researchers from the current study. At the end of this chapter, a section of references is followed, and other important data are given in the appendix of this thesis book.

CHAPTER TWO: A REVIEW ON FIBRE REINFORCED RUBBER CONCRETE

2.1.Introduction

Rubberized concrete is a special concrete made by incorporating Tyre Crumb Rubber, replacing either fully or partially the normal aggregates, having the same dimension of the replaced aggregate. Fibres are added randomly in a concrete matrix to produce a composite material named Fibre reinforced concrete(FRC). When steel fibres are added to rubber concrete matrix they produce a composite material which is Steel fibre reinforced Rubber concrete (SFRC) (M.A.AielloF.Leuzzi, 2010)

2.2.Use of waste tyre rubber in concrete

2.2.1. Waste Tyre properties

The RMA (Rubber Manufacturers Association) defines a scrap tyre as a tyre that can no longer serve its original intended purpose. According to the Waste Tyre Working group comprising key stakeholders such as NEMA, Kenya Revenue Authority, cement manufacturers, tyre manufacturers, and dealers, Kenya generates over 1,000,000 scrap tyres annually.

a. Physical Properties of tyres

Tyres consist of a rubber compound usually reinforced with steel and textile. Depending on their size and utilisation, tyres vary in design, construction and total weight. The weight of a used passenger car tyre in Europe is about 6.5 kg and that of a truck tyre is about 53 kg.2 Passenger car and truck tyres make up approximately 85% of the total tyres manufactured globally.

b. Chemical Composition of tyres

Approximately 80% of the weight of car tyres and 75% of truck tyres is rubber compound. The compositions of tyres produced by different manufacturers are reported to be similar. Table 2.1 shows the material composition of passenger car and truck tyres from the European Union (EU) as well as the composition of tyre rubber from Canada. (Newsealandltd, july 2004)

c. Thermal Properties of tyres

The net calorific value of a tyre is between 26 and 34 GJ/tonne, which is similar to that of common fuel sources such as coal. A tyre is difficult to ignite. It burns almost completely at 650°, producing principally carbon dioxide and water, plus inert resides such as ash and slag (zealand.ltd, 2014)

Table 2. 1.Comparison of material composition of passenger car and truck tyres

Materials	**Car tyre (%)**	**Truck tyre (%)**	**Tyre rubber (%)**
Rubber/elastomers	47	45	62
Carbon black	21.5	22	31
Metal	16.5	25	NA
Text	5.5	-	NA
Zink oxide	1	2	2

Sulphur	1	1	1
Additives	7.5	5	4

d. Post-Consumer Tyre Material

Product yields for post-consumer tyre materials do not correspond to new tyre composition because of most waste tyres have significant tread wear reducing the amount of rubber material available for product yield and increasing the percentage contributions of non-rubber constituents such as metals and fibre see table 2.2. Also, Crumb rubber contains some contamination of metals and fibres in most grades. Only the finest grades/powders are completely wire and fibre-free. What is identified as "crumb rubber" incorporates the rubber/elastomers, inevitably, some rubber materials adhere to the steel (Evans, May 2006).

Table 2. 2.Material Composition of the post –Consumer tyre Materials

Product yield	**Car Tyres (%)**	**Truck Tyres (%)**	**OTR Tyres (%)**
Crumb Rubber	70	70	78
Steel	17	27	15
Fibre &Scrap	13	3	7

e. Environmental issues due to uncontrolled disposal of waste tyres.

Based on available statistics it is estimated that in Kenya about 1.1 Million waste tyres have been burnt haphazardly, dumped, destroyed or re-used by methods that pollute air, soils and ground water in 2010. The Kenyan Environmental Management and Coordination Regulations for waste management have already been enacted in 2006, but they do not specifically address the treatment and disposal of waste tyres. There are indeed no such established and certified methods across East Africa. In cement production waste tyre chips, can be co-processed as an alternative fuel resource (AFR) replacing fossil fuel in an environmentally sound manner. However, without the regulatory framework to engage in such practices, approval will not be given by the authorities. Besides, many thousand people are engaged in recycling activities - most of them in the informal sector, picking, processing and trading recyclables from waste, not least of which are old rubber tyres. A minor percentage is used for producing shoes, ropes and other materials, but to a much bigger extent the tyres are burnt to separate the steel from the rubber, which is then sold to scrap traders. Those incomes generating interests cannot be left aside when trying to resolve the issue (BMZ, 2014)

f. Benefit of using Waste tyres rubber in structural concrete

The use of recycled tyre rubber in concrete promotes the development of eco-friendly constructions and encourages the concept of sustainable Construction materials, which is receiving greater attention nowadays. In addition to that, low density of rubber aggregate compared to a normal aggregate can substantially contribute to the development of semi-lightweight and lightweight concrete, which helps to reach a more economical design. Based on the report of different researches, inclusion of rubber aggregate in concrete results in improved ductility, strain energy capacity, impact resistance, deformation capacity and Energy absorption of concrete, however, mechanical properties reduce as the rubber aggregate content increase., which was reported to be caused by lower modulus of rubber aggregate compared to conventional ones and Poor adhesion between rubber aggregate and cement paste. Though different researches have been done to improve mechanical properties of rubber concrete by using treatment on rubber particles such as polyvinyl alcohol, sodium hydroxide, and sulphur compounds. However insignificant improvement was observed. Researches are still being conducted on how to improve mechanical properties of rubber aggregates. (American Concrete Institute, 2016)

2.2.2. Properties of Rubberized concrete

Prashant et al (2014) Conducted a research on the use of Waste Tyre Crumb Rubber in concrete as Partial Replacement to Fine Aggregate. The replacement was done by the mass of fine. The Crumb rubber was having size ranging between 600 µm-1.18mm. The waste tyre Crumb rubber was immersed into NaoH solution for 20 min and then dried before using in the concrete mix. NaoH treatment to the surface of rubber particle was to enhance the adhesion between the rubber particles and cement paste. Compressive, Tensile and Flexural strength tests were conducted on Concrete cube (150X150x150mm), Cylinders (150mm and 300mm height) and Concrete beam (150x150x700mm) respectively. The researchers observed from results that, for higher rubber content workability of concrete increases. They further added that for 0.5 and 1% replacement of Crumb rubber to normal sand in concrete, it has no effect on Compressive, Split tensile and Flexural strength of concrete. But at 2% replacement of Normal sand by Crumb rubber, they observed a decrease in compressive, Split tensile and flexural strength by 20.32 and 4.86% and 19.07% respectively. They concluded that, the workability of concrete increase with increase in Crumb rubber content, but Compressive, split tensile and Flexural strength decreases with the increase in Crumb rubber content. (Chavan, 2014)

Osama Youssef (2017) experimentally studied the effect of crumb rubber on mechanical performance of concrete. The researcher considered two different cases, when the Rubber concrete are unconfined and confined with Fibre reinforced polymers(FRP). 10 ,20 ,30 ,40 and 50% volume replacement of normal sand by Rubber crumb were added in concrete mixes. In the results, author stated that, at 10, 20, 30, 40 and 50%, the compressive and tensile strength reduced by 21.3 ,37.9 ,54.3 ,62.5 and 66.4%, and 15 ,40.1 ,44.1 ,48,9 and 58.5% respectively at 28 days in case of unconfined rubber concrete. They further stated that, Modulus of elasticity decreases by 4.8 ,16.4 ,30.1 ,34.8 and 51.5% as the rubber percentages replaces normal sand respectively. In the conclusion, the author said that, using Rubber in concrete nearly has a slight effect on concrete unit weight, only 6.9% reduction on unit weight was observed when 50% rubber content was used. They also added that, Compressive, split tensile and Flexural strengths reduced linearly at 7 and 28 days as the rubber increase in concrete (Osama Youssf,Reza Hassanli, Julie E.Mills, 2017).

Yazdi M.A (2015) made a review on Application of Waste Tyre in Concrete. The study was to summarize the achievement of different researchers in improvement of mechanical properties of on plain rubber concrete, by treatment of rubber aggregates, by varying the size and amount of rubber in concrete, using Cementous materials and examining the macrostructure behaviour of rubberized concrete. In their findings, the authors reported that, increasing energy absorption is one of the benefits of using waste rubbers in concrete. Tyre rubber particle pull-out and internal tyre rubber micro cracking are two toughening mechanisms for energy consumption in the rubber-concrete matrix that cannot be observed in ordinary concrete. The researcher mentioned that, the mechanical strength reduces significantly with increase in amount of rubber content, for untreated rubber, the optimum amount of rubber should be between 20-30% volume. They also stated that, some researchers relate the strength reduction of the rubberized concrete with increasing rubber content for two reasons: First, initiated cracks around of the rubber particles due to the softy property of rubber particles that accelerate the failure of the rubber aggregates and cement matrix. Secondly, because of the lack of bond strength and adhesion between the rubber particles and cement paste, and that soft nature of rubber may behave as voids in the concrete matrix (M. A. Yazdi, 2015).

Pelisser, F et al (2011), studied the morphology and porosity of the interface characteristic of between the rubber particles and the cement- matrix by scanning electron microscopy (SEM). Authors, concluded that, incorporating of rubber particles in concrete leads to the presence of large gaps in the interface between rubber and cement matrix. However, reduction in porosity was observed when the rubber treatment by sodium hydroxide and 15% silica fume was added. They claimed that this reduction is attributed to the high concentration of NAOH in the area, which is probably due to the hydrophilic effect of the treatment with sodium hydroxide.

Moreover, the presence of silica fume can contribute to better adherence and reduction of the weakness points. Other researchers have added that, mechanical properties reduction is rubber concrete is caused by the easily rise of rubber particles to the surface of concrete which creates uneven internal stress concentration due to un even distribution of the rubber and leads to weak interfaces and internal crack creation(Pelisser, F., et al, 2011). Reda Taha et al**.** (2008), made a thorough observation of microcracking system in the concrete rubber particle vicinity, which weakens the bond between tyre rubber particles and the cement matrix, and results proved that the soft property of tyre particles produce tensile strains on tyre rubber/ cement matrix surfaces and create microcracking in cement paste vicinity. He examined the effect of treatment of rubber aggregate with Anhydrous Ethanol on contact angle between rubber and cement paste. They concluded that, contact angle reduces as in the treated rubber concrete compared to untreated one (Reda Taha, M.M., et al., 2008).

Huang et al. (2015) Reported that, reducing rubber aggregate size means reducing stress and strain concentration. Crumb rubber filled concrete has more strengths than rubber chip-filled concrete. They further reported that, higher rubber content and smaller rubber particle size decreased compressive strength and modulus of elasticity of concrete, while the ultimate strain capacity increased with increase in rubber content with smaller rubber particle size. They added that, the number, length and size of cracks in concrete decreases with increase in rubber aggregate content. Workability and Permeability of concrete are more affected by rubber content than density and strength. The researcher concluded that, with treated and untreated rubber aggregate, the optimum rubber in concrete should be between 20-30% to maintain the strength and stiffness of rubberized concrete.

Osama Youssef (2017), conducted an experimental study on impact energy resistance of concrete containing high Crumb rubber content. They examined the performance of the rubber concretes when the concretes were uncoated and coated with different layers of Fibre reinforced polymers(FRP). Different percentages volume replacement of normal sand by Rubber crumb were added in concrete. The test was conducted according to ACI 544. rubber concrete discs of (150x50mm) with 25mm notches located at the end of specimens were used for this study. A steel ball of 65.5mm and 1.045kg was placed at the centre of the specimens and a 65.8x162.3mm steel cylinder with 4.5kg was the released repeatedly from a vertical height of 200mm through a hallow tube of diameter of 67mm.The results indicated that at 10 ,20 ,30,40 and 50% volume replacement of normal sand by Rubber crumb, the impact energy resistance increased by 1.55,1.91,2.14,3.14 and 3.52 times plain concrete respectively. The Researcher concluded that, the higher the rubber content, the higher to resist blows and hence the tendency to absorb more impact energy, which a characteristic of a material with improved ductility and toughness properties (Osama Youssf,Reza Hassanli, Julie E.Mills, 2017).

Ahamed Tareq Naoman (2015) studied Impact energy of concrete combined with Crumb rubber and hooked end steel fibre. Low velocity drop weight impact test was conducted to concrete beams of (500x100x100mm). Crumb rubber of 1-2 mm size were replaced 17.5% and 20% of conventional sands and 0.5% fraction volume of hooked end steel were added to the rubber concretes. In the results, they reported that, Compressive strength decreased at both Normal concrete and Fibre reinforced concrete incorporated with Crumb rubber, though there was a little improvement for the rubber concrete reinforced with steel fibre. Impact energy was highly improved with increase in Crumb rubber at 17.5 and 20% volume, Impact energy increased by 133 and 155% respectively. The researcher concluded that, both first crack and ultimate failure impact energy increase with the increase in crumb rubber. (Ahmed.Tareq.N, 2015)

Guo et al (2014) Conducted a research on the effect of rubber aggregate on ductility of concrete, reported that an appropriate rubber content increases ductility of concrete and added that higher volume of rubber aggregate may lead to negative effect on ductility. Grdic et al (2014) conducted a research on effect of rubber aggregate on ductility index of concrete with partially replacing normal sand by rubber sand at levels of 10 ,20 and 30% volume. They reported that ductility index increased with increase in rubber content .at 10,20 and 30% rubber content, the ductility indexes were 25 ,81.25, and 93.75% increment respectively.

2.3.Fibre reinforced concrete

2.3.1. Introduction

Fibre reinforced concrete (FRC) is a composite material made primarily of hydraulic cements, aggregates and discrete reinforcing steel fibres. The reinforcement is in the form of thin, short and distributed randomly throughout the concrete member. Fibres are commercially available and manufactured from steel, plastic, glass, organic polymer (synthetic fibres). Naturally occurring asbestos fibres and vegetable fibres, such as sisal and jute, are also used for reinforcement. Generally, the ratio of length to diameter (i.e. aspect ratio) of fibres is in the range of 20 to 100 with any of the several cross-sections that are sufficiently small to be easily and randomly dispersed in fresh concrete mix using conventional mixing procedure. (ACI 544.1R, 1996)

Fibres as reinforcing materials in concrete, is supposed to induce an increase in strength in concrete matrix as its name defines. For a fibre to be effective in a concrete matrix, it should have the following properties: Its tensile strength should be at least 2 to 3 times that of concrete, Bond strength with concrete should be of the same or higher in magnitude than the tensile strength of matrix, The elastic modulus in tension has to be significantly higher than that of concrete , and the poison's ratio and coefficient of thermal expansion should preferably be of the same order as that of concrete matrix (Jagadish K.S., 2007)**.**

Brittle materials are considered to have no significant post-cracking ductility. Fibrous composites have been and are being developed to provide improved mechanical properties to otherwise brittle materials. When subjected to tension, these unreinforced brittle matrices initially deform elastically. The elastic response is followed by microcracking, localized macrocracking, and finally fractures. Introduction of fibres into the concrete results in post-elastic property changes that range from subtle to substantial, depending upon several factors, including matrix strength, fibre type, fibre modulus, fibre aspect ratio, fibre strength, fibre surface bonding characteristics, fibre content, fibre orientation, and aggregate size effects. For many practical applications, the matrix first-crack strength is not increased. In these cases, the most significant enhancement from the fibres is the post-cracking composite response. This is most commonly evaluated and controlled through toughness testing (ACI 544.1R, 1996)

2.3.2. Different types of fibres

There are two main methods to categorize fibres based on their modulus of elasticity or their origin. In the view of modulus of elasticity, fibres can be classified into two basic categories, namely, those having a higher elastic modulus than concrete mix (called hard intrusion) and those with lower elastic modulus than the concrete mix (called soft intrusion). Steel, carbon and glass have higher elastic modulus than cement mortar matrix, and polypropylene and vegetable fibres are classified as the low elastic modulus fibres. Figure2. 1. Shows schematically different Types of Fibres. High elastic modulus fibres simultaneously can improve both flexural and impact resistance; whereas, low elastic modulus fibres can improve the impact resistance of concrete but do not contribute much to its flexural strength. According to the origin of fibres, they are classified in three categories of metallic fibres (such as steel, carbon steel, and stainless steel), mineral fibres (such as asbestos and glass fibres), and organic fibres. Organic fibres can be further divided into natural and man-made fibres. Natural fibres can be classified into vegetable origin or sisal (such as wood fibres and leaf fibres), and animal origin (such as hair fibres and silk). Man-made fibres can also be divided into two groups as natural polymer (such as cellulose and protein fibres), and synthetic fibres (such as nylon and polypropylene). (Johnston, 1982)

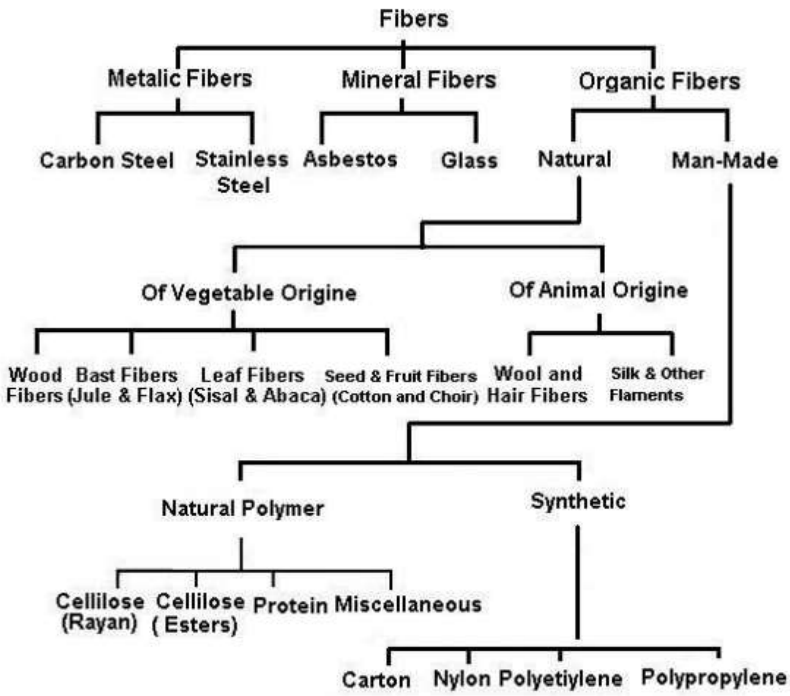


Figure 2. 1.Types of Fibres (James Patrick Maina Mwangi, 1985)

2.3.3. Fibre- matrix bond

A composite system such as FRC, the mechanical behaviour depends not only on the properties of the fibres and the cementitious systems, but also on the bonding between them. For properly designed FRC mixtures, the primary mode of failure is by fibre pull-out, since this consumes much more energy than is involved in breaking the fibres and leads to much better utilization of the fibres. Table 2. 3. Indicate Pull out strengths for different fibre matrices. For steel fibres, there is a combination of adhesion, friction, and mechanical interlock. For glass fibres, there is chemical reaction between the cement and the glass; alkali attack tends to weaken the fibre reinforcement, though to a much lesser extent with the alkali resistant glasses. With the organic fibres, the bond is primarily due to mechanical interlock (Gupa R.K, 2006)

The tensile cracking strain of cement matrix (less than 1/50) is very much lower than the yield or ultimate strain of steel fibres, as a result, when a fibre reinforced composite is loaded, the matrix will crack long before the fibres can be fractured. Once the matrix is cracked the composite continues to carry increasing tensile stress as can be seen on figure 2.2.; when the peak stress and strain of the composite are greater than those of the matrix alone and during the inelastic range between first cracking and the peak, multiple cracking of matrix occurs. Until the initial cracking of the matrix, it is reasonable to assume that both the fibres and the matrix behave elastically and there is no slippage between the fibres and the matrix. After the first cracking of the matrix, the composite will carry increasing loads only if the pull-out resistance of fibres at the first crack is greater than the load at first cracking, since in the post cracking stage, the failure of the composite is generally by fibre-pull-out rather than fibre-yielding or fracture. Table 2.3 shows typical pull-out strengths for a number of different fibres in various matrices (Gupa R.K, 2006)

Table 2. 4.Pull out strength for different fibre matrices

Matrix	**Fibre**	**pull-out Strength (Mpa)**
cement paste	Asbestos	0.8-3.2
	glass	6.4-10.0
	polycrystalline Alumina	5.6-13.6
	Steel	6.8-8.3
Mortar	Steel	5.4
Concrete	Steel	3.6 at first crack
		4.2 at failure
	Nylon	0.14
	Polypropylene	1

In FRC, the fracture is a continuous process and the cracking occurs over a wide range of loading and the de-bonding of fibres over several stages. The bond or the pull-out resistances of fibres depend on the average bond strength between the fibres and the matrix, the number of fibres crossing the crack, and the length and diameter of the fibres

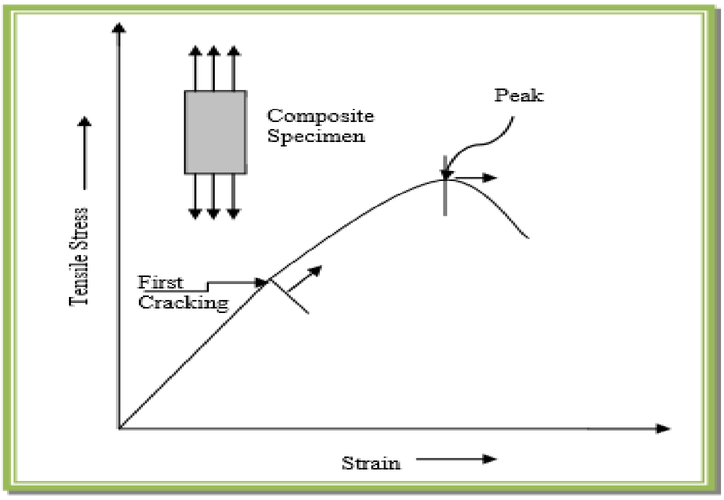


Figure 2. 2.Behaviour of Fibre Reinforced Concrete under Tensile Load

2.3.4. Properties of fibre reinforced concrete

a. Strength

It cannot be emphasized too strongly that, at the fibre volumes used in normal commercial application, the role of fibre is not to increase strength, though modest strength increases may occur. If what is desired is a strength increase, it is clearly much easier (and much cheaper) simply to redesign the plain concrete mix, primarily by reducing the w/c ratio. Similarly, fibres have no significant effects on either the shear strength or the torsional strength of concrete. They also have no particularity on the elastic modulus (Sidney Mindess, 2003)

b. Toughness

The principal role of the fibres is to bridge across the cracks that develop in concrete as it is loaded (or as it dries). If the fibre has sufficient strength and stiffness, and if they can achieve sufficient bond with the matrix, they will tend to keep the crack widths small and will permit the FRC to withstand significant stresses over a relatively large strain capacity in the post-cracking "ductility." In other words, they increase the toughness of the FRC (Sidney Mindess, 2003)

c. Impact resistance

The impact resistance of plain concrete, which is quite low, can be increased dramatically (by more than an order of magnitude) by the addition of fibres. Steel and carbon fibres are more effective in this regard than synthetic fibres, but all types of fibres increase both the fracture energy and generally the peak loads under impact. Related to impact resistance, it is generally found that fibre additions also improve both the abrasion resistance and the resistance of concrete to cavitation damage (Sidney Mindess, 2003)

d. Fatigue

The flexural fatigue strength of plain concrete (out to 2 million cycles of loading) is about 55% of the static strength, for all types of loading. A properly designed FRC, however, will display fatigue strengths of from 65% to 90% of the static load. This improvement is due largely to the effectiveness of the fibres in "tying" the cracks together, and thus inhibiting crack extension during the loading cycle (Sidney Mindess, 2003)

e. Creep and shrinkage

Up to fibre volumes of about 1%, fibre additions have little or no effect on either the creep characteristics or the drying shrinkage of concrete, though they tend to reduce the crack widths significantly during shrinkage. However, fibres can be very effective in reducing the plastic shrinkage. Indeed, this is one of the principal uses of polypropylene fibres in modern FRC technology (Sidney Mindess, 2003)

f. Durability

Durability is as important as strength in determining the suitability of concrete for any specific application. Generally, durable concrete should be dense and impermeable. It has been found that well-made FRCs are slightly less permeable than plain concrete, though the decrease is not large enough to have a significant effect on the overall durability of the concrete. Synthetic fibres are not subject to corrosion. Steel fibres may, of course, rust. However, it has been found that for good quality FRC, this rusting is confined to the "skin" of the concrete; fibres in the interior of the concrete are protected by the alkaline environment. Thus, even with steel fibres, corrosion leads only to cosmetic effects. If this is a problem in a specific application, stainless steel may be used though at a considerable increase in cost.

Ordinary E-glass will be attacked by the alkaline environment, and even FRC made with alkali-resistant glass show some degradation in properties of over time. Natural organic fibres are likely to suffer from alkaline, bacterial, or fungus degradation and require special treatment if they are to be used widely in FRC (Sidney Mindess, 2003) (ACI 544.1R, 1996)

2.3.5. Factors affecting properties of fibre reinforced concrete

Fibre reinforced concrete is the composite material containing fibres in the cement matrix in an orderly manner or randomly distributed manner. Its properties would obviously, depend upon the efficient transfer of stress between matrix and the fibres, which is largely dependent on the type of fibre, fibre geometry, fibre content, orientation and distribution of the fibres, mixing and compaction techniques of concrete, and size and shape of the aggregate. These factors are briefly discussed in the following sections.

a. Relative fibre matrix stiffness

The modulus of elasticity of matrix in most cases is lower than that of fibre for efficient stress transfer. Low modulus of fibres such as nylons and polypropylene are, therefore, unlikely to give strength improvement, but they help in the absorption of large energy and, therefore, impart greater degree of toughness and resistance to impact. High modulus fibres such as steel, glass and carbon impart strength and stiffness to the composite. Interfacial bond between the matrix and the fibres also determine the effectiveness of stress transfer, from the matrix to the fibre. A good bond is essential for improving tensile strength of the composite. The interfacial bond could be improved by larger area of contact, improving the frictional properties and degree of gripping and by treating the steel fibres with sodium hydroxide or acetone (Sidney Mindess, 2003)

b. Volume of fibres

The strength of the composite largely depends on the quantity of fibres used in it. Increases in volume of Fibres resulted in increase in toughness and strength. It has been reported that the use of higher percentage of fibres is likely to cause segregation and harshness of concrete and mortar.

c. Aspect ratio of the fibre

Another important factor which influences the properties and behaviour of the composite is the aspect ratio of the fibre. It has been reported that up to an aspect ratio of 75, increase in the aspect ratio increases the ultimate strength of the concrete linearly. Beyond 75, relative strength and toughness is reduced. Table 2.4 indicates the effects of aspect ratio on strength and toughness of FRC (Sidney Mindess, 2003)

Table 2. 5.Effect of Fibre aspect ratio on Toughness and strength (Shetty M.S., 2003)

Type of Concrete	**Aspect Ratio(l/d)**	**Relative strength (FRC/Plain)**	**Relative Toughness**
Plain Concrete with Randomly distributed fibres	0	1	1
	25	1.5	2
	50	1.6	8
	75	1.7	10.5
	100	1.5	8.5

d. Orientation of fibres

One of the differences between conventional reinforcement and fibre reinforcement is that in conventional, bars are oriented in the direction desired while fibres are randomly oriented. To see the effects of randomness, mortar specimens reinforced with 0.5 percent volume of fibres were tested. In one set specimens, fibres were aligned in the direction of the load, in another along the direction perpendicular to that of the load, and in the third randomly distributed. It was observed that the fibres aligned in the direction of the applied load offered more tensile strength and toughness than randomly distributed or perpendicular fibre (Sidney Mindess, 2003)

e. Mixing

Mixing of fibre reinforced concrete needs careful conditions to avoid balling of fibres, segregation, and in general the difficulty of mixing the materials uniformly. Increase in the aspect ratio, volume percentage and size and quantity of coarse aggregate intensify the difficulties and balling tendencies. A steel fibre content more than 2 percent by volume and an aspect ratio of more than 100 are difficult to mix. It is important that the fibres are dispersed uniformly throughout the mix. This can be done by the addition of fibres before the water is added. When mixing in a laboratory mixer, introducing the fibres through a wire mesh basket will help even distribution of fibres. For field use, other suitable methods shall be adopted.

f. Workability and composition of ***concrete***

The use of fibre reinforced concrete (FRC) has passed from experimental small-scale applications to routine factory and field applications involving the placement of many hundreds of thousands of cubic meters annually throughout the world. This has created a need to review existing test methods and develop new methods, where necessary, for determining the properties of FRC

2.3.6. Measurement of properties of fibre reinforced concrete

Measurement of properties of FRC is very important for practice as well as for research purpose. Some of these properties are largely matrix dependent and can be measured using methods originally developed for conventional concrete. On the other hand, some properties of FRC, like crack control and impact resistance, are quite different from those of conventional concrete and the effects of fibre inclusion are observed primarily on these properties. Thus, test methods specifically developed for FRC should be used to evaluate these properties. Some of these test methods are well established and are in the form of standard tests while some are still in development. Since later in the experimental programs measuring the toughness and the impact resistance is the major task, this section gives an overview of the common test methods used to evaluate the toughness and impact resistance of FRC, however detailed information on testing procedures is not provided as it can be found in the references cited (Sidney Mindess, 2003)

a. Toughness and Flexural strength measurement of FRC

According to the definition provided by ACI toughness is a measure of the energy absorption capacity of a material and is used to characterize the material's ability to resist fracture when subjected to static strains or to dynamic or impact loads. Toughness is conventionally characterized by the area under the load-deflection curve. Although toughness tests can be carried out under different loading conditions like tensile, compressive, and torsional loading, most of the toughness measurements are performed on beams in flexure using four-point bending arrangement. In addition to being simpler, the flexural test simulates the loading conditions for many practical applications of FRC. In order to obtain the complete load-deflection curves, the testing system must be equipped with strain or deflection measurement gauges. Obtaining a reliable curve in the post crack zone is very important, thus a closed loop servo controlled rigid testing machine is highly recommended to be used (Mindess.S, 1990).

Various attempts have been made to quantify load-deflection curves in terms of a parameter, which would be useful for comparison between different fibres and fibre contents. An advantageous approach for quantification of load-deflection curves is using a unitless value termed as the toughness index. The practical application of this approach began with the introduction of ACI 544 toughness index, which is defined as the ratio of the amount of energy required to deflect a FRC beam by a prescribed amount to the energy required to bring the beam to the point of first crack, see Fig. 2.3. Similar notions were used in the development of the ASTM C 1018 standard. On the other hand, another commonly used method was developed by Japan Society of Civil Engineers, which yields absolute toughness. The toughness factor suggested in JSCE SF-4 standard is an indicator of the average flexural strength. All these test methods are based on evaluation of the recorded load versus mid-span deflection curve for a four-point bending test (JSCE) (ACI 544.1R, 1996)

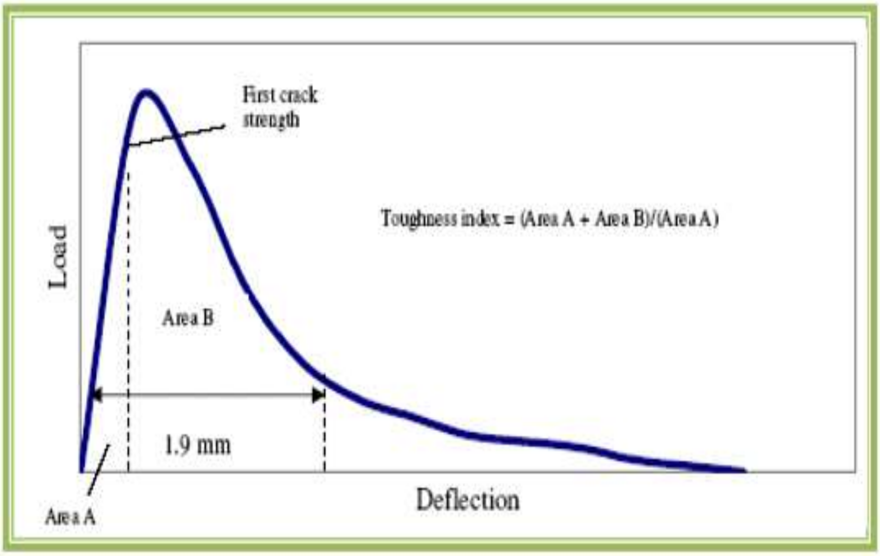


Figure 2. 3.Toughness and Flexural strength measurement of FRC

a.1. ASTM 1018 Standard Test Method

This ASTM standard test evaluates the flexural performance of fibre-reinforced concrete by testing a simply supported beam under third-point loading. From this test, toughness parameters can be derived in terms of the area under a load-deflection curve. The behaviour of the fibre-reinforced concrete up to the load at which first crack occurs can be characterized by the first-crack strength. The behaviour thereafter, is characterized by the toughness indices, which also reflect the post-crack behaviour, it is defined as, the numbers obtained by dividing the area up to a specified deflection by the area up to first crack. The type and quantity of fibres in the concrete matrix influence these parameters (ASTM C1018-97, 1998). Figure 2.4 illustrates major characteristics of a load-deflection curve of fibre reinforced concrete under Flexural bending tests, which are discussed below.

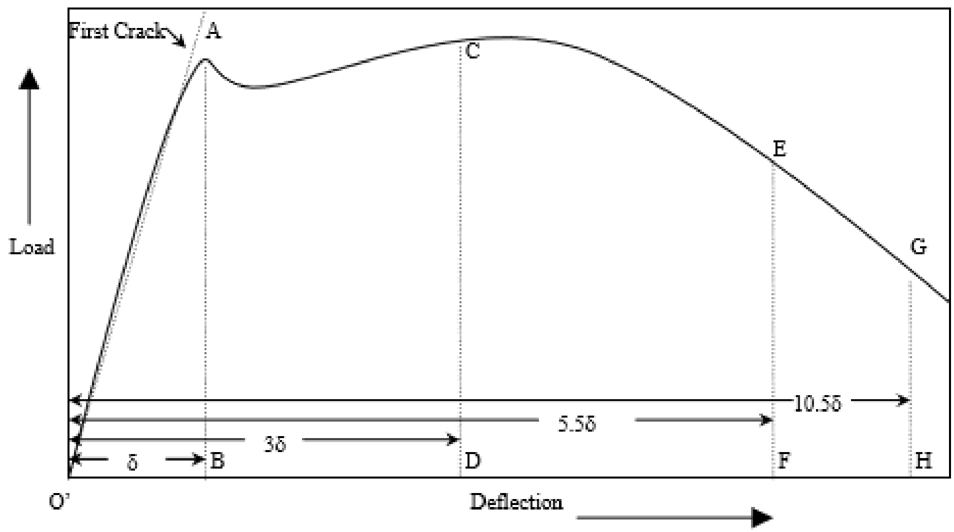


Figure 2. 4.Load-deflection Curve for fibre reinforced concrete under flexural bending test

The first-crack deflection, δ, is determined by measuring the distance O'B in Figure 2.4. The toughness indices I_5, I_{10} and I_{20} are determined as follows:

I_5 = Area O'ACD/ Area O'AB

I_{10} = Area O'AEF/ Area O'AB

I_{20} = Area O'AGH/ Area O'AB

Where: I_5 = Toughness Index up to 3.0 times the first-crack deflection, I_{10} = Toughness Index up to 5.5 times the first-crack deflection and I_{20} = Toughness Index up to 10.5 times the first-crack deflection. Area O'AB is the triangular area under the curve up to first-crack deflection. Area O'ACD is the area under the curve from zero to three times the first-crack deflection. Area O'AEF is the area under the curve from zero to 5.5 times the first-crack deflection. Area O'AGH is the area under the curve from zero to 10.5 times the first-crack deflection.

Residual strength factor $R_{5,10}$, is defined as the number obtained by calculating the value of 20 ($I_{10} - I_5$). And residual strength factor $R_{10,20}$ as the number obtained by calculating the value of 10 ($I_{20} - I_{10}$). Residual strength factors, represent the average level of strength retained after first crack as a percentage of the first-crack strength for the deflection intervals CE and EG respectively.

In ASTM C 1018 the first crack point is defined as the point at which the curvature first increases sharply and then slope of the curve exhibits a definite change. This is a subjective definition and often the load-deflection curves lack a distinct point as mentioned in the definition due to micro cracking and subsequent multiple cracks before the peak load is reached. There is a need for an objective definition of first crack so that determination of first crack point is not affected by whom the test is performed and evaluated (ACI 544.1R, 1996) (ASTM, 2004)

a-2. JSCE-4 Standard Test Method

In this method, the area under the load deflection curve up to a deflection equal to span/150 is calculated and results obtained from this test method yield an absolute toughness value. Determination of first crack point is not a concern in this method as shown in Fig. 2.5. However, the deflection chosen in this test method is often criticized for being much greater than the acceptable serviceability limits (JSCE)

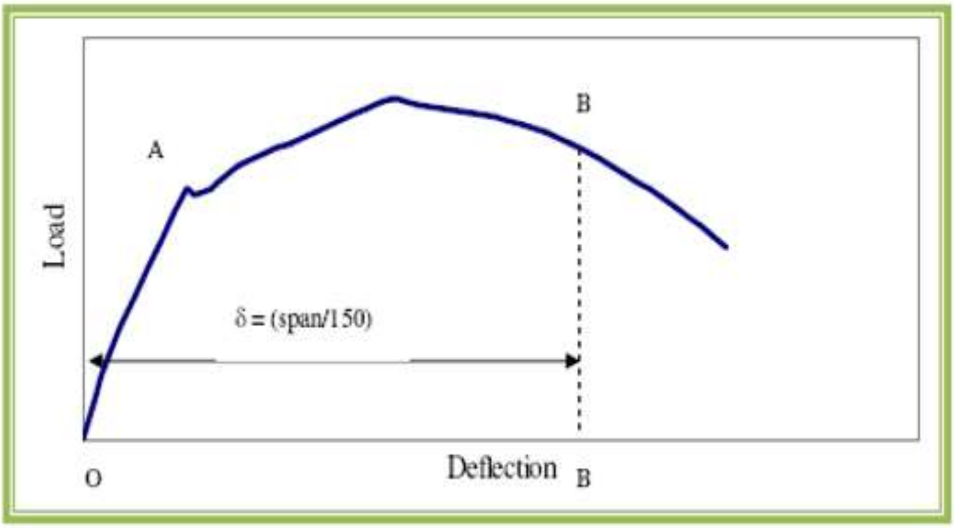


Figure 2. 5.Flexural toughness by JSCE-4 Standard Test Method

b. Impact Resistance Measurement of FRC

Improved impact resistance or dynamic energy absorption as well as strength is one of the important attributes of FRC. Thus, FRC is a suitable material for applications where dynamic loading conditions such as impact loadings are present. Impact resistance of FRC can be measured by using a number of different test methods described by ACI committee, which can be broadly listed as follows: Repeated drop weight test, instrumented impact test, and projectile impact test.

Conventionally, the resistance of material is characterized by a measure of one of the following criteria: the number of blows in a repeated impact test to achieve a specified distress level, energy needed to fracture the specimen, and the size of damage, measured using crater size, perforation, or scab (Mindess.S, 1990)

Results from such tests are useful for ascertaining the relative merits of the different mixtures as well as for providing answers to specific practical problems. However, they depend on the specimen geometry, test system compliance, loading configuration, loading rate, and the prescribed failure criterion. Additional information about the behaviour of FRC under impact loading can be obtained by performing instrumented and projectile impact tests. In this manner load-deflection histories and magnitude of the ultimate strength can be determined. However, these test methods require the use of highly sophisticated measuring devices, which are rarely available (ACI 544.1R, 1996).To this effect only the simplest of the conventional tests, that is, the repeated drop weight test is discussed in the next subsection.

b-1. Reaped Drop Weight Test

This is the simplest test for evaluating impact resistance proposed by ACI Committee 544. This test method does not yield quantitative results; rather the test is designed to obtain the relative Performance of plain concrete and FRC containing different types and amounts of fibres. A disc 150 mm in diameter, 63.5 mm in thickness is subjected to repeated blows by dropping a 4.54 kg hammer from a height of 457 mm. The load is transferred from the hammer to the specimen through a steel ball 64 mm in diameter. The number of blows to cause the first visible crack on the surface of the specimen is recorded as the first crack strength. Loading is continued until the specimen failure that is the specimen opens so that it touches three of the four positioning lugs. Number of blows to cause the failure of the specimen is recorded as the ultimate strength. Although this test method is very simple and useful for comparison purposes, it yields highly variable results and has poor reproducibility (ACI committee 544, 1978). Fig 2.6 and 2.7 shows the plan and section view of the impact test equipment respectively.

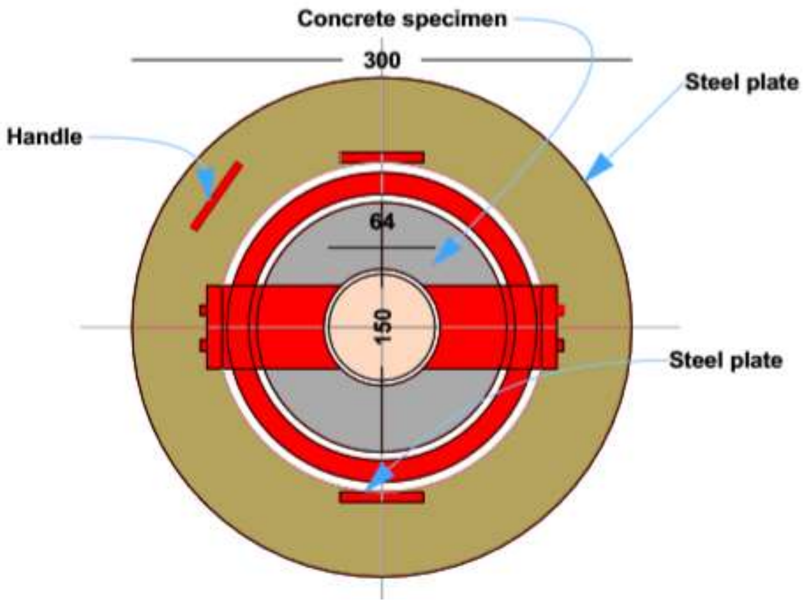


Figure 2. 6.Plan view of drop weight method impact test equipment

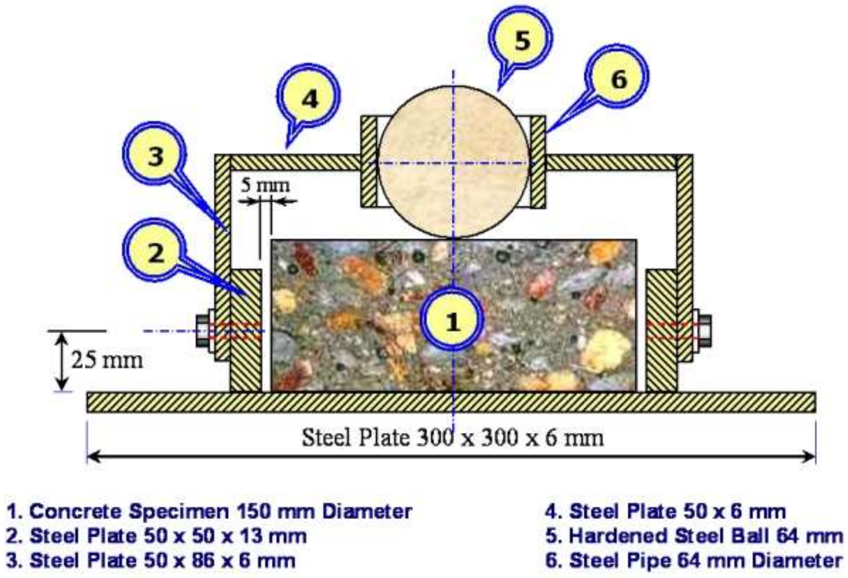


Figure 2. 7.Section view of drop weight method impact test equipment

2.3.7. Advantages and Disadvantages of Fibre reinforced concrete

It was reported that the addition of fibres in concrete matrix enhance substantially many of the engineering properties of the concrete, such as Impact Strength, toughness, Ductility, Flexural strength, fatigue endurance, deformation Characteristic, tensile strength, and ability to resist cracking and spalling. However, fibres have no significant effect on the compressive, shear and torsional strength, elastic modulus and creep characteristics which leads to saving in Time, cost and materials. The extent of improvement in reinforced concrete properties will vary based on the concrete matrix strength characteristics, Types, quantity and orientation of fibres, mixing, compaction and maximum aggregate size. Measurement of properties of FRC is very essential. As some of the properties are matrix dependent, they can be measured using test methods originally developed for conventional concrete. Despite of Excellent mechanical properties and physical properties of Fibre reinforced concrete, it has some drawbacks. On SFRC, it was reported that, loose fibres at hardened surface, might be blown into aircraft engines or tyres, which leads to unsafe operations. Injury also to personnel being cut by an exposed fibre while working on concrete surface can possibly happen. (Elasaigh W.A., 2001) (Nasiri, 2009)

2.4.Steel fibre reinforced concrete

2.4.1. Generalization

American concrete institution (ACI 544.IR, 1996) defines SFs as discrete, short lengths of steel having aspect ratio (ratio of length to diameter) in the range of 20 to 100 with any of the several cross-sections which are sufficiently small to be easily and randomly dispersed in fresh concrete mix using conventional mixing procedures. To enhance the workability and stability of SFRC, superplasticizers (chemical admixtures) may also be added into the concrete mix.

The behaviour of SFRC can be classified into three groups according to its application, fibre volume percentage and fibre effectiveness; for instance, SFRC is classified based on its fibre volume percentage as follows: 1-Very low volume fraction of SF (less than 1% per volume of concrete), which has been used for many years to control plastic shrinkage and as pavement reinforcement. 2-Moderate volume fraction of SFs (l% to 2% per volume of concrete) which can improve modulus of rupture (MOR), flexural toughness, impact resistance and other desirable mechanical properties of concrete. 3-High volume fraction of SFs (more than 2% per volume of concrete) used for special applications such as impact and blast resistance structure; these include SIFCON (Slurry Infiltrated Fibre Concrete), SIMCON (Slurry Infiltrated Mat Concrete

In most cases, SFs may act as secondary reinforcement used along with conventional steel bars or pre-stressing strands as the main reinforcement. In the class of high volume fraction of SFs (more than 2% per volume of concrete), the SFs have excellent mechanical properties and can be used without other continuous reinforcement; however, these composite materials are often suited for highly specialized applications due to the limitations associated with processing and cost (ACI 544.1R, 1996)

2.4.2. Fundamental of steel fibres

a. Types of steel fibres

Steel fibres are produced in number of ways. Round, straight steel fibres are produced by cutting or chopping wire, typically wire having a diameter between 0.25 to 1.00 mm. Flat, straight steel fibres having typical cross sections ranging from 0.15 to 0.64 mm thickness by 0.25 to 2.03 mm width are produced by shearing sheet or flattening wire (Fig 2.8a). Crimped and deformed steel fibres have been produced with both full-length crimping (Fig. 2.8b) or bent or enlarged at the ends only (Fig. 2.8c, d). Some fibres have been deformed by bending or flattening to increase mechanical bonding. Some fibres have been collated into bundles to facilitate handling and mixing. During mixing, the bundles separate into individual fibres (Fig. 2.8c). Fibres are also produced from cold drawn wire that has been shaved down to make steel wool. The remaining wires have a circular segment cross-section and may be crimped to produce deformed fibres. There are also available steel fibres made by a machining process that produces elongated chips. These fibres have a rough, irregular surface and a crescent-shaped cross section (Fig. 2.8e) (ACI 544.1R, 1996)

Steel fibres are also produced by the melt-extraction process. This method uses a rotating wheel that contacts a molten metal surface, lifts off liquid metal, and rapidly solidifies it into fibres. These fibres have an irregular surface, and crescent shaped cross-section (Fig. 2.8f) (ACI 544.1R, 1996)

It is possible to make classification of steel fibres either based upon the product or shape of cross-section as provided here under for ASTM and JSCE respectively. ASTM -A 820 provides a classification for four general types of steel fibres based upon the product used in their manufacture: Type I - Cold-drawn wire. Type II - Cut sheet. Type III - Melt-extracted. Type IV - Other fibres. The Japanese Society of Civil Engineers (JSCE) has classified steel fibres based on the shape of their cross-section: Type 1 - Square section. Type 2 - Circular section. Type 3 - Crescent section

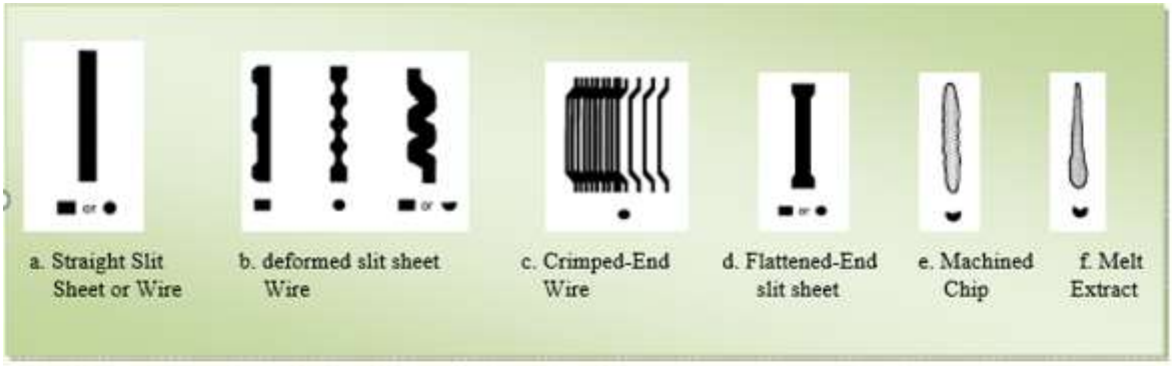


Figure 2. 8.Different steel fibre Geometries

b. Steel fibres properties

The composition of steel fibres generally includes carbon steel (or low carbon steel, sometimes with alloying constituents), or stainless steel. Different applications may require different fibre compositions. The fibre strength, stiffness, and the ability of the fibres to bond with the concrete are important fibre reinforcement properties. Bond is dependent on the aspect ratio of the fibre. Typical aspect ratios range from about 20 to 100, while length dimensions range from 6.4 to 76 mm

2.4.3. Mix Design for Steel Fibre Reinforced Concrete

By making certain adjustments to conventional concrete practice, it is possible to produce SFRC. The primary concern is to introduce sufficient amount of uniformly distributed fibres in concrete to achieve improvements in mechanical properties, keeping the concrete workable to permit proper mixing, placing, and finishing.

Compared to conventional concrete, some SFRC mixtures are characterized by higher cement content, higher fine aggregate content, and decreasing slump with increasing fibre content. There are various procedures for proportioning of SFRC mixtures proposed by different researches. To provide better workability of concrete, amount of paste in the mixture should be increased. This requires higher cement content or moving the ratio of fine aggregates to coarse aggregates upwards. Alternatively, pozzolanic admixtures can be used to replace cement. The use of superplasticizers enhances the workability of the concrete however it does not necessarily provide the ability to incorporate higher steel fibre content. Regardless of the mix design, in all cases trial mixes should be prepared to ensure workability and strength properties (ACI Committee-544)

2.4.4. Properties of Freshly Mixed SFRC

The properties of SFRC in its freshly mixed state are influenced by the aspect ratio of the fibre, fibre geometry, its volume fraction, Duration of mixing, aggregate size, shape and roughness, the matrix proportions, and the fibre-matrix interfacial bond characteristics. For conventionally placed SFRC applications, adequate workability should be insured to allow placement, consolidation, and finishing with a minimum of effort, while providing uniform fibre distribution and minimum segregation and bleeding. For a given mixture, the degree of consolidation influences the strength and other hardened material properties, as it does for plain concrete.

SFRC may be very stiff in fresh state, however may respond very well to vibration. The performance of the hardened concrete is enhanced more, as more fibres with a greater aspect ratio are included in concrete. This is due to the improved fibre-matrix bond. However, a high aspect ratio reduces the workability of fresh concrete. When shaken together fibres with aspect ratio greater than 100 tend to interlock in a way to form a mat from which it is very difficult to dislodge by vibration alone. Movement of fibres may be prevented by coarse aggregates in the matrix, which often are of larger size than the average fibre spacing if the fibres were uniformly distributed. This leads to bunching and greater interaction of fibres between the coarse aggregate particles and the effect becomes more pronounced as the volume and maximum size of the aggregate increase (Hannat DJ., 1987)

2.4.5. Mechanical properties of Steel Fibre Reinforced Concrete

The crack-arrest and crack-control mechanism of SFs has three major effects on the behaviour of SFRC structures (Ocean Heidelberg Cement Group, 1999).

The addition of SFs delays the onset of flexural cracking. The tensile strain at the first crack can be increased as much as 100 percent and the ultimate strain may be as large as 20 to 50 times that of plain concrete.

The addition of SFs imparts a well-defined post-cracking behaviour to the structure. The crack arrest property and the consequence increase in ductility impart a greater energy absorption capacity (higher toughness) to the structure prior to failure.

a. Compressive Strength

Johnston (1974), and Dixon and Mayfield (1971) found that an addition of up to 1.5% of SFs by volume increases the compressive strength from 0 to 15%. A gradual slope in the descending part of the stress-strain curves indicates the improved spalling resistance, ductility and toughness of SFRC

b. Shear Strength

Previous research has shown that addition of SFs substantially increases the shear strength of concrete (Noghabai, 2000; Oh et al., 1999; Narayanan and Darwish, 1987; Barr, 1987). The ultimate shear strength of SFRC containing 1 % by volume of SFs increases up to 170% compared to RC without SFs (Narayanan and Darwish, 1987). Traditional transverse shear reinforcement can be completely replaced by addition of SFs as an effective alternative (Noghabai, 2000; Williamson, 1978).

c. Tensile Strength

Addition of 1.5% by volume of SFs can improve the direct tensile strength of concrete up to 40% (Williamson, 1974). Those SFs aligned in the direction of the tensile stress contribute to an appreciable increase in the direct tensile strength of concrete as up to 133% for the addition of 6% by weight of smooth, straight SFs. However, for randomly distributed fibres, the increase in strength is much smaller, ranging from as low as no increase in some instances to perhaps 60%, with many investigations indicating intermediate values. Splitting-tension test of SFRC show similar result. Thus, adding fibres merely to increase the direct tensile strength is probably not worthwhile. However, as in compression, steel fibres do lead to major increases in the post-cracking behaviour or toughness.

d. Impact Resistance

The impact resistance of SFRC against dynamic loads due to the dropped weights or explosives is 8 to 10 times higher than that of the plain concrete. The test results of the specimens containing high tensile strength, crimped SFs with the diameter of 0.50mm indicate an improvement in the concrete toughness under impact loading more than 400 percent. An increase in fatigue strength with increasing the percentage of SFs has also been noticed.

e. Durability

Corrosion in concrete structures due to the cracks is less severe in the SFRC structures compared to conventional RC ones (Mangat and Gurusamy, 1987; Williamson and Morse, 1977; Halvorsen et al., 1976; Aufmuth et al., 1974). Schupack (1985) found that a well-compacted SFRC has a limited corrosion of fibres close to the surface of the concrete even when concrete is highly saturated with chloride ions. Turatsinze et al. (2005) conducted a research to investigate the corrosion of SFRC due to the cracks. Prismatic SFRC specimens with the dimensions of 100*100*500mm containing hooked SFs with the dimensions of 60 mm in length and 0.8 mm in diameter were prepared.

Specimens with vertical cracks were exposed to a marine-like environment for one year. After one year, the prisms were tested in three-point bending setup with the span of 200 mm and load -deflection curves were plotted and concluded that only those SFs crossing the crack within a 2 to 3mm rim from the external faces of the specimens exhibited extensive corrosion. Besides, no SFs corrosion was observed in narrower parts of the cracks whilst in the wider parts of the cracks a light corrosion of the fibres with no reduction in their section was observed. Furthermore, no concrete bursting or sapling was recorded due to the corrosion of the fibres. The measurement of concrete electrical resistivity can give an indication of concrete durability (Chen and Hwang, 2001; Woodrow 1980).

f. Flexural Strength and Toughness

Hartman (1987) found that the influence of SFs on the flexural strength of concrete is much greater than its influence on direct tension or compression. Oh et al. (1999) reported that the flexural strength of SFRC is increased by about 55% with the addition of 2% of SFs. Hartman (1999) experimented with 12 different SFRC beams produced by SFs of Dramix RC-65/35-BN type with two different dosages of 60 kg/m3 and 100 kg/m3, and concluded that the ratio of the measured ultimate load to the theoretical ultimate load turned out to be greater for those SFRC beams having the dosage of 60 kg/m3

2.4.6. Application of steel fibre reinforced concrete

a. Highway and air-field pavements

SFRC can be used in the construction of new pavements or for the repair of existing pavements using bonded or un-bounded overlays to the beneath slab. It leads to a higher flexural strength causing a decrease in the pavement's thickness required. Besides, the resistance to impact and repeated loading will be increased. The greater tensile strain capacity of SFRC leads to a drop in the maximum crack widths than in plain concrete.

b. Hydraulic Structures

The most important advantage of using SFRC in hydraulic structures is the resistance of SFRC to cavitation or erosion due to the high velocity of water flow compared to conventional RC.

c. Fibre Shotcrete

Fibre shotcrete are used in rock slope stabilization, tunnel lining and bridge repair. A thin coating of plain shotcrete applied monolithically on top of the fibre shotcrete, maybe used to prevent surface staining due to rusting of SFs. The fibre shotcrete can be used in the protection of steel structures.

d. Refractory Concrete

Steel-fibre reinforced refractory concretes have been reported to be more durable than their unreinforced counterpart when exposed to high thermal stress, thermal cyclic, thermal shock or mechanical abuse. The increased service span is probably due to the combination of crack control, enhanced toughness, spalling and abrasion resistance imparted by the SFs.

e. Precast Application

SFRC can be used in the construction of precast products such as manhole covers, concrete pipes, and machine bases and frames. Improved flexural strength and impact resistance of SFRC may allow the use of these products in rough handling situations.

f. Structural Applications

Addition of SFs into the conventional RC members has several advantages such as the followings, thereby increasing the use of steel-fibre-added RC (SFARC) structures compared to conventional RC members.

1. Addition of SFs can provide an increased impact resistance to conventional RC members, thereby enhancing the resistance to local damage and spalling.

2. Addition of SFs can inhibit crack growth and crack widening; this may allow the use of high strength steel bars without having excessive crack width or deformation at service loads.

3. Addition of SFs increases the ductility of conventionally RC members, and hence, enhances their stability and integrity under earthquake and blast loadings.

4. Addition of SFs increases the shear strength of RC members. Therefore, punching shear strength of slabs will be increased and sudden punching failure can be transformed into a gradual ductile failure (Gambhir, 1995)

2.5.Recycled waste tyre steel cord in concrete

Recycling steel waste tyre-based fibre to be used as mechanical or chemical constituents is the most environmentally sound way of disposing the waste tyres. currently tyre steel cord and bead wires are being used in concrete to produce Recycled tyre steel reinforced concrete which is environmentally and economically sound.

2.5.1. Method of Recovering of waste tyre steel cord

Tyre shredding and the cryogenic process can be used to mechanically recover RSF from used tyres. In addition, steel fibres can be recovered by utilising anaerobic thermal degradation, such as conventional pyrolysis and microwave-induced pyrolysis of tyres. The amount of extracted steel fibres depends mainly on the type of tyre. Tyres of light vehicles contain up to 15% steel, whereas truck tyres contain up to 25% steel (Hylands V. , K. N. and Shulman, 2003)

a. Shredding Process

The shredding process reduces tyres into rubber granules and steel fibres through several cutting and granulating stages. In the first stage of processing, a complete tyre is chopped or shredded until it is reduced to pieces ranging in size from about 50 to 150 mm. The rubber pieces, which still contain steel, are then fed into a second shredder that reduces them to smaller pieces. At the end of this stage, magnets are used to separate the steel from the rubber. Figure 2.10, indicates a typical image of recovered steel cords by shredding. The rubber is then fed into a knife or hammer mill, where it is granulated to approximately 1 to 10 mm in size. The number of grinding cycles depends on the desired size of the rubber granules. During the granulating process, magnets are used to remove any remaining steel. The steel extracted after the second stage of shredding and the final stage of grinding differs in quality. The former contains large pieces of rubber as well as much of the textile wire in long lengths. The cord is sometimes undamaged, but much of it is deteriorated into individual wires.

b. Cryogenic Process

The cryogenic process involves the cooling of tyres, and their subsequent brittle fracturing and reduction to rubber, steel, and textile. In a typical cryogenic process, the used tyres are initially shredded at ambient temperature, and then transferred to a deep-freezing tunnel system. Inside the first tunnel section, the fragmented tyres are pre-cooled by a counter-current of gaseous nitrogen at approximately -120°C. The tyre pieces are then transferred into the main cooling tunnel, where they are cooled down below their embrittling temperature and, as a result, they become nearly brittle. At the next stage, the fragmented tyres are granulated through a series of mills, and are reduced to rubber, steel fibres, and textile. The steel and textile are separated, whereas the rubber granules are dried, passed through a steel extraction unit, and finally sieved.

c. Pyrolysis Process

Pyrolysis of tyres is the process where tyres are thermally decomposed, in the absence of oxygen, to their organic and inorganic components. The process generates gases (hydrogen, methane and other hydrocarbons), oil, and solid residuals of steel and char, which is a low-grade carbon black. The balance between the end-products of the process can be altered by changing the imposed conditions, such as the heating temperature and duration. In a typical pyrolysis plant, used tyres are fed into a pyrolysis reactor, where they are heated to the desired temperature. The gases and the liquids are separated from the extracted vapours through a system of gas-liquid separators. At the end of the process, the steel is separated from the char and the char is ground. (Pilakoutas K. N., 2004) Fig 2.9 shows recovered tyre steel cords by pyrolysis process. The steel cords are very clean from Rubber particles.

Figure 2. 9. Tyre Steel cord from pyrolysis

Figure 2. 10.Tyre steel cord from shredding

2.5.2. Property of recycled tyre cord

Pyrolyzed recycled steel fibres (PRSF) are very clean from rubber, their tensile strength is not affected (1250MPa), they contain carbon black on their surfaces and they are not easy to cut while, Shredded Recycled steel fibres (SRSF) contain small amount of rubber and fluff, and these fibres are magnetised to be removed. The fibres tent to ball up, with inconsistent size and shape with a diameter of 0. 23mm.The pyrolyzed recycled steel fibre have 12 wires of diameter 0.23mm twisted on a core of 0.85 and surrounded another 15 twisted wires. On the surface there is a twisted single wire. the total effective diameter is 1.16mm. (Tremat, 2003) Fig 2.11 shows physical properties of tyre steel cords recovered by Pyrolysis process.

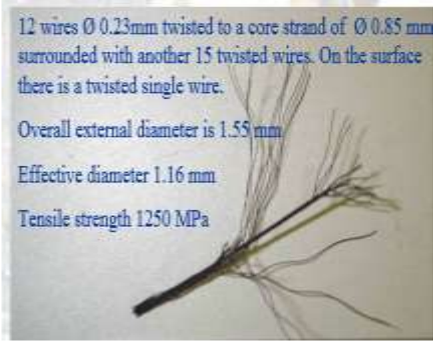


Figure 2. 11.Properties of Steel cord from from pyrolysis (Tremat, 2003)

2.5.3. Application of Recycled tyre fibre in concrete

Pilakoulas K. (2014) reported on application of Recycled tyre-based steel in structural concrete production. On tested conducted on recycled steel cord, they found that, RTSF can substitute Manufactured /Industrial steel fibres based on pull-out test conducted on recycled tyre steel fibre(RTSF). RTSF are very high strength steel, more flexible and Better for microcrack Control. The researcher, conducted tests on concrete reinforced with RTSF together with Manufactured Steel Fibre (MSF), and results showed that, inclusion of these hybrid steel fibres help maintain integrity after failure, there is also moderate enhancement of strengths at increased RTSF fibre volume, post crack capacity is also enhanced. But he stated that, Strength may decrease at high fibre volume due to extra voids that may be formed. Pilakoulas concluded that, addition of the Recycled tyre steel fibre in concrete leads to improved tensile concrete strength, improved post-peak tensile concrete behaviour, enhanced flexural behaviour and

Crack mouth opening control. He added that, since millions of tones steel used for fabrication of Industrial steel fibres requires millions of energies accompanied by releasing of tones of CO_2 while for fabrication of RTSF requires 98% less; RTSF found be economically and environmentally a substitute of Industrial steel fibre. (Pilakoutas K. , 2014)

Marijana et al (2013) made a reaserch on the use of Recycled tyre fibre from mechanical shredding of waste tyre in concrete. Four different tyre-based fibre from mechanical shredding of tyres. Three different types (Industrial steel, Recycled tyre steel fibres purified and non-purified, and recycled textile fibres) were mixed together in concrete for various percentage mass. They revealed that the capacity of fibres to limit propagation of cracks is the basic parameter that extends the structure's life span and cuts down maintenance costs simply because the occurrence of cracks on the concrete surface exposed to weather and other impacts greatly affects life span of concrete structures. In their findings, the found that, Textile fibre can act as autogenous and drying shrinkage cracks arrestors limiting crack initiations. Recycles steel fibres can be used in civil engineering as a less costly alternative to industrial steel fibre. Studies conducted so far to define possibilities for the use of steel fibres from waste tyres have revealed several positive features of this material. In fact, recycled fibres are an economically and environmentally justified alternative to industrial fibres, especially when used in greater proportions and if mixed with industrial fibres. Combining Recycled Steel fibre and textile fibres limit propagation of cracks and increase toughness of the composite compared to ordinary concrete, even in case of separation and pulling out of the composite. They stated that, if recycled steel fibres are used in the amount of two per cent of the total mass of the composite, this results in significant improvement of the resistance to fatigue, ductility and prevent crack propagation. Cracks. Addition of textile fibre reduces deformation due to shrinkage and positive influence on durability properties of concrete. They concluded that, tyre-based fibre can be used as environmentally, economically and functionally alternative to industrial fibre (Marijana Serdar, 2013).

Fabio P. Figueredo et al (2017) studied the effect of waste tyre fibres in concrete for structural fire protection in concrete tunnel linings. The fibres were recycled polymer and recycled steel fibres from mechanical shredding of waste tyres. All these fibres were of high quality as the manufactured fibre. Recycled Tyre polymer fibre (RTPF) were tangled to be added immediately in concrete and balling were prevented by dispersal of RTPF method using plastic string to separate the fibre, all these fibres were having different length and different diameter due to mechanical shredding process. Test were conducted on concrete slab with C70 high performance, high-strength and self-compacting concrete. Before adding and during fire, the slab was subjected to uniaxial compressive strength. The results showed a good performance of concrete reinforced with tyre polymer and steel fibre in terms of structurally fire protection. They concluded that, all specimen with RTSF at a dosage equal to or above to 2 kg /m3 did not spall, it appeared that, combining RTSF and RTPF was sufficient to prevent fire induced spalling of concrete, which means maintain integrity of the tunnel lining structure during fire with subjection to external stresses (Fabio P. figueireho, 2017).

Hand Hu et al (2017) examined flexural performance of concrete reinforced with manufactured and recycled tyre steel fibre. The manufactured steel fibres were of two types with different lengths and different diameters. RTSF was also of different aspect ratio from mechanical shredding of tyres. The maximum fibre volume was maintained constant 45kg/m^3 with only varying the content of the different types of the fibres. Flexural strength tests were conducted on 3 point notched prisms and a concrete slab. A simplified equation of relationship of between post-cracking tensile strength of SRFC and required supported slab thickness was established. Residual strengths were used to characterise the post crack behaviour. The results showed that, adding all those hybrids Steel fibres did not considerably affected the compressive strength of concrete. Flexural strength was highly improved. For only 10% dosage of RTSF, the Residual strengths coefficient was 30%. It was found that, the smallest required slab thickness was obtained from fibre hybrids containing 10kg/m^3 of RTSF. Hand Hu et al concluded that, RTSF is a competent substitute to Manufactured steel fibre (MSF) partially or possibly fully.

E Martinez-Cruz ,(2013) conducted a research on Polymer concrete reinforced with recycled tyre fibres from mechanical shreeding.The Polymer Concrete was reinforced with recycled-tyre fibres to improve the compressive and flexural strength. Polymer concrete specimens were prepared with 70% of siliceous sand, 30% of polyester resin and various fibre concentrations 0.3, 0.6, 0.9 and 1.2% volume. The results showed increment of 50% in average of the compressive and flexural strength as well as on the deformation when adding 1.2 vol% of recycled-fibres. Researcher concluded that, the flexural and compressive strength were modified with the addition of recycled polymer fibres, these properties have a concentration dependence of reinforcements utilized. Mechanical properties of PC are improved when the fibre concentration is enough to decrease the negative effect of a poor elastomer-matrix adherence but with a percentage of reinforcement less than one volume (E Martínez-Cruz, 2013)**,**

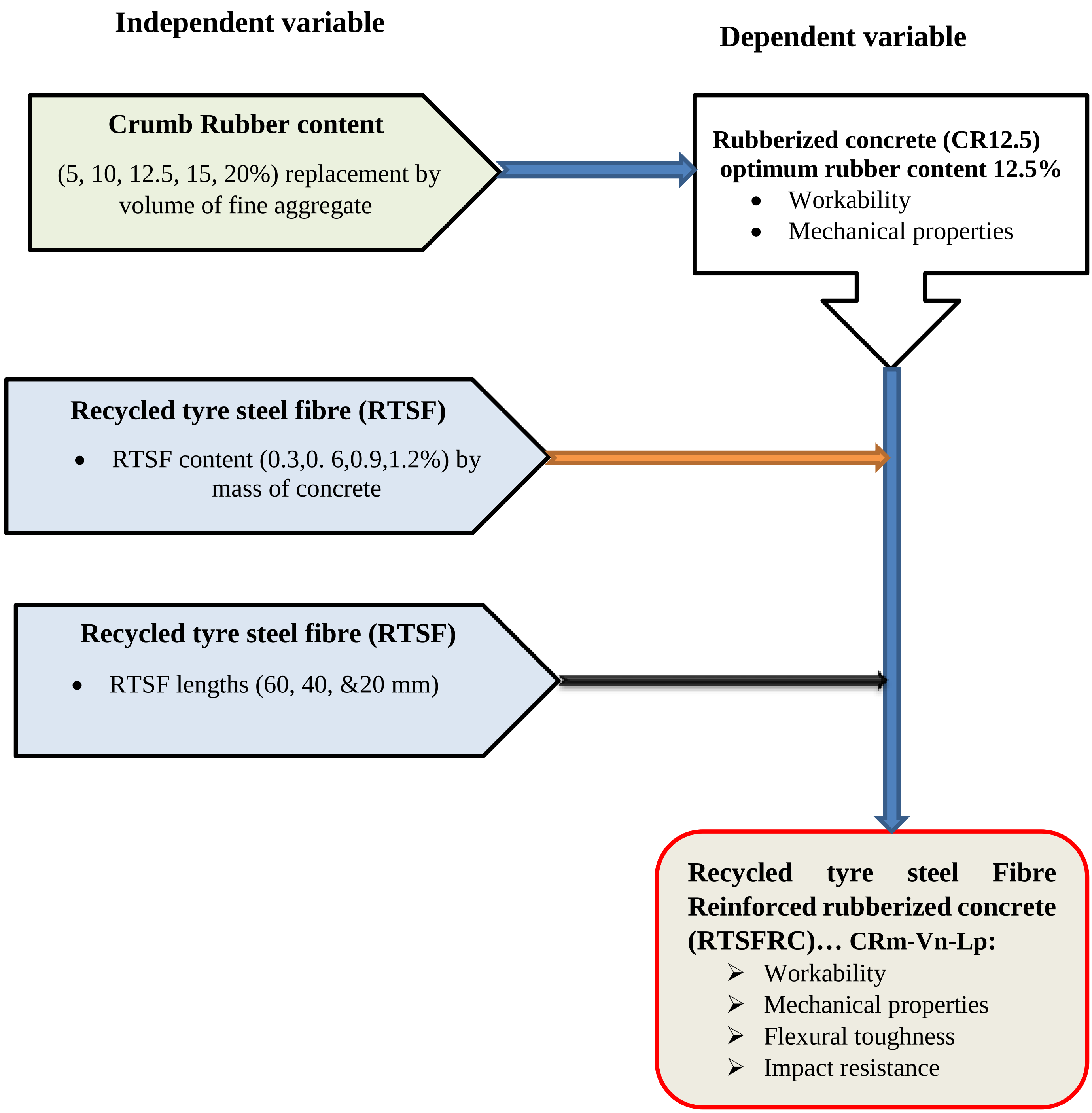
Bedewi Nasiri (2009), Conducted a research on steel fibres reinforced concrete made with steel wires extracted from used tyres (bead wires) to investigate its mechanical behaviour. He used bead wire having a diameter of 0.89 mm extracted from burnt tyres. The produced steel fibres having three grades of SFRC namely C-25, C-40 and C-60 incorporating three different volumes of fibres i.e. 0.5, 1.0, and 1.5%. The test conducted included slump test, compressive strength test, impact resistance test, flexural tensile strength and toughness tests.

In his results, he concluded that, workability of fresh concrete is largely influenced by the presence of steel fibres; he added that, Compressive strength is unlikely affected by inclusion of Steel fibres in concrete. Addition of steel fibres in concrete, increase greatly, flexural tensile strength and the post-crack energy absorption capacity. He again found that impact resistance was enormously improved both at first crack and ultimate failure strength. The interesting results confirm the promising application of concrete reinforced with steel fibres extracted from used tyres (Bedewi Nasiri, 2009).

2.6 summary

Based on results of researches made on the use of waste tyre rubber as aggregates in concrete ,most conclusions made were that , rubber concrete strengths properties decrease with addition of rubber aggregates in concrete, and that treatment of rubber surface with inorganic compounds have added so little improvement on rubber concrete strengths, for that reason they recommend to use rubber concrete for structures where load is not a major design consideration, which hinders the use of waste tyre rubber in concrete production . As it was reported that industrial steel fibre improves mechanical properties of concrete, and recycled tyre steel fibres have demonstrated similar performance in concrete as of industrial steel fibres, mixing crumb rubber and recycled steel fibre would improve properties of rubber concrete to be used in structural construction ; it is of this reason, a study was made to assess the impact of RTSF on structural performance of rubber concrete by adding randomly distributed recycled tyre steel fibre at different percentages with different aspect ratios and crumb rubber in concrete. Once positive results are achieved, the rubber concrete will be introduced as structural material in Civil engineering construction and a as result, huge amount of waste tyres dumped in environments will be used in concrete will be friendly disposal of waste tyres.

2.7. Conceptual framework



CHAPTER THREE: MATERIALS AND METHOD

3.1.Introduction

The general objective of this research study, is to produce steel fibre reinforced rubberized concrete (SFRRC) made with Crumb Rubber as partial replacement of fine aggregates and steel cord extracted from waste tyres as steel fibre reinforcement and, characterising its mechanical properties and Impact energy characteristics (Compressive, Split tensile, Flexural, Impact strength and toughness and ductility) in hardened state as well as its properties in fresh state. a granulated waste tyre Crumb Rubber of max size passing sieve 4.75mm and a steel cord of average diameter 1.15mm extracted from used tyre by pyrolysis process was used. A concrete grade C-30 was designed as control for all mixes to measure the relative performances of the different mixtures.

Five different percentage volume of Crumb Rubber replacement of normal sands by 5,10,12.5,12.5,15 and 20% were mixed and casted to obtain the optimum volume of rubber to mix with different percentage of recycled tyre steel fibres which are 0.3 ,0.6 ,0.9 and 1.2% mass of concrete with 3 different fibre lengths (20mm,40mm and 60mm). Since SFRC properties are influenced by different factors, such steel fibres geometry, mechanical properties and its bond between the concrete matrix, in this research, the properties of recycled tyre steel fibre and the properties of other concrete constituents were studied. Three groups (CR0, CR5, CR10, CR12.5, CR15, CR20); (CR0, CR12.5, CR12.5-V0.3L60, CR12.5-V0.6L60, CR12.5-V0.9L60, CR12.5-V1.2L60); and (CR12.5-V1.2L20, CR12.5-V1.2L40, CR12.5-V1.2L60) were casted and tested . In the first group, 36 cubes and 36 cylinders were casted and tested to evaluate the effect of rubber content on compressive and tensile strength of concrete at 7 and 28 days. The second group,24 cubes ,24 cylinders,18 concrete beams and 24 concrete discs were casted and tested for assessing the effect of the recycled steel fibres on Compressive, tensile strength, flexural toughness and impact resistance of Recycled steel fibre reinforced rubber concrete respectively. In the third group,12 cubes, 12 cylinders ,6 concrete beams and 8 concrete discs were casted and tested to assess the influences of the recycled steel fibre lengths on properties of rubberized concrete. For each mix, 3 specimen of concrete cube (150x150x150mm) and 3 specimen of concrete cylinders (100x200mm) ,3 specimen of concrete beams(150x150x500mm) and 4 specimens of concrete discs (150x63±0.5mm) were being considered as mean of the test results. Cubes were used to study compressive strength, cylinders were used to determine the tensile strength, beams were used to evaluate the flexural toughness and strength and discs were used to determine the impact resistance.

3.2.Materials properties

3.2.1. Cement

The cement used in the all mixes was a locally manufactured Portland limestone cement of class 42. 5MPa. The product conforms to the KS EAS 18-1 cement standards as adopted from the EN-197 specification that is equivalent to the Uganda specification US 310-1 or US EAS 18-1. The product is classified as a CEM II/A-L 42,5 N Portland Limestone Cement. The chemical composition, physical and mechanical properties test results and other characteristics provided by manufacturer are detailed in Table 3.1.

Table 3. 1.Chemical, physical and mechanical properties of the cement (Bamburi Cement LTd.2017)

Physical and mechanical composition	**Description**	**Requirement as per EN197-1 and KS EAS 18-1:2001**
Specific gravity	3.05	-
Initial setting time(min)	145	Not lesser than 60min
Final setting time (min)	205	Not more than 600min
soundness (mm)	0.43	Lesser than 10.0mm
Fineness	2.65	2.65
2 -days Compressive strength (N/mm2)	18.7	Greater than 10.0
28 -days Compressive strength (N/mm2)	47.9	Greater than 42.5
Chemical composition		
Sio2(%)	≤ 3.5	≤ 3.5
Boiling / Melting point(0C)	>1000	>1000
Freezing point	None, solid	None, solid
Viscosity	None, solid	None, solid
pH wet cement	12 - 14	12 - 14

3.2.2. Aggregates

The coarse aggregates used in this research were crushed basaltic stones from Meru central Kenyan, with a maximum size of 15mm. The specific gravity of the coarse aggregate was found to be 2.61 with aggregate crushing value (ACV) and aggregate impact value(AIV) of 19.1 and 7.6 respectively. The moisture content was 1%. The aggregates were screened Prior to usage. The fine aggregates used were river sand from Meru (central Kenya) with the maximum size passes the sieve 9.5 mm, with specific gravity of 2.48. The silt content was 6.01 which is allowable based on British stand and Kenyan stand requirements. Crumb Rubber used was from Crushed and granulated truck tyres from (Acqualine distributor ltd). The maximum size of the Crumb Rubber passes sieve size (4.75mm). Sieve analysis was done based on BS 410.Physical properties and sieve results of all aggregates used are listed in Table 3.2 and APPENDIX 1 respectively.

Table 3. 2.Physical characteristics of Aggregates and Crumb Rubber

Characteristics	**Coarse aggregate**	**Fine aggregate**	**Rubber**
Dry -rodded density	1456.6	1659.3	615
Dry-loss density	1296.2	1518.7	592
Bulk specific gravity (SSD condition)	2.61	2.48	0.83
Aggregate Crushing Value (%)	19.1	3	1.2
Aggregate Impact value (%)	7.6	-	-

3.2.3. Water

Potable water supplied by Municipality was used on the all mixes. The rule of thumb for water quality is, if you can drink that water, you can use it for making concrete.

3.2.4. Chemical admixtures

To maintain the consistency of the tyre steel fibre rubber concrete, a high-range water reducers(HRWR) SP430 was used in all RTSFRC mixes. The superplasticizers conform with BSE934-2, BS5075 Part 3 and with ASTM C494.The product manufacturer, recommends, for high strength, water reduced concrete, the normal dosage range is from 1.00 to 3.00 litres/100 kg of cementitious material, including PFA, GGBFS and micro silica. For high workability concrete the normal dosage range is from 0.70 to2.00 litres/100 kg of cementitious material. For this project 0.85 was used in the all mixes. Table 4.3 is the properties of the superplasticizers used

Table 3. 3.Properties of superplasticizers

Properties	
Appearance	Brown liquid
Main component	Sulphurated naphthalene
Specific gravity (BSEN 934-2)	1.18@22ºC+2ºC
Water absolution Chloride (BSEN 934-2)	Nil
Alkali Content (Na2O equivalent /liter of admixture) (BSEN 934-2)	55g

3.2.5. Recycled Tyre steel fibres.

The fibres used in this research were from (Acqualine Distributor Ltd). The company is producing oil from used tyres through Pyrolysis process. They heat waste tyres at high temperature and their final products are; oil, steel cords, bead wires and carbon black. Due to the surface texture of the tyre steel cords (twisted wires), they were preferred over bead wires. The surface texture could enhance the bonding strength (pull-out strength) between the steel fibres and concrete matrix as it was reported by Houssan Themed 2003 that steel cord from Pyrolysis has a better energy absorption and bond stiffness over other commercial steel wires. The failure mode of fibre in concrete matrix are either tensile failure or slip of the fibres and the latter being common failure of fibre reinforced concrete. The steel cord collected were undamaged with carbon black on its surface and the Tensile strength was not affected since no burning takes place for they heat at absence of oxygen. On 20 samples of the steel cords tested, the mean values of effective diameter and tensile strength were 1.15mm and 1014.7MP respectively. This strength meets the requirements specified by ASMT A820, that "The average tensile strength shall not be lesser than 345MPa and the tensile strength of any one of 10 tests specimens shall not be lesser than 310MPa". The recycled tyre steel fibres with different lengths and aspect ratios, were achieved by cutting the recycled steel cord into 20mm,40mm and 60mm lengths. All properties of the fibre used are summarized in Table 3.4

Table 3. 4.Properties of The Recycled Tyre steel fibre

Properties	**Description**
Lengths (mm)	20,40,60
Diameter (mm)	1.15
Aspect ratio	17,35,52
Tensile strength (Mpa)	1054.7
Shape	Cylindrical
Surface texture	Rough (twisted steel wires)

Colour	Black

3.3.Mix proportions

The control mix was designed to achieve concrete Characteristic compressive strength of 30MPa.The design was according to BS8110 and BS1988.The grade C30 adopted as control was designed to have a slump value of 30-60mm and a 28-days compressive strength of 30N/mm^2 with a water cement ratio of 0.5. Crumb Rubber volume of 5, 10,12.5,15 and 20% replacing normal sand were differently mixed and their corresponding compressive and tensile strength of the rubber concrete were determined. Among these rubber percentage volumes replacement, only 12.5% was mixed with different percentages of recycled tyre steel fibres which are 0.3,0.6,0.9 and 1.2% of the total designed mass of concrete. Among these percentages of steel fibres, 1.2% was having different lengths, 20mm,40mm and 60mm. A total of 12 mixes were used to study the effect of tyre steel fibres on mechanical properties and impact energy characteristics of recycled steel fibre Rubber concrete in hardened state. The mix design data sheet is attached on Appendix 2. The concrete mixes were designated in such way that (CRm-VnLp), where m, n, p subscripts represent: Crumb Rubber volume, tyre Steel fibre volume and Recycled tyre steel fibre length respectively. The proportions of all these mixes are presented in Table 3.5

For facilitating easy batching of materials for mixing, the percentage volume of Crumb rubber was converted in mass that correspond to the different volume replacement of the normal sand, using the following relation

$$m_{CR} = \left[\frac{\delta_{cr} * m_A}{\delta_a}\right]\left[\frac{x}{100}\right]$$

Where m_{CR} is mass of rubber required in a cubic meter of the designed concrete which corresponds to X percentage volume of rubber replacement of normal sand, m_A is the mass of the sand required in one cubic meter of the concrete, and , δ_{cr} *and* δ_a correspond to density of the used Crumb rubber and fine aggregate respectively. Note the concrete mix design is based on one cubic meter.

Table 3. 5.Mix proportions of all materials

Mix Designation C30	**Rubber (kg/m³)**	**W/C Ratio**	**Water Content (kg/m³)**	**Cement Content (Kg/m³)**	**Fine Agg. (Kg/m³)**	**Coarse aggregate (kg/m³)**	**Admix. (l/m³)**	**Steel fibres (kg/m³)**
CR0	0	0.5	195	390	727.75	1047.25	3.3	0
CR5	12.4	0.5	195	390	691.3	1047.25	3.3	0
CR10	24.8	0.5	195	390	654.9	1047.25	3.3	0
CR12.5	31	0.5	195	390	636.8	1047.25	3.3	0
CR15	37.2	0.5	195	390	618.6	1047.25	3.3	0
CR20	49.6	0.5	195	390	582.2	1047.25	3.3	0
CR12.5-V0.3L60	31	0.5	195	390	636.8	1047.25	3.3	7.2
CR12.5-V0.6L60	31	0.5	195	390	636.8	1047.25	3.3	14.4
CR12.5-V0.9L60	31	0.5	195	390	636.8	1047.25	3.3	21.6
CR12.5-V1.2L60	31	0.5	195	390	636.8	1047.25	3.3	28.2
CR12.5-V1.2L40	31	0.5	195	390	636.8	1047.25	3.3	28.2
CR12.5-V1.2L20	31	0.5	195	390	636.8	1047.25	3.3	28.2

3.4.Mixing and sample preparations

Trial and error method was used to achieve the required slump (30-60mm), the sampling, mixing and slump measurement was according to (BS1881: part -102, 1983),. Initially a half of the required amount of water was added to the aggregates to bring them to Saturated surface dry. After mixing for with all materials in dry condition, Recycled tyre steel fibres were added even as form of rainfall and were distributed evenly at the same time mixing to avoid the balling effect of the steel fibres. After the composite material is well mixed with rest of the designed water, three slump tests were measure on one mix and the average was taken as mean of the slumps.

Mould and samples were made according to BS 1881-108, ASTM- C31, C470, and D1557. All the moulds were wetted with lubrification agent to facilitate demoulding of the forms. Freshly mixed concrete was poured in three layers each layer being compacted with vibrator to removed air trapped in the concrete and achieve homogenous mixing of materials in the entire concrete batch.

72 Concrete cubes of 150x150x150mm and 72 concrete cylinders of 100x200mm were casted for compressive and split tensile strength respectively at 7 and 28 days of curing. 24 prisms of 150x150x500mm were also casted for flexural strength and toughness tests at 28 days of curing. Finally ,32 discs of 150 mm diameter and 63±5 mm thickness was made from cutting of full 8 cylinders for impact resistance test. After casting all the moulds, they were kept for 24 hours before demoulding and then the specimens were placed in curing tank(room) to be tested on 7 and 28 days

3.5. Experimental procedures

3.5.1. Slump test

The slump values were measured in accordance with BS 1881–102. The standards specify a slump cone of height of 300 mm, a bottom diameter of 200 mm and a top diameter of 100 mm was used for slump measurement. According to BS 1881, based on the profile of slumped concrete, the slump is termed either true slump, shear slump or collapse slump. Only true slump is accepted, and if a shear or collapse slump is achieved, a fresh sample should be taken, and then be tested again. A collapse slump indicate that the mix is too wet. The cone was filled with freshly mixed concrete in three layers and each layer was tamped 25 times with a 600 mm-long bullet-nosed metal rod measuring 16 mm in diameter. At the end of the third stage, the concrete was struck off flush with the top of the cone. The metal cone was then carefully lifted vertically upwards, so as not to disturb the concrete cone. The slump of the concrete was measured by measuring the distance from the top of the slumped concrete to the level of the top of the slump cone. A mean of 3 slumps test for each mix was used as the slump value of the mix.

3.5.2. Compressive and split tensile strength test

Compressive strength and split tensile tests were performed in Universal testing machine (UTM) with nominal capacity of 2000KN. Dimensions and weight of each samples were measured prior to testing and 7 and 28 compressive and split tensile strengths were determined according to (BS 1881:part -116, 1987) and (BS 1988: part -117, 1983) respectively. The loading was maintained constant at the rate of 0.5MPa /Sec for all tests. The UTM could display, the maximum compressive and split tensile load, and the corresponding compressive and split tensile strengths. The average of 3 cube compressive and 3 cylinder split tensile strengths were adopted as mean compressive and tensile strength of the concrete mix respectively at 7 and 28 days.

3.5.3. Flexural strength and toughness tests

Flexural strength and flexural toughness were carried out according to ASTM-C1609 and C1018 respectively. 24 prisms of 150x150x500mm size each were tested for flexural strength and toughness properties at 28 days. Four points flexural bending test method were used. The four-bending point bending test set up and specimen geometry are illustrated on Figure .3.1 and Figure A-8-28. Testing was performed in oil hydraulic machine with the manual controlling loading rate capability. Linear variable differential transducers(LVDTs) were used to record vertical displacements (deflections) and a load cell on central top of the beams was mounted to monitor loadings and load-deflections data were recorded and displayed on data recording system (Data logger) prior to plot load -deflection (P-d) curves. Ultimate Flexural strengths were determined based on the maximum flexural load recorded during the test using Eq.3.2. Flexural toughness or energy absorption was presented by the area under load-deflection curves at specified deflection in accordance with JCI-SF4 and Toughness indices which is calculated as the area under the load-deflection curve (Figure 2.3) up to 3, 5.5 and 15.5 multiple of first crack deflection divided by the area up to the first crack strength (proportional limit) as according to ASTM-C1018. Residual strength factors were determined from Indices values obtained using method described in section 2.3.6.1.1. Other important parameters of a beam under bending were deduced from beam bending formula which is given by Eq.3.1.

$$\frac{M}{I} = \frac{\sigma_b}{Y} = \frac{E}{R} \qquad (3\text{-}1)$$

With:

M = Bending moment resisted by the beam (Nmm)

I=Second Moment of Inertia of the beam (mm^4)

σ_b = Bending Stress resisted by the beam in N/mm^2

Y= Distance of the beam fibre from N.A

E=Young's Modulus or modulus of elasticity (KN/mm^2)

R= Radius of curvature

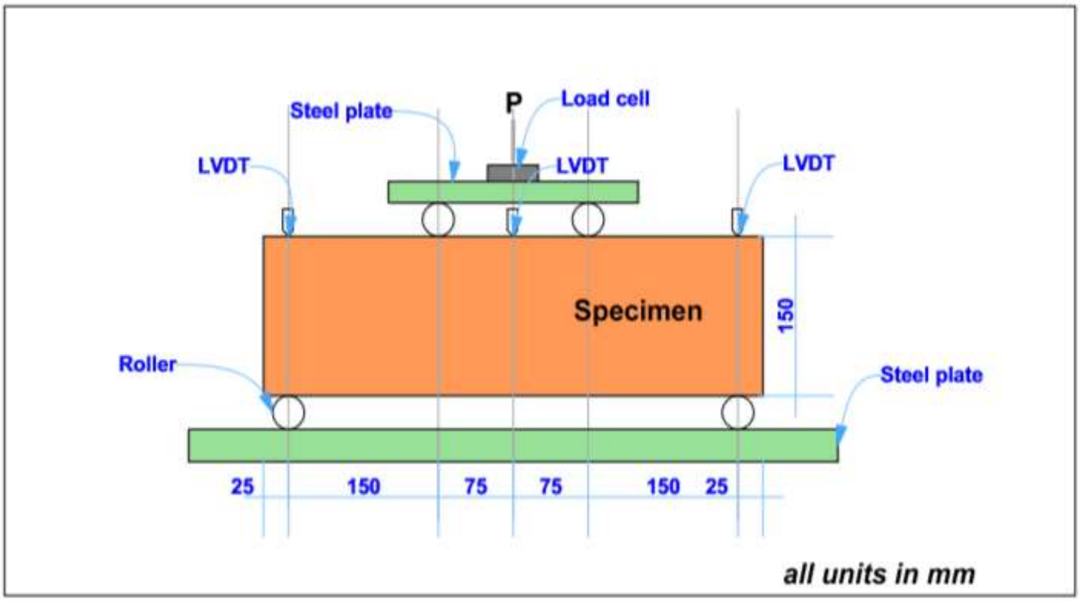


Figure 3. 1.Test Setup for Four Bending beam test -ASTM C1018

Flexural strength or Modulus of Rapture, according to JSCE SF-4 Standard was determined from equation 3-2

$$\sigma_b = \frac{Pl}{bh^2} \quad (3\text{-}2)$$

and, Flexural toughness factors are deduced from Flexural toughness values as indicated in equation 3-2

$$\sigma b = \frac{T_b l}{\delta_{tb} b h^2} \quad (3\text{-}3)$$

Where, σ_b is Flexural strength in N/mm^2

P is maximum load obtained in accordance with JSCE SF-4 in N

L is the span in mm

b is the width of the beams in mm

h is the height of the beam in mm

σ_b is the Flexural toughness factor

T_b is the Flexural toughness in Joule

δ_{tb} is the deflection up to 1/150 of span in mm

3.5.4. Impact resistance

Impact resistance tests were carried out on 32 specimens of 150mm diameter and 63.5mm height by drop-weight test method. The test was done in accordance with ASTM- C31, C470 and D1557.This simplest method of impact resistance tests, yields number of blows necessary to cause a prescribed amount of distress in the test specimen. The number of the blows serve as a quantitative estimate of energy absorbed by the specimen at that amount of distress. Eight full cylinders of 150 diameter and 300mm were casted and cut into 63.5mm Thickness at 28 days to produce standard spacemen for impact testing as described in ASTM- C31.The data being recorded were number of blows at first crack and number of blows required to cause the specimen at total failure. White paint was smeared on the surface of the specimens to facilitate to identify easily the first crack however, it is still subjective matter to observe with precision the first crack. For this test, average results of 4 specimen was adopted as mean energy absorbed by that specimen due to the small specimen are subjected to variation caused by variability of fibre locations. The equipment used for this test was fabricated in Jomo Kenyatta University of Agriculture and Technology Mechanical Engineering Department workshop. The equipment is illustrated on APPENDIX A-8-41

Figure 3. 2.Setup impact equipment test -ASTM-31

In calculating impact energy, the equation from Eq3-4 to Eq3-8 were used.

$$E_I(dynamic) = \frac{1}{2} * m * v^2 * N \quad (3\text{-}4)$$

$$E_I(Static) = \frac{1}{2} * m * h * g * N \quad (3\text{-}5)$$

$$V = gt \quad (3\text{-}6)$$

$$H = \frac{1}{2} * g * t^2 \quad (3\text{-}7)$$

$$m = W/g \quad (3\text{-}8)$$

where E_I - Impact Energy(N-m)

m - Drop hammer mass

V -Impact speed (m-s)

H -Height of drop mass(mm)

N-Number of blows

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1.Test results on fresh concrete

4.1.1. Workability

Workability of freshly mixed concrete is the ability of concrete or mortar to be mixed, transported placed, finished and consolidated with ease and minimal loss of homogeneity. In the existing different methods of testing workability of concrete, slump test is the cheapest and easiest method. Incorporating steel fibres in concrete significantly affects the workability of concrete and it is difficult to predict it due to more fibre properties that affect workability of concrete such as, aspect ratio, volume fractions and surface texture or shape. For the purpose of this work, only effects of aspect ratio and volume fractions of recycled tyre steel fibre were investigated.

It is so difficult to predict the workability of tyre steel fibre rubber concrete, due to different parameters involved in the concrete that can affect workability. For this reason, in this research, trail mixes method was used. Concrete mixed with higher recycled tyre steel fibre content appeared to be stiff and unworkable and the concrete materials bond together and resist to free movement as compared to control with main reason being the aspect ratio, volume fraction and twisted surface texture of tyre steel cord. To overcome this movement resistance to flow of RTSFRC, 0.85% mass of cement of Superplasticizers was added in all mixes so as to improve the workability. The control was designed to have a slump value of 30-60mm, after adding superplasticizers it was increased to 79mm.

The results of workability test showed that, the presence of tyre steel fibre and Rubber concrete affect workability of concrete. The slump tests were performed in each concrete mix and, it was found that, increasing Crumb Rubber from 5 to 20% in concrete, workability was increased from 80mm to 89mm. It was also noted that, when the volume fractions of tyre steel fibre added vary between 0.3 to 1.2%, workability decreased from 61mm to 11 mm relative to control. The effect of the fibre aspect ratio on workability of concrete was also studied. Figure 4-1 indicates that, when the Crumb rubber content increases, the workability increases, and Figure 4-2 shows that the workability decreases with increase in RTSF volume content. Figure 4-3 indicates the variation of slump value due to change in aspect ratio of the RTSF. It is clearly seen that as the aspect ratio of Recycled Tyre steel fibre increases when workability decreases making the concrete to be stiff, reducing free flow of the concrete. The least Slump Value was found from the mixture with higher Fibre content and Higher aspect ratio which CR12.5-V1.2L60 with a value of 11mm.In general workability of Recycled Tyre Steel Fibre reinforced rubber concrete (RTSFR) increases with increase in crumb rubber content and decreases with increase in fibre content and Further decreases with increase in fibre aspect ratio. The results of this test agree with what Sidney (2003) stated that, increase in steel fibre content in concrete increases tendency of balling of fibres hence reducing slump value.

However, the reduction in slump values of recycled Tyre steel fibre reinforced rubber concretes was obvious, all the concretes were workable and easily placed and compacted. One can deduce that, slump test value provides not much indication of whether the SFRRC is workable, compactable, placed. Since this test seems inadequate to yield the exact effect of tyre steel fibre inclusion on workability of concrete, Other methods must be used to assess the variability in the tests results.

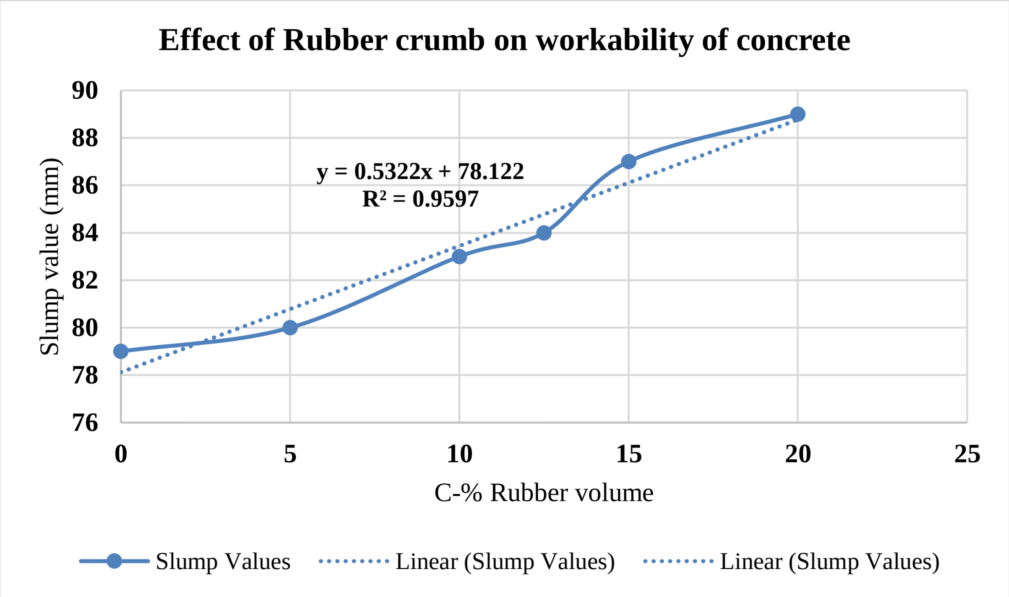


Figure 4. 1.Comparison of slump values of concrete mix Group I.

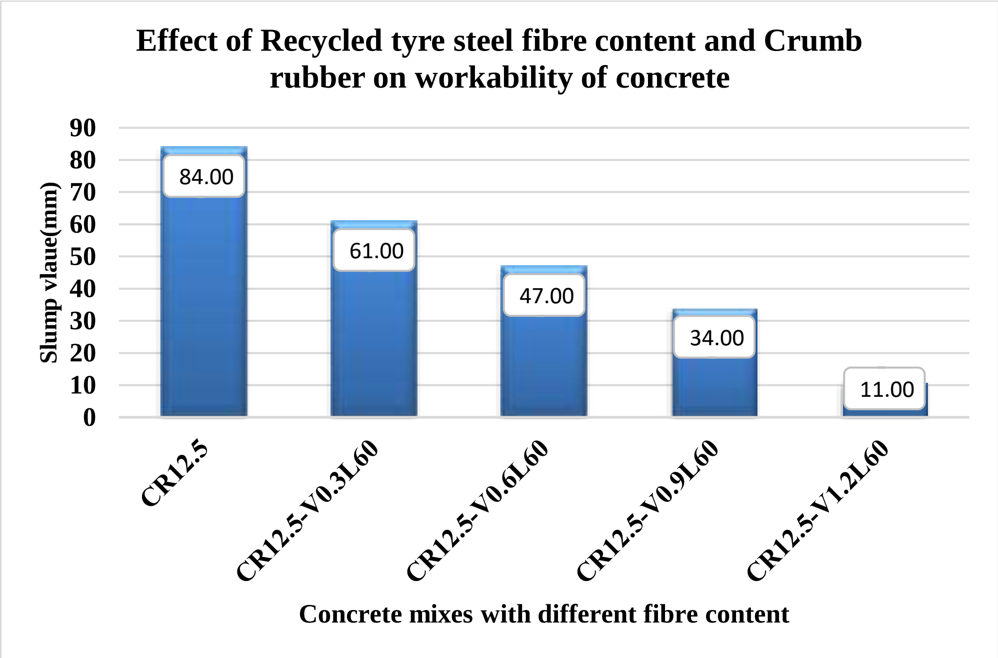


Figure 4. 2.Comparison of slump values of Concrete Mix Group II.

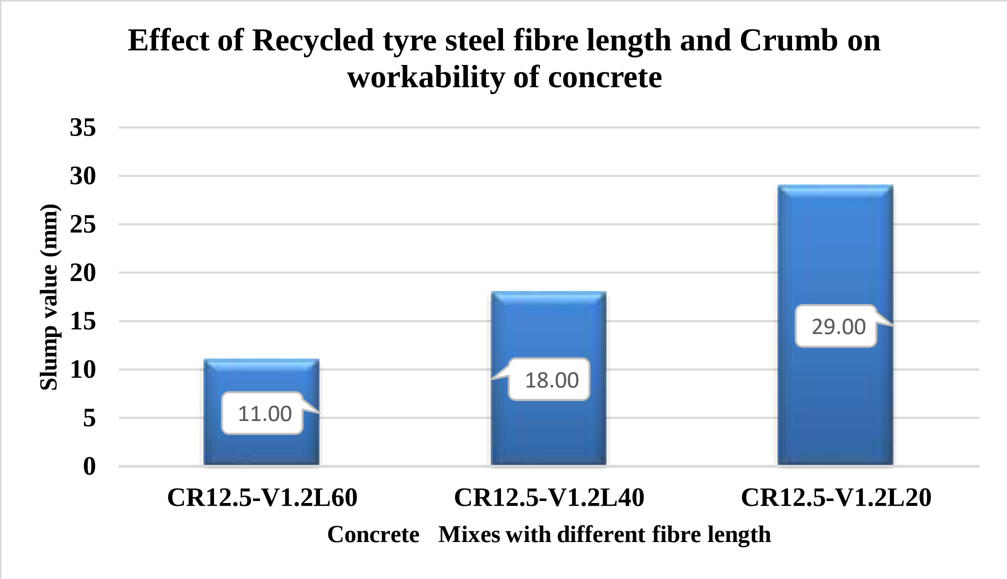


Figure 4. 3.Comparison of slump values of Concrete mix group III.

4.2.Test results on hardened concrete

4.2.1. Compressive strength

The results on Compressive strength of concrete mixes of the group I to Group III at 7 and 28 days are presented on Figure 4-4-6. The result of Control compressive strength at 7 and 28 days were 25.28 Mpa and 39.20 Mpa respectively. The addition of 5, 10, 12.5, 15 and 20% Crumb rubber replacement to fine aggregates in concrete, the compressive strength reduces by 4.76, 13.39, 19.84, 25.64 and 41.07%; and 4.78 ,15.55 ,21.51 ,32.13 and 42.69% at 7 days 28 days respectively and the results are presented on Figure 4.4.

The compressive strength results on rubber concrete mix CR12.5 was found to be 20.26 Mpa and 30.77Mpa, which correspond to a decrease in compressive strength of 19.84 and 21.51% at 7 and 28 days respectively. The addition of Recycled Tyre steel fibre to this rubber concrete at fraction of 0.3 ,0.6 ,0.9 and 1.2%, the Compressive strength reduced by 21.15 ,16.85 ,13.37 ,8.73%; and 22.48 ,17.39 13.29, and 10.38% at 7 and 28 days respectively. This means that, there have been a little improvement on Compressive due to inclusion of RTSF in rubber concrete.

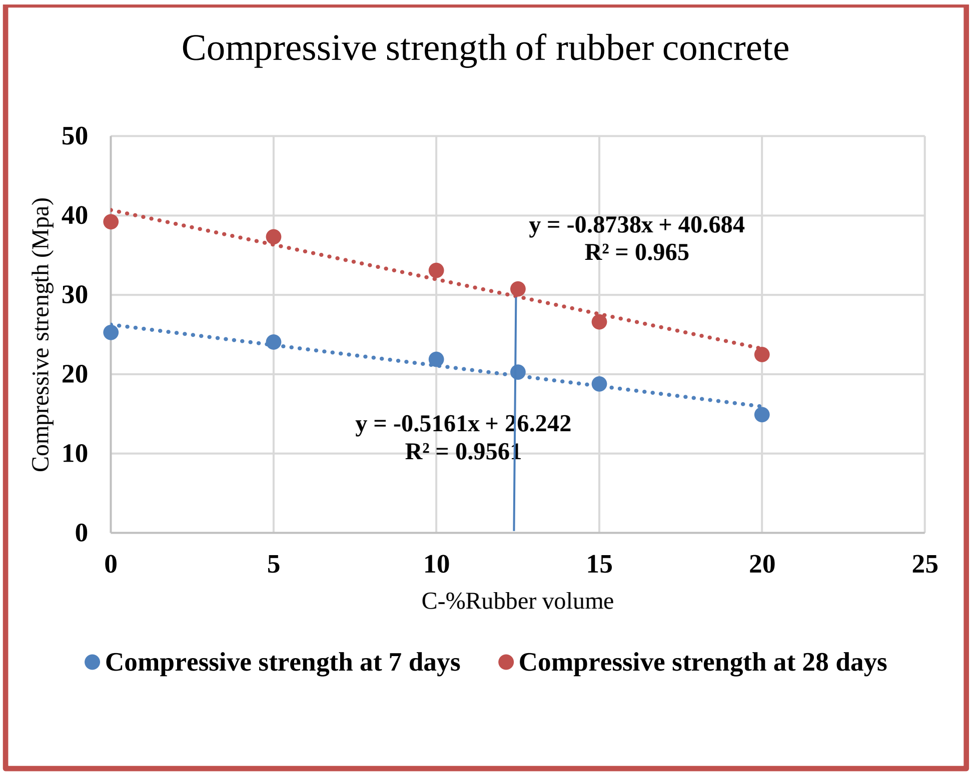


Figure 4. 4.Comparison on compressive strength of Concrete mixes of Group I

From the Fig 4.5, It can be concluded that, when the fibre volume increases, the compressive strength slightly increases too. The maximum value of compressive strength was found to be on a rubber concrete mixture with 1.2% percentage content of RTSF with fibre length of 40mm. The figure 4.6 shows effect of fibre aspect ratio on compressive strength , and results indicated that was also studied, and from the aspect ratio of RTSF has an effect on compressive strength of rubber concrete .The maximum value of compressive strength was found at 1.2% fibre volume with fibre length of length of 40mm.The reason might be that, the longer fibre tends to make balling in concrete causing poor distribution of the fibre in concrete mix ,but this was not the case for flexural and tensile strength test results .

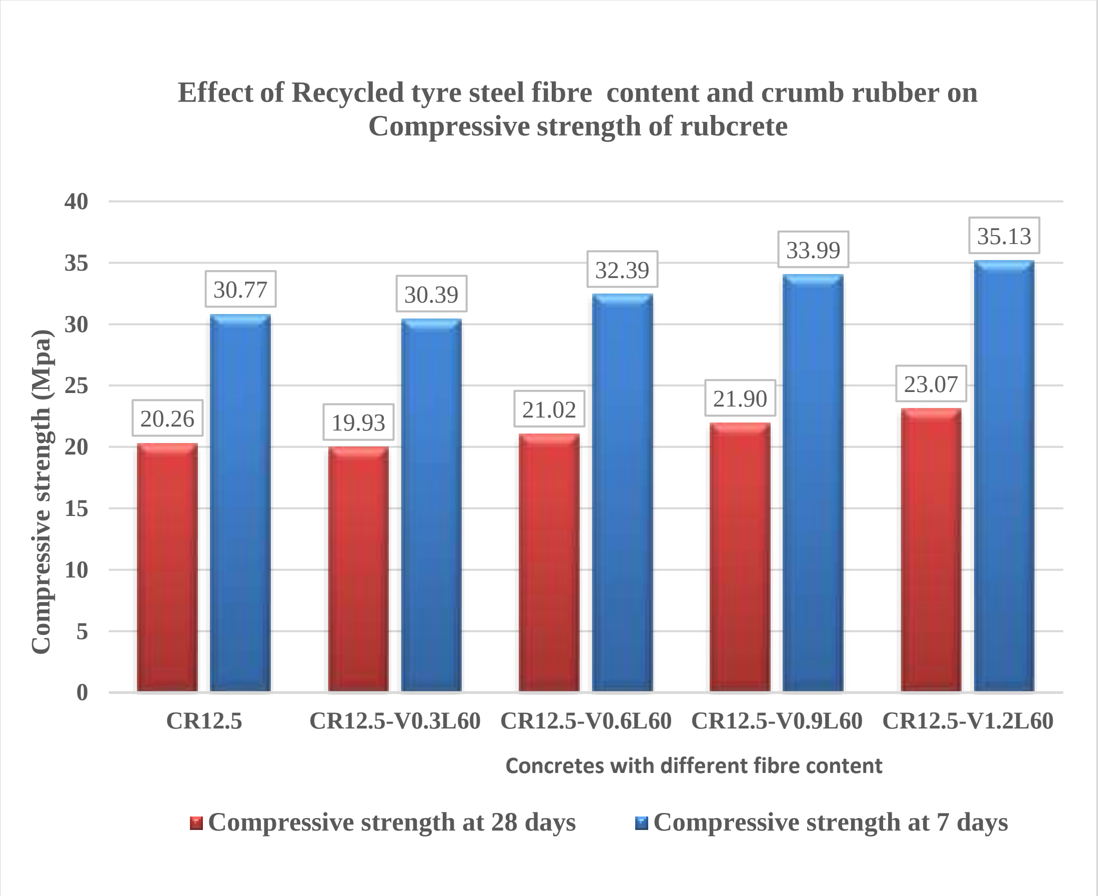


Figure 4. 5.Comparison on compressive strength of Concrete mixes of Group II

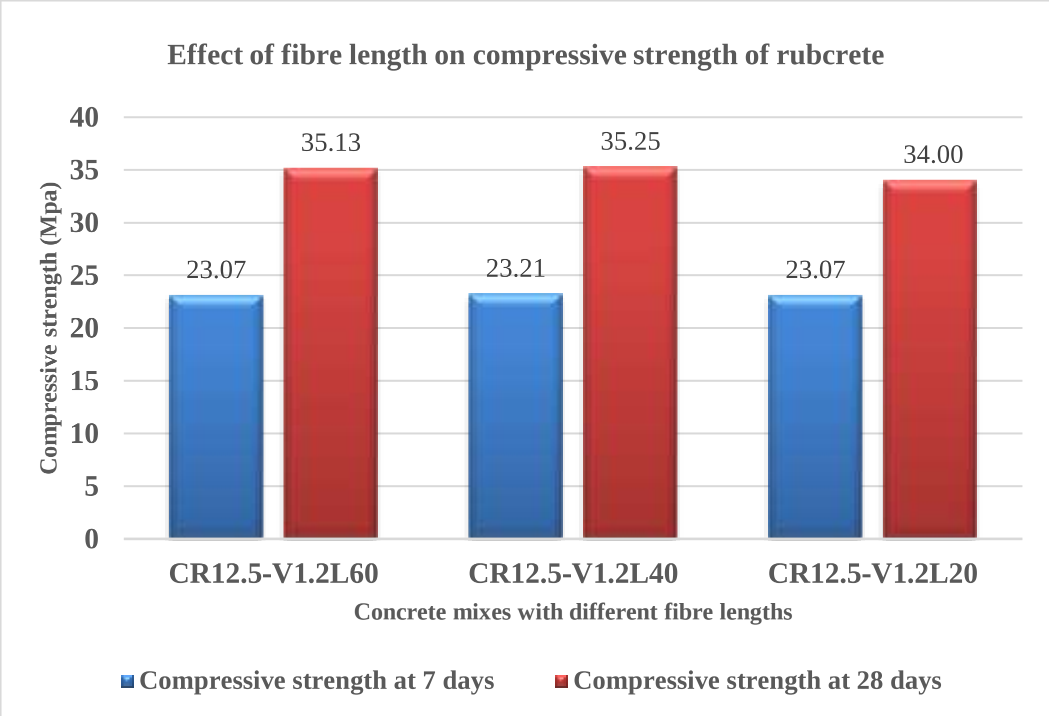


Figure 4. 6.Comparison on compressive strength of Concrete mixes of Group III

4.2.2. Split Tensile strength

Tests on Split Tensile strength tests on 7 and 28 days of all concrete mixes of the group I to Group III have been presented on Figure 4.6-9 respectively. The Split tensile strength of the control mix found to be 2.21Mpa and 3.11 at 7 and 28 days respectively. The replacement of fine aggregate by 5 ,10 ,12.5, 15 and 20% of Crumb rubber in concrete resulted in reduction of Split tensile strength by 3.38, 10.30, 17.31 ,22.02 and 31.70%; and 1.2, 10.7, 17.44, 23.75, and 33.36% at 7 and 28 days respectively. From Figure 4.7, it can be concluded that, split tensile strength decreases with increase in crumb rubber in concrete, this result agrees with what was stated in literature that concrete tensile strength reduces linearly with increases in rubber content. The main reason was reported to be the weak bond between the rubber aggregate and cement paste in concrete matrix and the lower modulus of elasticity of crumb rubber compared to conventional sand.

At 12.5% crumb rubber replacement, the rubber concrete split tensile strength was1.83Mpa and 2.56Mpa which correspond to reductions of 17.31% and 17.44% at 7 and 28 days respectively. The inclusion of randomly distributed RTSF of different volume 0.3 ,0.6 ,0.9 ,1.2%, the reductions in split tensile strength were 15.25 ,7.43 ,1.17 and 0.30%; and 14.97 ,10.42 ,5.55 and 0.27 at 7 and 28 days respectively. As it can be seen on Figure 4.8, The split tensile strength increases with increase in Recycled tyre steel fibre content. This is in accordance with what Williamson 1974 stated, that steel fibre can increase Split tensile strength up 40% and on the current research, it increased up to a maximum of 17.17% at 28 days.

Different fibre lengths with a constant fibre volume of 1.2% were added in rubber concrete, the results showed that RTSF with 60mm length performed better than other two lengths on split tensile strength of rubber concrete and it is shown on Figure 4.9 of this book. The maximum Split tensile strength was found at 1.2% of fibre volume with aspect ratio of 52, where the values were 2.20Mpa and 3.10Mpa at 7 and 28 days respectively. It can be concluded that, the split tensile strength increases with increase in aspect ratio, though higher value of aspect ratio can affect the strength causing fibre balling, hence limitation should be put.

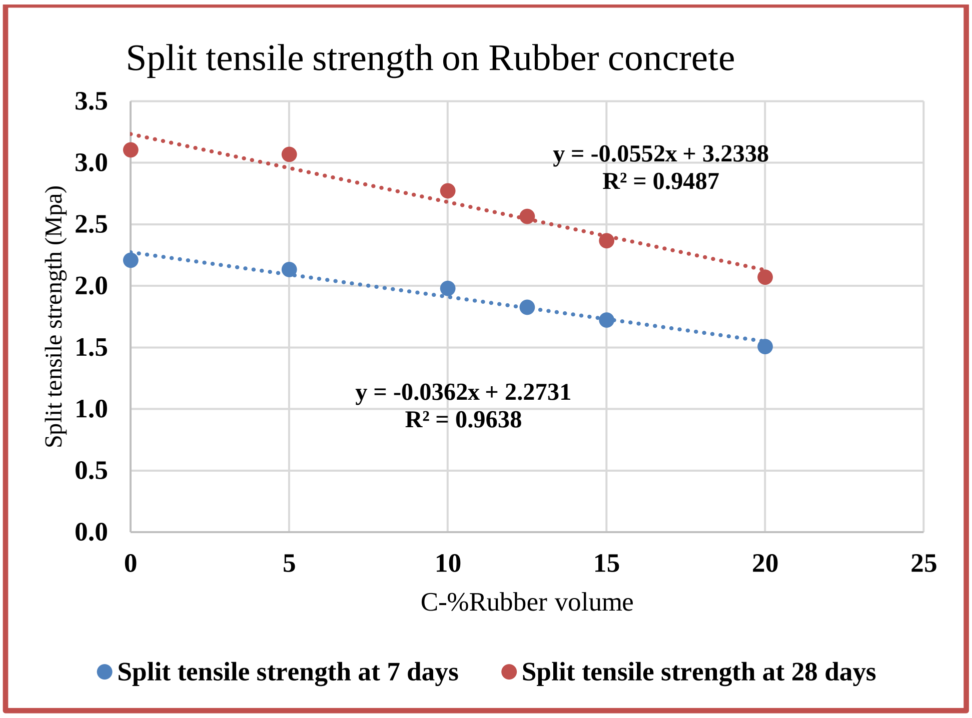


Figure 4. 7.Comparison on Split tensile strength of Concrete mixes of Group I

The addition of recycled tyre steel fibre volume up to 1.2 % of mass of concrete significantly increased the split tensile strength of the rubber concrete. The results showed again that, the aspect ratio of the RTSF has an influence on split tensile strength property, in among the three lengths, the fibre with 60mm length performed better others in terms of split tensile strength, which is the concrete mix C12.5-V1.2VL60 where tensile strength was 2.20Mpa and 3.10 Mpa respectively at 7 and 28 days.

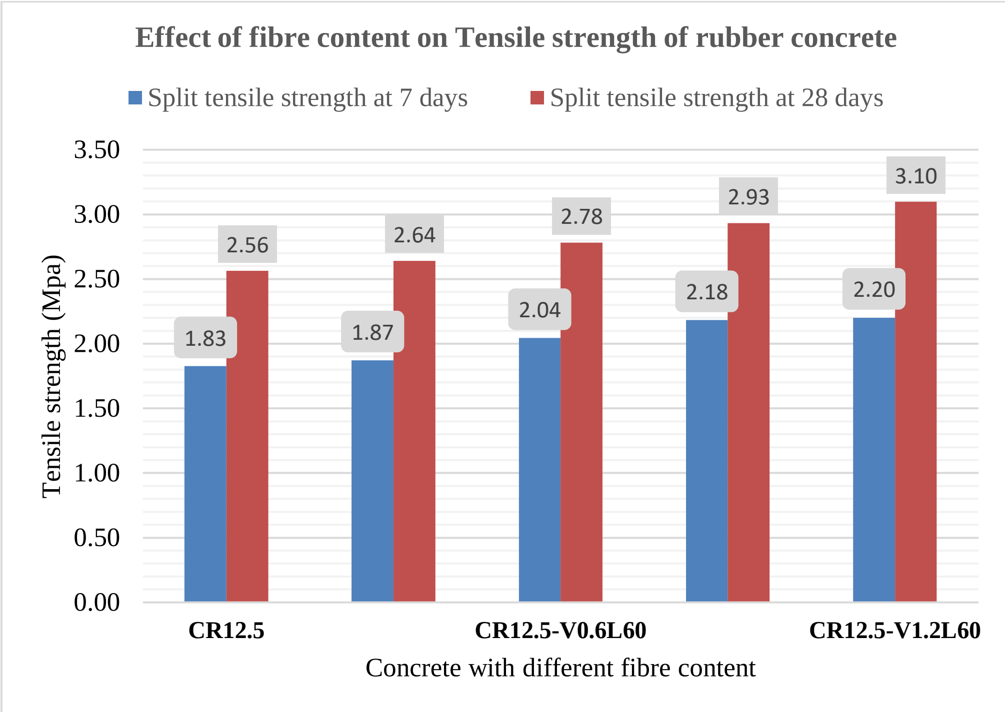


Figure 4. 8.Comparison on Split tensile strength of Concrete mixes of Group II

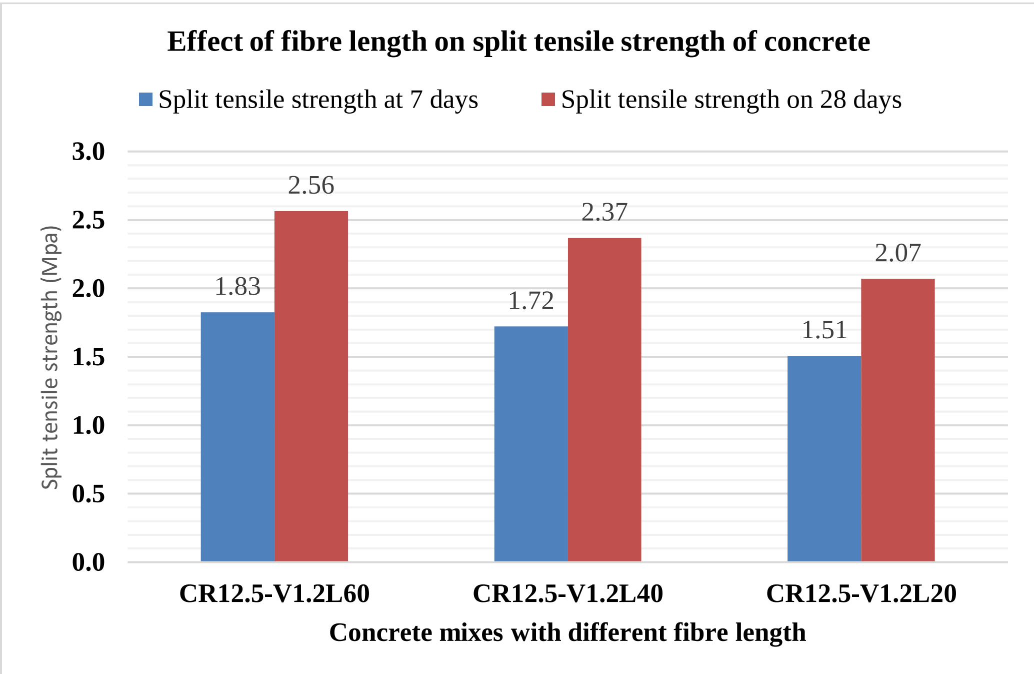


Figure 4. 9.Comparison on Split tensile strength of Concrete mixes of Group III

The additional of Recycled tyre steel fibre in rubber concrete slightly enhanced Compressive and split tensile strength properties of rubber concrete. For addition of RTSF up to 1.2% volume, the decrease in tensile strength of the mix CR12.5 decreased from 17.44 to 0.27% of tensile strength which is 17.17% increment. Same applied to Compressive strength, the addition of RTSF up to 1.2%, the decrease in compressive strength of CR12.5 mix were from 21.51 to 10.38%, which is 11.13% increment. The results agree with what was reported that, the addition of steel fibre in concrete matrix will have minor effect on compressive strength (0 to 15%) increment but, the tensile strength will have an increment of up to 2.5 times that of unreinforced one (Fousil Fouad Wafa, 1990).

Generally, based on Figure 4.10, the inclusion of RTSF enhanced split tensile strength more than compressive strength. The Recycled tyre steel fibre counteracted the negative effect of 12.5% Crumb rubber content on split tensile strength of concrete. Though there is a remarkable increase in compressive strength by incorporating randomly distributed recycled tyre steel fibre in rubber concrete, this increase is so minor, it can be ignored in design considerations. On the other hand, incorporating of recycled tyre steel fibre in concrete has a positive effect on mechanical properties of concrete.

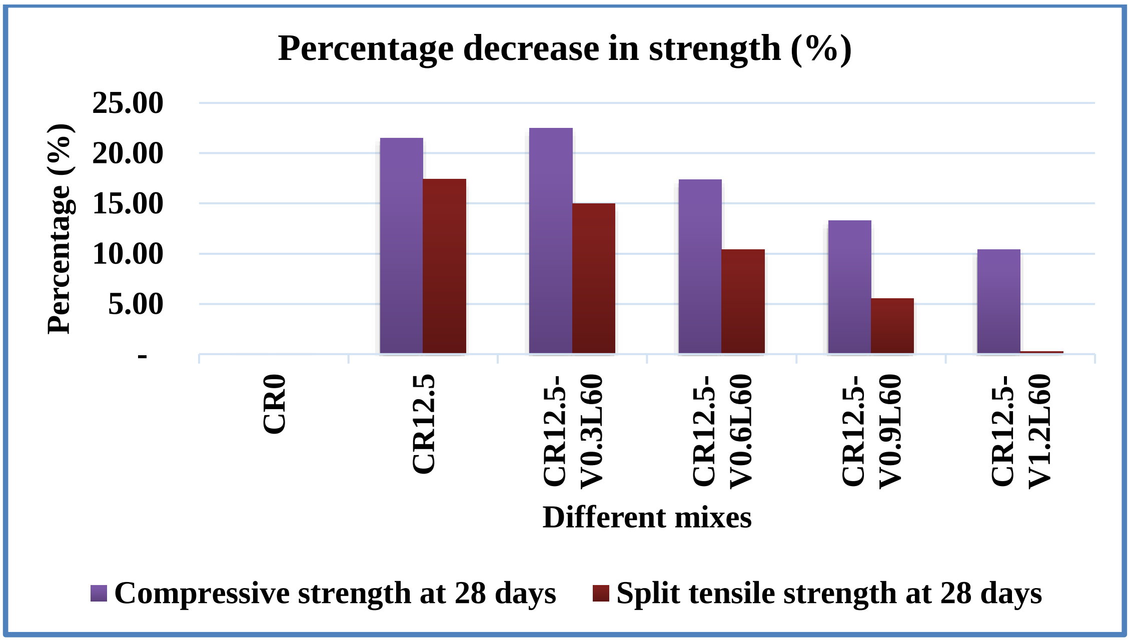
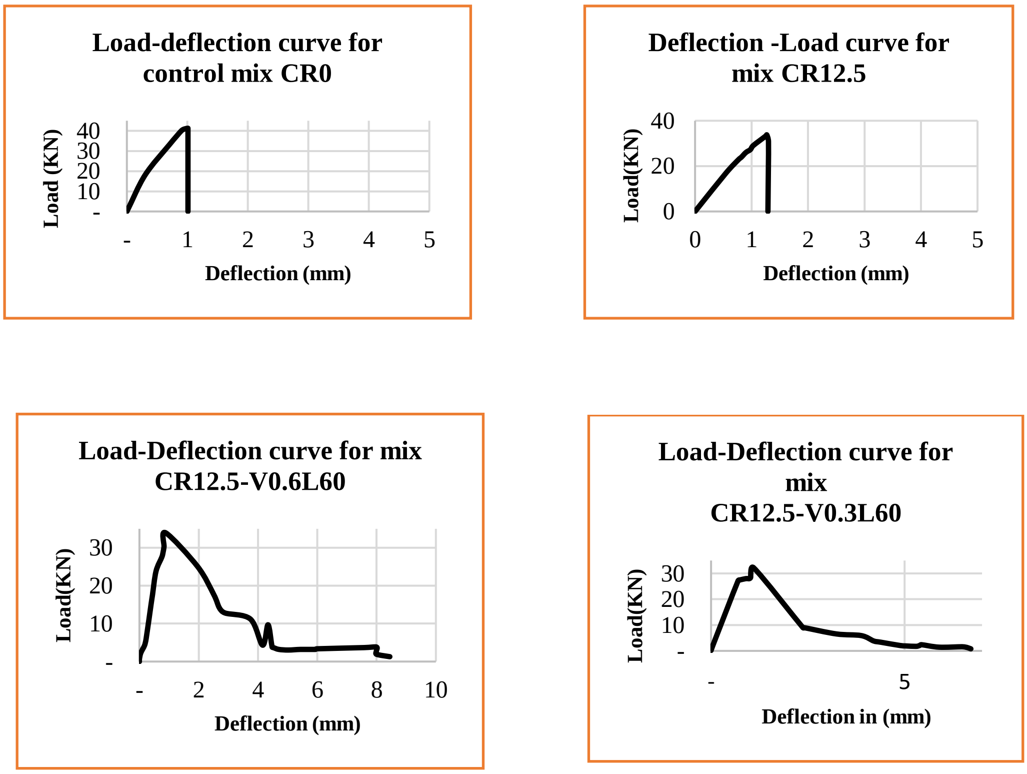


Figure 4. 10.Comparison on decrease in Compressive and Split tensile strength of concrete mix of Group II

4.2.3. Flexural strength

Flexural strength test was conducted on Four-point loading test method. There exist basically two methods for Flexural strength test, Three-point loading (or centre loading) test and Four-point loading (two-point loading) loading test. The latter was preferred over the former due to different advantages that it offers. The benefit of the four-point bending test arrangement is the constant value of the bending moment with no shear force in the middle third of the specimen and hence elimination of the effect of shear force. The four-point bending test can safely localize the weakest part (representative) of cross-section, but the three-point bending cannot which makes it unsuitable for Composite material (Adam Podstawka, Marek Foglar,Vladimir Kristek, 2015).

Load -deflection data were recorded on data logger and produced (P-d) load -deflection curves are presented on figure 4.11. based on the plotted graphs, load carrying capacity reduced by inclusion of crumb rubber and started increasing as recycled tyre steel fibre were added. The most advantage of fibre reinforced concrete is its failure mode, which is ductile. It can be seen on the figure that normal and rubber concrete without fibres completely failed immediately after reaching peak loads while RTSFRC retained some more loads after peak loads hence increased ductility. For the analysis effect on toughness, Area under load deflection curves were determined and results are discussed in this chapter.



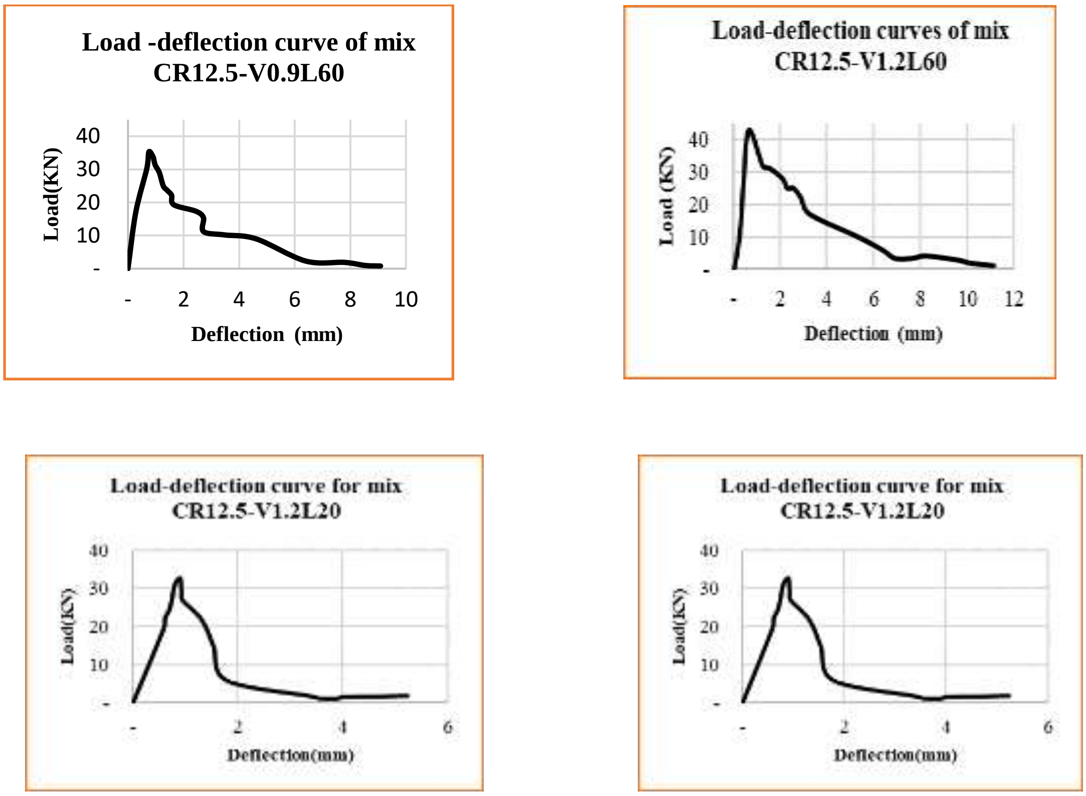


Figure 4. 11.Load-deflection Curves

The First crack flexural strength and Ultimate Flexural strength were calculated from the first crack load and Ultimate failure load obtained during four-point loading test.

The result indicated that, first crack Flexural strength and Ultimate Flexural strength of control (CR0) mix were 5.50Mpa and 5.50Mpa respectively, and that of rubber concrete (CR12.5) mix were 4.11Mpa and 4.51Mpa which correspond to 25.29% and 18.12 % reduction at first crack and ultimate flexural strength respectively. This was due to reduced load carrying capacity of rubber concrete. The control exhibited brittle failure since the first crack flexural strength was equal to ultimate flexural strength. By incorporating recycled Tyre steel fibre in concrete with volume fraction of 0.3 ,0.6,0.9

and 1.2%, the resulted strengths were 3.73Mpa, 3.85Mpa ,4.00Mpa and 4.93Mpa; and 4.29Mpa, 4.52Mpa, 4.70Mpa and 5.74Mpa first crack and ultimate flexural strengths respectively. The inclusion of recycled tyre steel fibre up to 1.2% content in concrete, decreased the percentage reduction in flexural strength of rubber concrete from (-)18.2% to (+) 4.26%, meaning 1.2% of fibre volume overbalanced the negative percentage value of strength reduction in rubber concrete by 4.26%.

As it can obviously be seen on the Figure 4.12 that, the flexural strength of rubber concrete increase as the volume of RTSF increased. The maximum value obtained was at concrete mixture CR0-V1.2L60, where the concrete contains the maximum percentage of RTSF. The effect of fibre length on flexural strength of rubber concrete was also studied, the results as it indicated on Fig 4.13 showed that, the flexural strength increased when the aspect ratio increase, the maximum value of flexural strength of concrete of group III was found on mix CR12.5-V1.2L60 which is 5.70Mpa where the fibre length was 60mm.This correspond to Flexural strength increment of 22.38% from the flexural strength of control mix.

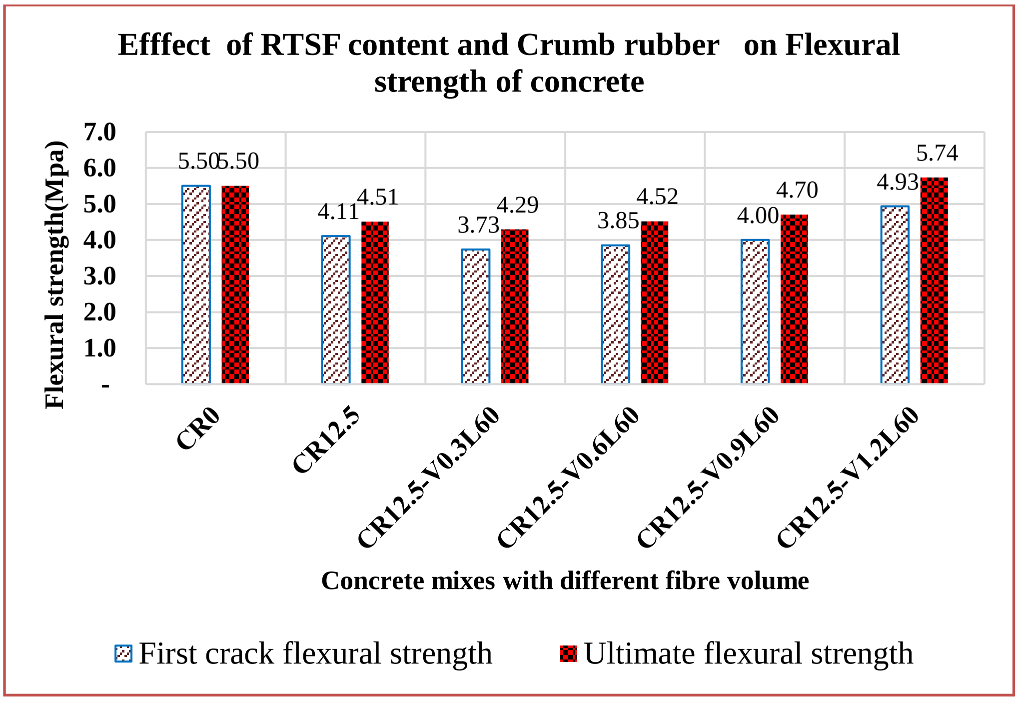


Figure 4. 12.Comparison on Flexural strength of concrete mixes of Group II

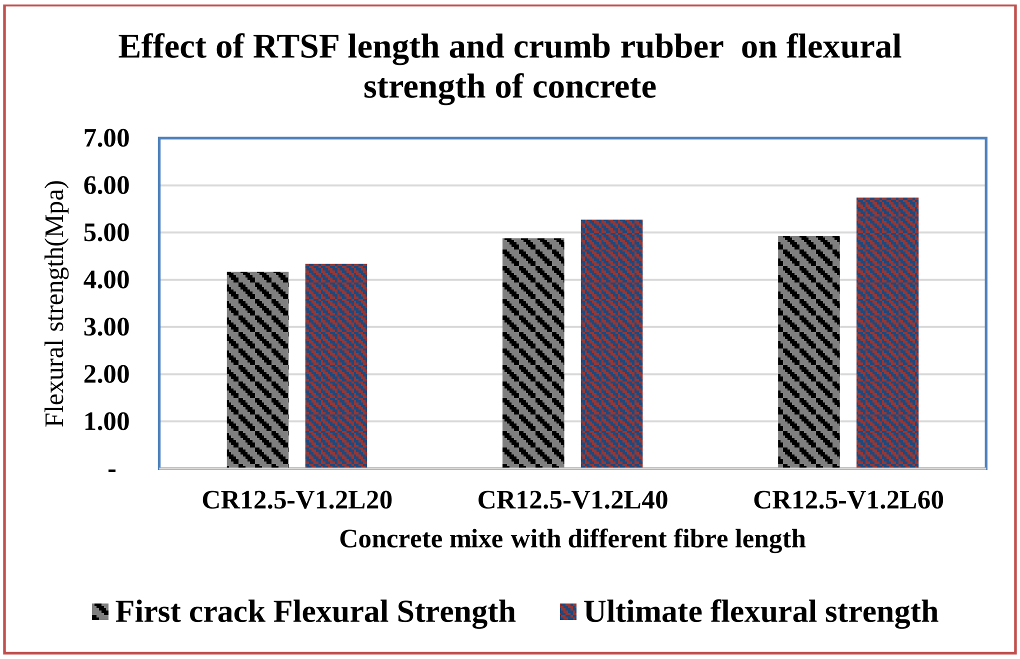


Figure 4. 13.Comparison on Flexural strength of concrete mixes Group III

4.2.4. Flexural Toughness

For evaluating flexural performance of the various concrete mixtures; terms, First -crack load, ultimate failure loads and their corresponding mid span deflections were used. first crack Flexural strength and ultimate flexural strength values were determined from First crack load and ultimate failure load using Formula for modulus of rapture given in test method ASTM-C78 in four points bending tests method according to ASTM-C1609-10.3. Flexural Toughness and Flexural toughness indices were determined in accordance with and JSCE-SF4 and ASTM-C1609 respectively. Flexural toughness is represented by the area under load -deflection curve. ASTM defines First crack, as the point on the load-deflection curve at which the form of curve first becomes nonlinear (approximately on onset of cracking on concrete mix). In the JSCE-SF4, the first crack point is not a concern on load-deflection (P-d) curve, according to JSCE-SF4, the toughness is represented by the area under load -deflection curve up to supported span over 150.

The produced load-deflection curves for different mixes are presented on Figure 4.11. The results of flexural toughness, toughness indices and residual strengths are presented in Tables 4.1. From the produced load-deflection curves, it showed that the maximum flexural load supported by rubber concrete was generally lower than that of normal concrete due to inclusion of crumb rubber. The mechanism is the same as that of compressive strength test though, the reduction in flexural load carrying capacity is smaller than that of compressive strength tests. At 12.5% crumb rubber ratio, the ultimate flexural strength reduced by 17.8%. Addition of recycled tyre steel fibres at different percentages increases flexural load carrying capacity of rubber concrete. At

1.2% ratio of recycled tyre steel fibre, there marked 4.3% positive increment from a negative percentage of 17.8% of flexural strength of rubber concrete .The enhanced ductility and toughness were observed on combined crumb rubber and the tyre steel fibre concrete beams, where the concrete beams retained more loads after reaching at first-crack level, while in the concrete without fibres, the concretes could not carry anymore loads after immediate first-crack appeared, it exhibited brittle failure. This can further be observed on the shape of the load-deflection curve which is sharper than that of (RTSFRC) curves.

The results shown in Fig 4.14 and Fig.4.15, indicate that, the Flexural toughness of RTSFRC increased significantly as the fibre content and aspect ratio increase respectively. The maximum value was observed at 1.2% volume of fibre and aspect ratio of 52 where increase in flexural toughness based on JSCE-SF4 was 258% compared to that of normal concrete. It was reported that flexural toughness of fibre reinforced concrete depending on amount and shape of fibres used, can increase from 10 to 40 times that of plain concrete (ACI committee5 44, 1978) (ACI committtee 544, 1982).

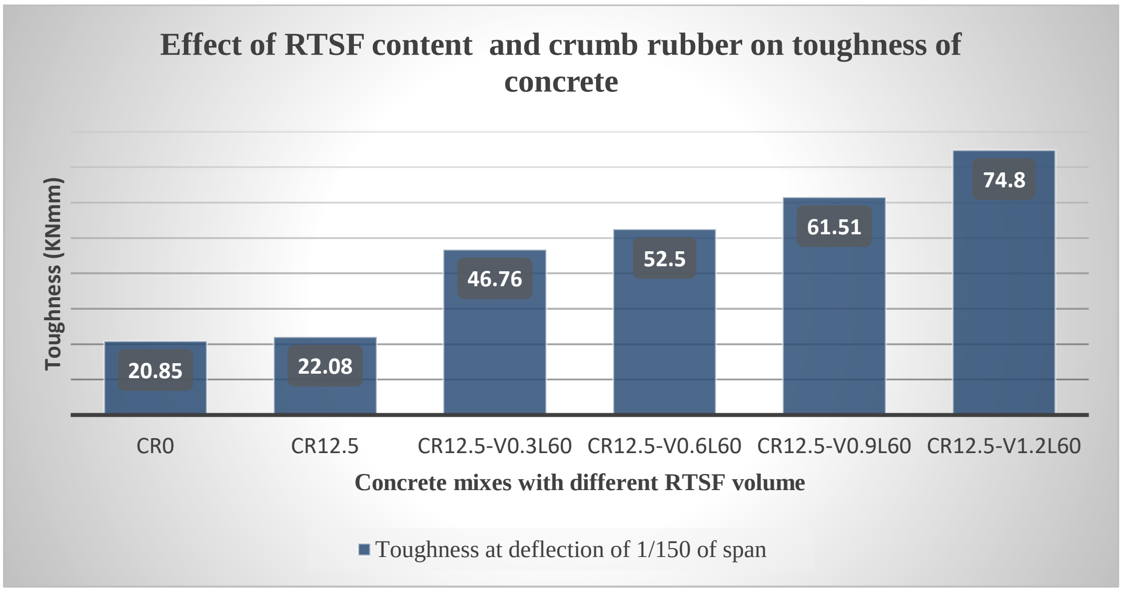


Figure 4. 14.Comparison on effect of RTSF content and crumb rubber on flexural toughness of concrete

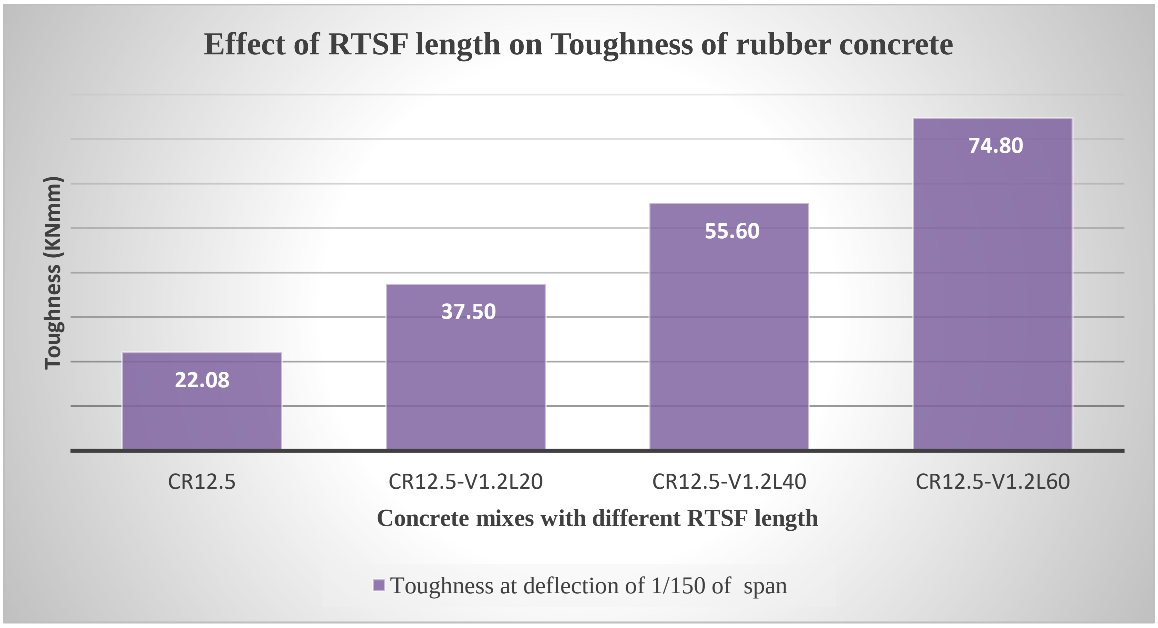


Figure 4. 15.Comparison on effect of RTSF lengths and crumb rubber on flexural toughness of concrete

To examine the level of post-crack performance of fibre reinforced concrete, ASTM-C1018-97 introduces terms, Toughness indices I_5, I_{10}&I_{20} and Residual strength factors $R_{5,10}$, $R_{10,20}$. Toughness Indices enable actual performance to be compared with a readily understood reference level of performance. In this regard, the values 5,10, and 20 for I_5, I_{10}&I_{20} respectively correspond to linear elastic material behaviour up to first crack and perfectly plastic thereafter. The residual strength factors $R_{5,10}$, $R_{10,20}$ represents the average level of strength retained after first crack as percentage of the first crack strength for deflection intervals (5.5-3)δ and (10.5-5.5) δ,where δ being the first crack deflection .100 residual strength factor corresponds to perfectly plastic behaviour, however lower values indicate inferior Flexural performance.

From the results of the current study, toughness Indices and residual strength factors of plan and rubber concrete were nearly 1and 0 respectively as it can be seen on Table 4.1. The Combination of Rubber 12.5% percentage volume and recycled tyre steel fibres in concrete, increased the Toughness index and Residual strength factor from 1.08 to 7.68 and 0.0 to 55.8 respectively at fibre volume of 1.2% and fibre length of 60mm.This shows a good level of performance of RTSFRC in terms of Flexural toughness and ductility compared to plain concrete and rubber concrete.

It has been noticed on Fig 4.16. and Fig 4.18 that, the toughness indexes and residual strength values respectively increase with increase in RTSF volume and similarly on Fig 4.17 and Fig 4.19 it shows that, toughness indexes and Residual strength factors respectively increase with increase in aspect ratio which can be obviously seen on the result of concrete mixture CR12.5-V1.2L60.

Table 4. 1.Results on Toughness Indexes and Residual strengths

Mix	First crack deflection(mm)	Energy absorption in (Joule)			Toughness Index		Residual strength factor R5,10
		$\delta = \delta_{Fc}$	$\delta = 3\delta_{Fc}$	$\delta = 5.5\delta_{Fc}$	I_5	I_{10}	20(I10-I5)
CR0	1.01	20.85	20.85	20.85	1.00	1.00	-
CR12.5	1.25	20.50	22.08	22.08	1.08	1.08	-
CR12.5-V0.3L60	0.91	12.74	42.22	53.13	3.31	4.17	17.12
CR12.5-V0.6L60	0.82	11.85	43.10	67.30	3.64	5.68	40.85
CR12.5-V0.9L60	0.68	10.25	44.38	69.40	4.33	6.77	48.82
CR12.5-V1.2L60	0.55	10.10	49.41	77.60	4.89	7.68	55.82
CR12.5-V0.9L60	0.68	10.25	44.38	69.40	4.33	6.77	48.82
CR12.5-V1.2L40	0.71	10.75	47.36	73.25	4.41	6.81	48.17
CR12.5-V1.2L20	0.87	12.61	44.50	53.68	3.53	4.26	14.56

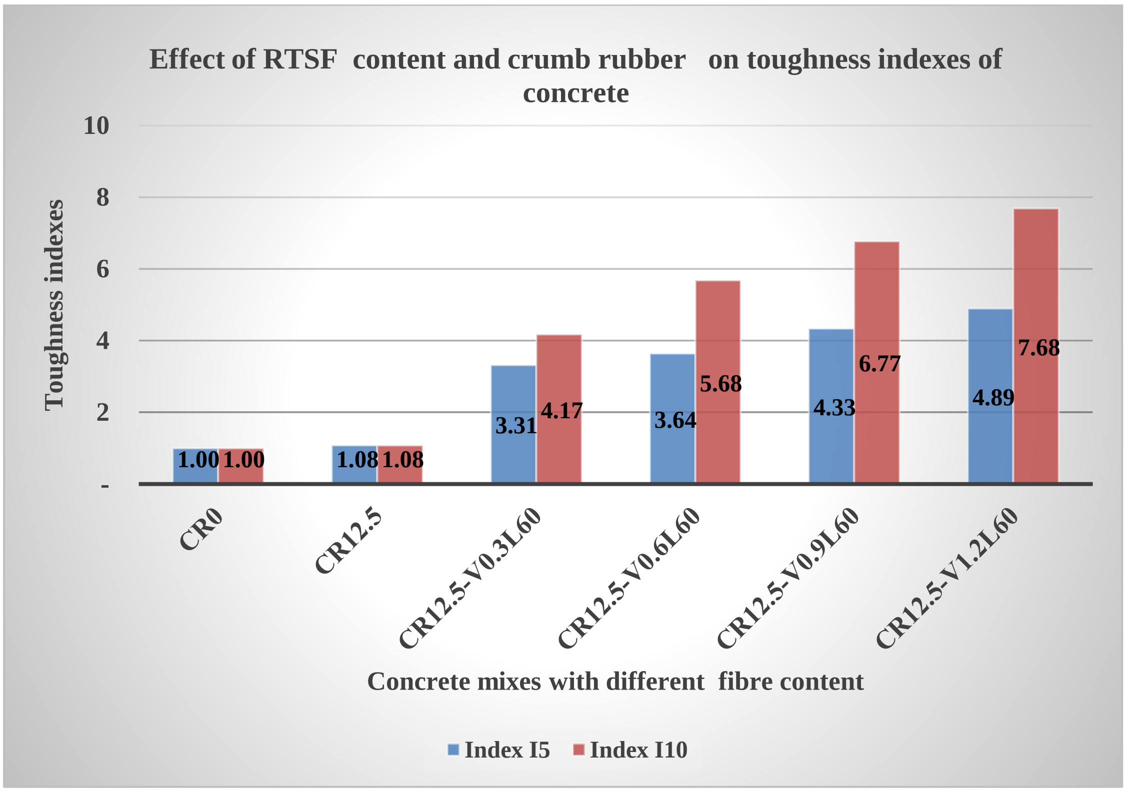


Figure 4. 16.Comparison on effect of RTSF content and crumb rubber on toughness Indexes of concrete

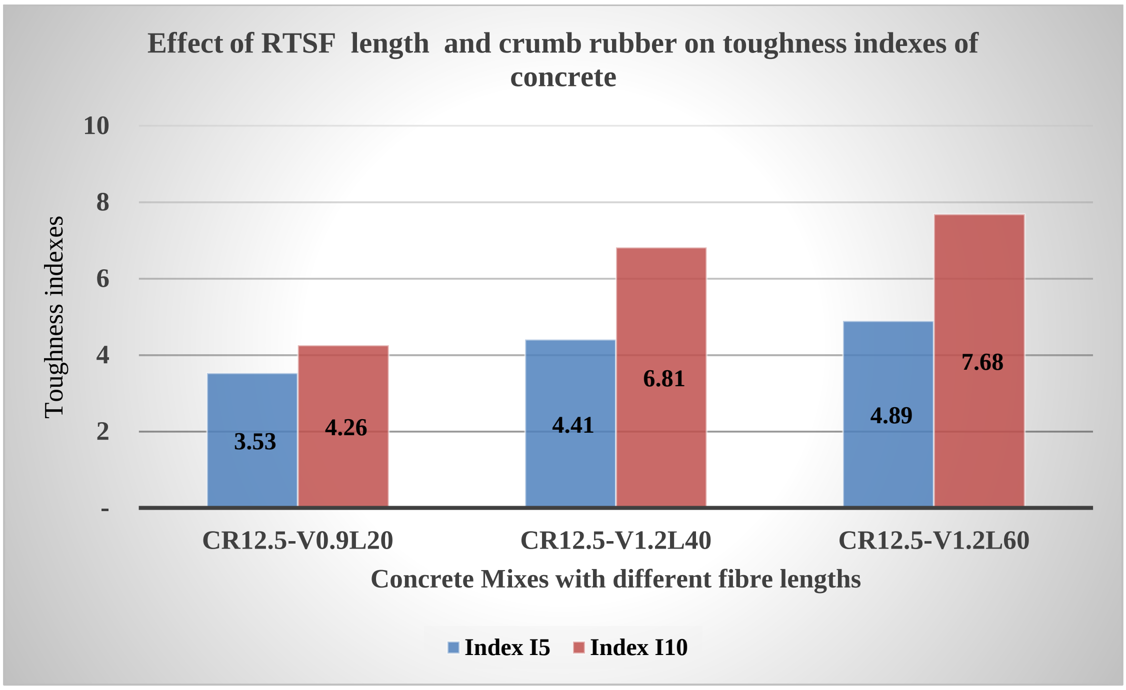


Figure 4. 17. Comparison on effect of RTSF length and crumb rubber on toughness indexes of concrete

The flexural stiffness or bending stifness (K) was also determined from Load-deflection curves of the concrete beams. K was detrmined as the gradient of the slope of linear part of load deflection-curves.The reduced bending stiffness value is an indication of an increase in deformability which makes a material absorb more energy and exhibit ductile response when subjected to external forces. It is ovious that all Recycled tyre steel fibre reinforced rubber concrete (RTSFRC) exhibited higher ductility and toughness compared to normal concrete.The enhancement was due to increase in ultimate deflection offered by RTSFRC mixtures .Bending stiffness of plain conceret was 40.87KN/mm ,and the combination of 12.5% of crumb rubber replacement of conventional sand and Recycled tyre steel fibres reforcement up to 1.2% with aspect ratio of 52, the beinding stiffeness increased up to 67.27 KN/mm, that corresponds to an increment of 26.4% relative to plain concrete. The results in Table 4.1, showed that, the bending stiffness decreases with inclusion of crumb rubber in concrete ,and slightly increase with increase of Recycled tyre steel fibre.Since the bending stiffness is in function of load and deflection parameters and being a gradient of the curve of load-deflection and reduced load and increased deflection resulted in a decreased bending stiffness which is the case for Rubber concrete.While inclusion of RTSF resulted in increased load carrying capacity and increased peak deflection hence a slight increase in bending stifness. Concrete with higher value of toughness, ductility and higher bending stiffness is preferably needed in the design of earthquake resisting structure, pavements and other structures exposed to blast loadings.

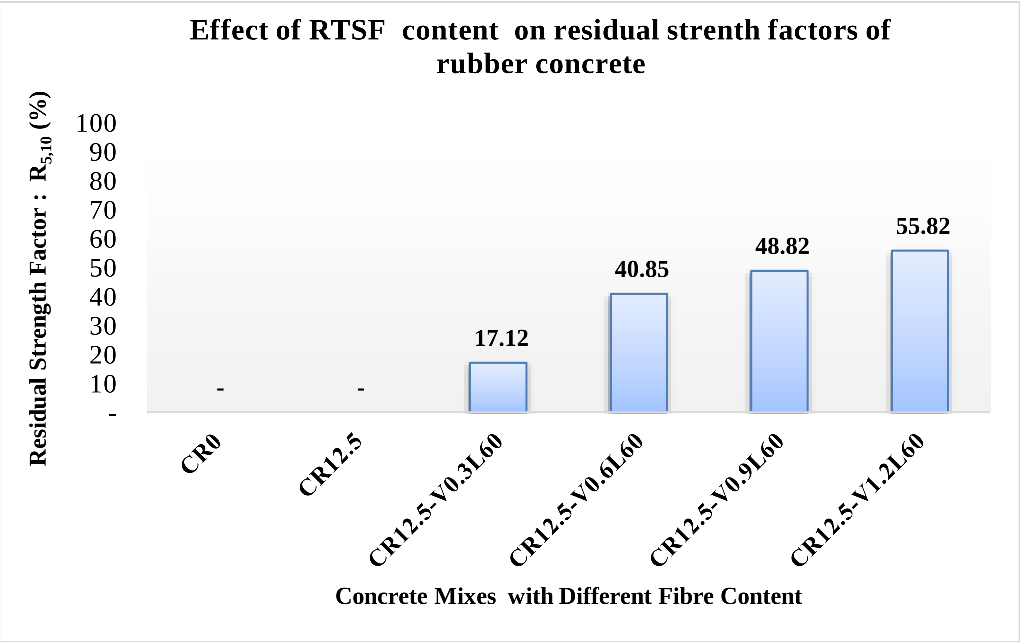


Figure 4. 18 .Comparison on effect of RTSF content and crumb rubber on Residual strength factors of concrete

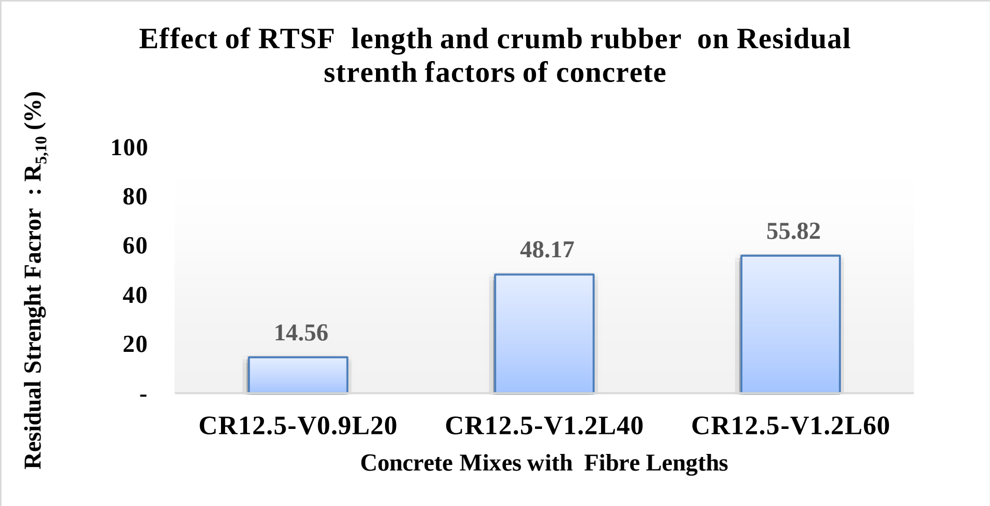


Figure 4. 19. Comparison on effect of RTSF length and crumb rubber on Residual strength factors of concrete

4.2.5. Impact resistance

In assessment on the impact energy performance of the recycled tyre steel fibre reinforced rubber concretes against the plain and rubber concrete; Number of blows required to cause first visible crack and ultimate failure of the sample specimen were recorded. Impact energy stored in each sample under drop weight test were calculated using Equation .3-4. This test was performed in accordance with ACI committee 544.It is the simplest and the cheapest method for impact resistance test. The results of number of blows required to bring the sample specimen at first crack and at Ultimate failure and their corresponding impact energies under drop -weight impact test is summarized in Table.4.2.

During impact test, plain concrete exhibited brittle failure as can be seen in Table 4.2, after appearance of the first crack, only 3 blows were required to bring the control mixture samples to a complete failure, while for the concrete samples made with 12.5%

of rubber volume replacement and 1.2% Recycled tyre steel fibre reinforcement, a mean of 98 blows were required to bring the sample specimen to a total failure which is an indication of an increased impact post-crack resistance of Recycled tyre steel fibre reinforced rubber concrete. For 1.2% recycled tyre steel fibre with 60mm length in Rubber concrete, ultimate impact energy increased from 58 to 391.18% compared to rubber concrete without fibre. This indicates that RTSFRC stored much more impact energy than that of plain concrete and rubber concrete alone after peak impact load. The results of this test conform with the reported that, Impact energy can increase 5 to 10 times that of plain concrete depending on fibre volume and its aspect ratio (Fousil Fouad Wafa, 1990). The increased post-crack impact behaviour of RTSFRC composite materials is attributed to be caused by the recycled tyre steel fibre which act as arrestors bridging the gapes of cracks and limiting initiation and further propagation of created cracks. It can be concluded from Figure 4.20 and Figure 4.21 that, the number of blows required to bring a concrete sample at first visible crack and ultimate failure increases with increase in RTSF content and further increases with increase in aspect ratio respectively. Similarly, as it is represented on Figure 4.22 and Figure 4.23, the impact energy resisted by a concrete sample up to first visible crack and to a complete failure increases with increase in recycled tyre steel fibre volume and further increases with increase in aspect ratio.

Table 4. 2.Results on Impact resistance of the mix group II and III

Mix designation	Number of blows at First visible crack	Number of blows at Ultimate failure	Impact Energy at first visible crack (KN-mm)	Impact energy at ultimate failure (KN-mm)	Relative % gain in Impact Energy at first crack (%)	Relative % gain in Impact Energy at Ultimate failure (%)
CR0	13.25	17.00	274.88	352.68	-	-
CR12.5	17.00	27.00	352.68	560.14	28.30	58.82
CR12.5-V0.3L60	19.25	35.25	399.36	731.30	45.28	107.35
CR12.5-V0.6L60	26.00	55.50	539.40	1,151.40	96.23	226.47
CR12.5-V0.9L60	27.00	78.25	560.14	1,623.37	103.77	360.29
CR12.5-V1.2L60	44.75	143.00	928.38	2,966.68	237.74	741.18
CR12.5-V1.2L40	37.00	104.00	767.60	2,157.58	179.25	511.76
CR12.5-V1.2L20	22.25	83.50	461.60	1,732.29	67.92	391.18

To evaluate the contribution of aspect ratio of fibre on impact energy, the steel cords were cut into 3 different sizes,20mm,40mm, and 60 mm. These fibres were mixed in concrete at constant value of fibre volume which was 1.2% and results showed that, for the mixture CR12.5-V1.2L20, CR12.5L40 and CR12.5-V1.2L60, the impact energy increased by 67.92 %, 179.25 %, and 237.74 %; and391.18 %,511.76 and 741.18 at First crack and ultimate failure respectively. This indicates that the fibre with

60mm length performed better than the rests, where the maximum impact energy was at the mixture CR12.5-V1. 2L60.The Results showed that, Impact energy increases with increase in fibre volume and of aspect ratio. Fig 9 and Fig 10 show the comparison of the results of impact energy and number of blows respectively at different fibre aspect ratio.

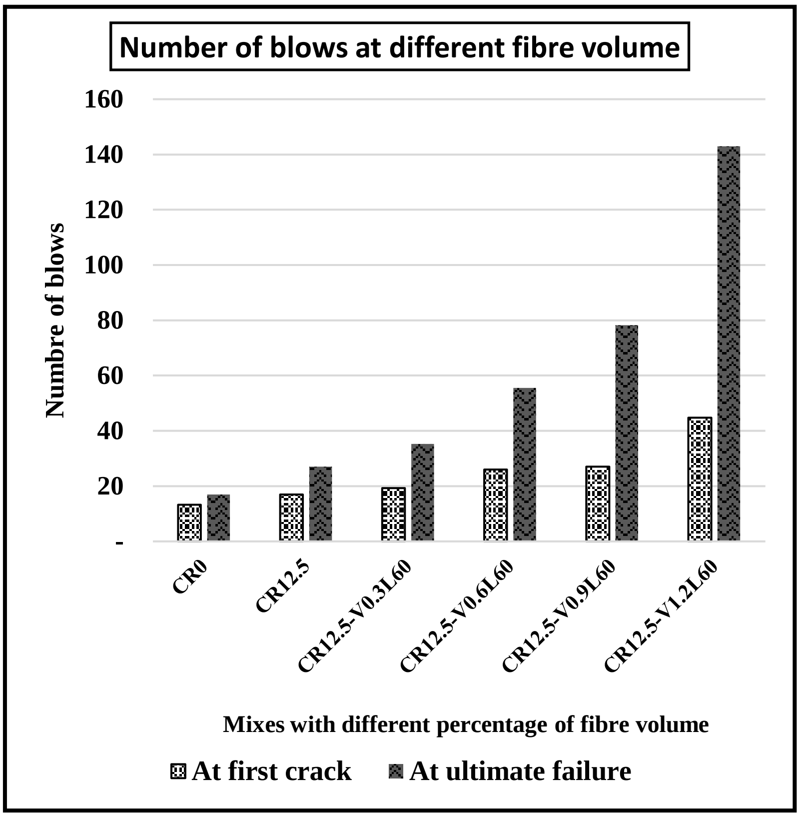


Figure 4. 20.Comparison on effect of RTSF content and crumb rubber on number of blows concrete

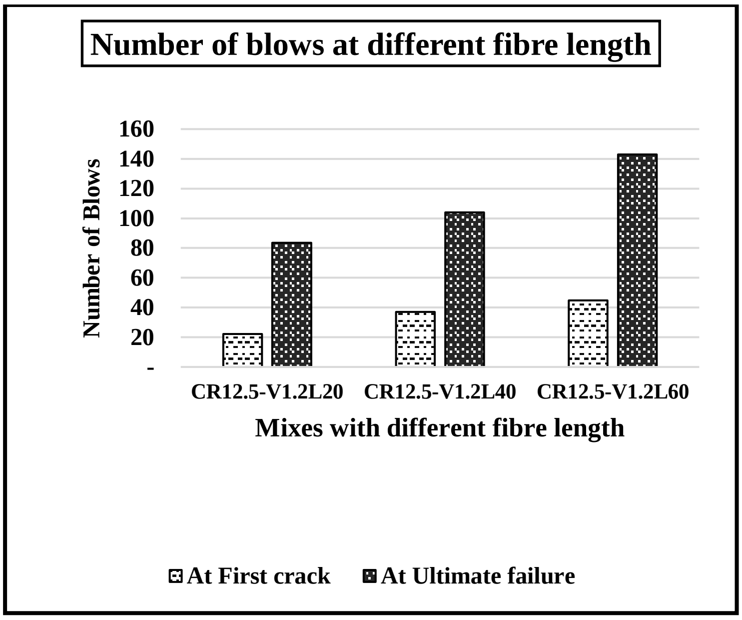


Figure 4. 21.Comparison on effect of RTSF length and crumb rubber on number of blows concrete

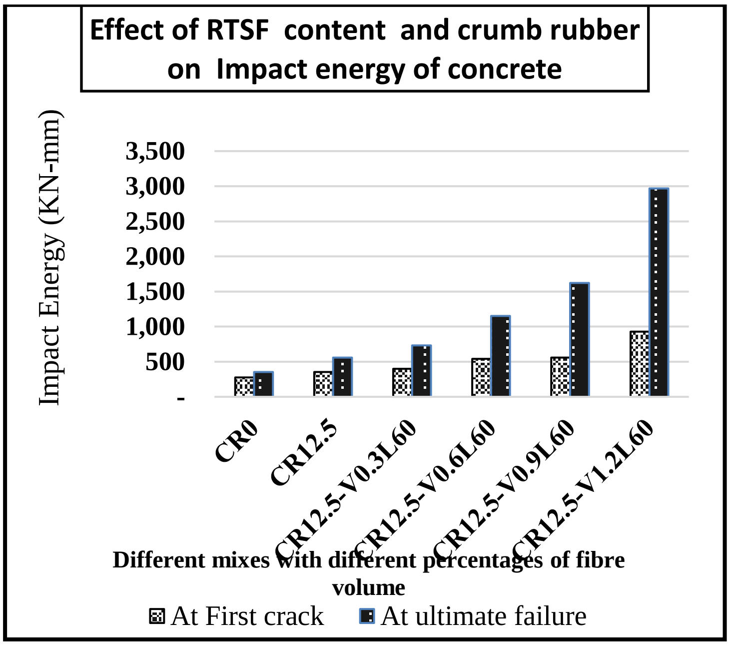


Figure 4. 22.Comparison on effect of RTSF content and crumb rubber on toughness of concrete

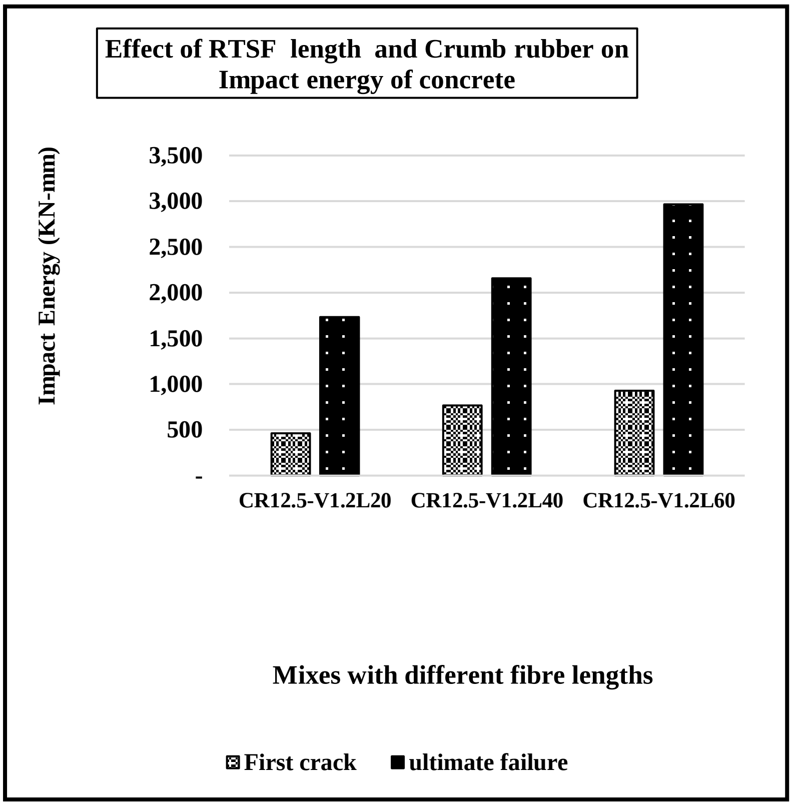


Figure 4. 23.Comparison on effect of RTSF length and crumb rubber on toughness of concrete

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1.Conclusion

This research was limited to experimentally Investigating effect of recycled tyre steel fibres as reinforcement on mechanical properties, flexural toughness and impact energy resistance of rubber concrete. Based on results of this study, the following conclusions have been made:

Workability of concrete increase with increase in crumb rubber replacement of fine aggregates. The additional of RTSF in rubber concrete reduces workability because, the composite concrete tends to be stiff and become less practicable. Water reducers (superplasticisers) as additives are required in RTSFRC to improve the workability. It was noticed that, when the RTSF volume increase, workability decreases, and it further decreases with increase in its aspect ratio

The compressive and split tensile strength of concrete reduce with increase in crumb rubber aggregate in concrete. This reduction is reported to be caused by weak bond between rubber particles and cement paste, as well as low modulus of elasticity of rubber compared to conventional aggregates. In this research ,12.5% crumb rubber volume was taken as optimum rubber volume where the reduction in compressive strength was nearly not more than 20%. Incorporating of different percentages of RTSF in CR12.5 mix resulted in a little improved compressive strength where at 1.2% addition of recycled tyre steel fibre with 40mm length, the compressive strength reduced by 10.07%, which is almost 9% increment from the rubber concrete compressive strength. Rubber concrete with 1.2% volume of RTSF and 40mm length performed better than other RTSFRC mixtures in terms of compressive strength, while the RTSFRC mixture with fibre length of 60mm performed better than that of 40mm and 20mm.

Increase in crumb rubber substitutions in concrete reduces flexural load carrying capacity (peak load), hence reduced flexural strength. The ductility of concrete increase with increase in crumb rubber. Combining RTSF with crumb rubber resulted in a significantly increased ductility and toughness of concrete. The RTSFRC mixes evidenced an enhanced post-crack strength behaviour allowing further deflections after peak load is reached. Index I_{10} and residual strength $R_{5,10,}$ of a concrete mixture with 1.2% of RTSF were 7.68 and 55.82 while for the plain concrete were 1 and 0 respectively. Meaning that, the composite material retained furthermore flexural loads after first crack. The maximum toughness was observed for a mixture CR12.5-V1.2L60 where, flexural toughness increased by 258.75% compared to plain concrete. This indicates that, toughness increases with increase in RTSF volume and further increases with increase in its aspect ratio. However, limitation must be but put on percentage volume and aspect ratio of RTSF since beyond 1.2% volume, the fresh composite concrete was almost unworkable and with RTSF length longer than 60mm, the fibres tend to make balling in concrete matrix.

Brittleness of concrete poses serious impact in a situation where impact loading occurs. The plain concrete load carrying capacity drops all sudden when peak load is reached. This is an indicator of a poor post-crack strength material. In drop weight test method conducted on impact resistance of RTSFRC, the results showed that, substituting crumb rubber in concrete resulted in an enhanced first-crack impact energy. Combining RTSF and crumb rubber in concrete showed substantially improved both first crack and post-crack energy. At addition of 1.2% fibre fractions and 60mm length, the first crack and ultimate impact energy increased by 237.74% and 741.18% compared to plain concrete respectively. The Recycled tyre steel fibre reinforced rubber concrete exhibited a higher ductility and toughness under impact loading. Based on the results found, both first -crack impact energy and ultimate impact energy increase with increase in RTSF content and further increase with increase in aspect ratio.

It is concluded that the behaviour of concrete reinforced with RTSF can be comparable to that of concrete reinforced with industrially produced steel fibres. The fibres could therefore be used in different range of applications, such as foundations, impact barriers, industrial floor slabs for crack control. The results of this study showed a promising application of recycled tyre steel fibre and crumb rubber in concrete, which is technically sound and environmentally safe.

5.2.Recommendation

5.2.1. Recommendation for the current study

1. The location of first crack point under flexural bending test has been a subjective matter, objective procedure has to be developed so that, the results of this tests do not vary from whom the test has been conducted.
2. High variation on the number of blows of one specimen to the other of the same mixture on repeated drop weight test was observed in this test. This makes it

difficult to assess the performance and leads to highly variable results, therefore an instrumented impact test technique should be developed to evaluate impact resistance.

5.2.2. Recommendation for further study

1. Studies must be made for design of concrete using RTSF to replace minimum reinforcement required for ground slabs or a pavement to resist shrinkage and temperature cracks.
2. Investigations on the structural performance of Recycled tyre steel fibre in Ultra-high-performance concrete have also to be made since steel fibre structural contribution is affected by concrete strength and pull-out strength between fibre and concrete matrix.
3. Further studies must be done to have a thorough understanding of structural behaviour of RTSFRC and specific practical application areas. And, economic evaluation of the adoption of available Recycled tyre steel fibres and currently extraction technology should be investigated

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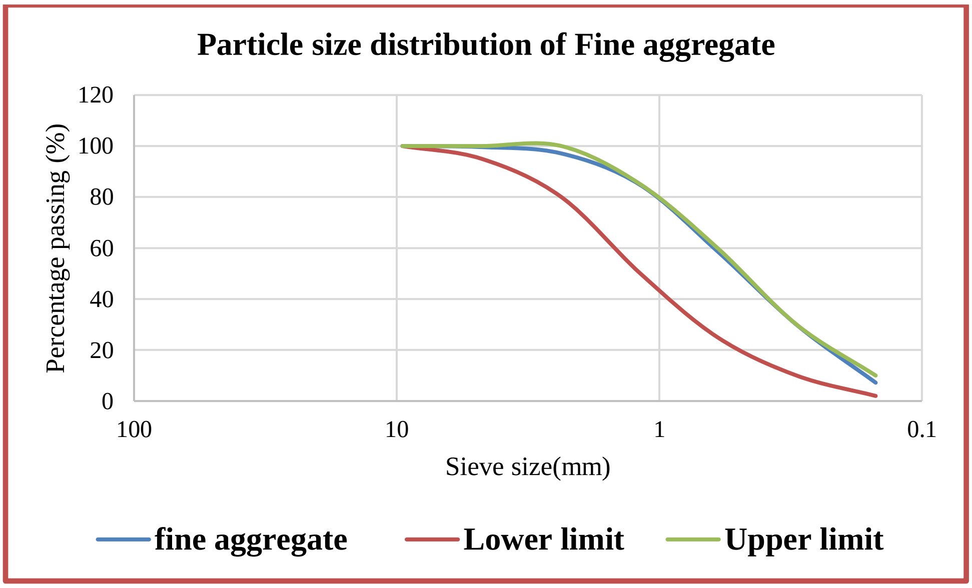
APPENDICES

APPENDIX 1.SIEVE ANALYSIS RESULTS

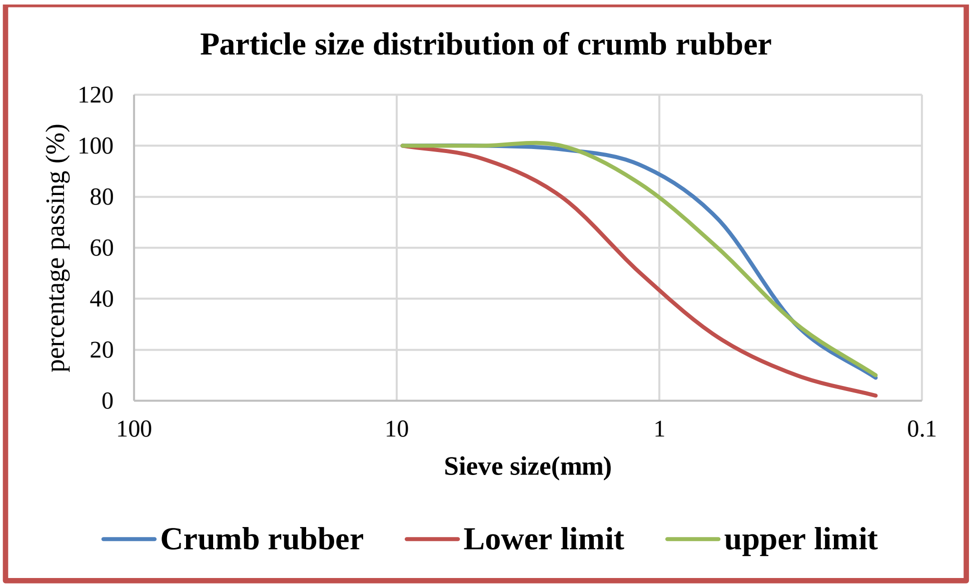
A.1-1: SIEVE ANALYSIS RESULTS OF FINE AGGREGATES

Sieve size (mm)	**Weight retained (gr)**	**Percentage retained (%)**	**Cumulative percentage retained (%)**	**Percentage passing (%)**	**lower limit (%)**	**Upper limit (%)**
9.5	0	-	0	100.00	100.00	
4.75	4	0.40	0.40	99.60	95.00	100.00
2.36	250	2.50	2.90	97.10	80.00	100.00
1.18	124	12.40	15.30	84.70	50.00	85.00
0.6	260	26.00	41.30	58.70	25.00	60.00
0.3	288	28.80	70.10	29.90	10.00	30.00
0.15	227	22.70	92.80	7.20	2.00	10.00
pan	72	7.20	100	-		
FM:2.23						



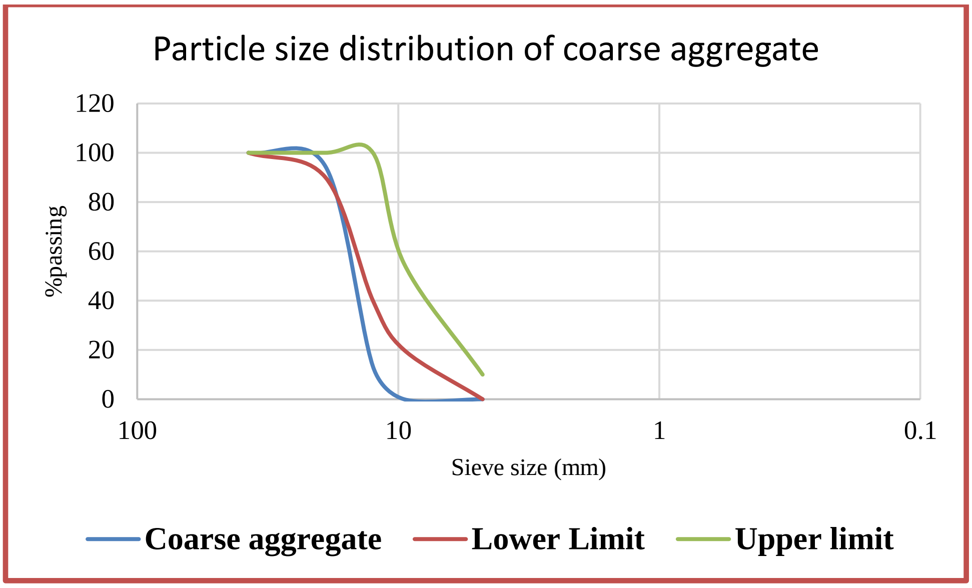
A.1-2: SIEVE ANALYSIS RESULTS OF CRUMB RUBBER

Sieve size (mm)	Weight retained (gr)	Percentage retained (%)	Cumulative percentage retained (%)	percentage passing (%)	lower limit (%)	Upper limit (%)
9.5	0	0	0	100	100.00	
4.75	0	0	0	100	95.00	100.00
2.36	7	1.4	1.4	98.6	80.00	100.00
1.18	31	6.2	7.6	92.4	50.00	85.00
0.6	105	21	28.6	71.4	25.00	60.00
0.3	209	41.8	70.4	29.6	10.00	30.00
0.15	103	20.6	91	9	2.00	10.00
pan	41	8.2	100	0		
FM:1.99						



A.1-3: SIEVE ANALYSIS RESULTS OF COARSE AGGREGATES

Sieve size(mm)	Weight retained (gr)	Percentage retained (%)	Cumulative percentage retained (%)	Percentage Passing (%)	lower limit (%)	Upper limit (%)
37.50	0	0	0	100	100	
19.00	0	0	0	100	90	100
12.50	111	5.55	5.55	94.45	40	100
9.50	1623	81.15	86.70	13.3	20	55
4.75	266	13.3	100	0.0	0	10
Pan	0	0	100	0	0	5
FM:6.92						



APPENDIX 2.MIX DESIGN DATA SHEET

Mix design					
Stage		**References**	**Calculated values**		**Condition**
1	1.1	Characteristic strength	Specified	Compressive strength 30N/mm2 at 28 days 5% defective	
	1.2	Standard deviation	Fig.3	6N/mm2	
	1.3	Margin	C1	(k=1.64), 1.64*8=9.9N/mm2	
	1.4	Target mean strength	C2	30+9.9=39.9N/mm2	
	1.5	Cement type	Specified	OPC	
	1.6	Aggregate type:	coarse	Crushed stone	
			Fine	uncrushed	
	1.7	Free-water /cement ratio	table2, Fig4	0.57	use lower value
		maximum free water/cement ratio		0.5	
2	2.1	Slump	specified	slump between 30-60mm	
	2.2	Maximum aggregate size	Specified	20mm	
	2.3	Free water content	table -3	195kg/m3	
3	3.1	Cement content	C3	195÷0.5=390kg/m3	
	3.2	maximum Cement content	specified	………...kg/m3	Use 3.1 if ≤3.2 and 3.3 if ›3.1
	3.3	Minimum cement content		…………kg/m3	

	3.4	Modified free water/cement ratio		……………..	
4	4.1	Relative density of aggregate (SSD)		2.48	**Known** /assumed
	4.2	Concrete density	fig 5	2360kg/m3	
	4.3	Total aggregate content	C4	2360-390-195=1775kg/m3	
5	5.1	grading of Fine aggregate	%passing 600µ, with max. C. A=20mm		
	5.2	proportions of fine aggregate	Fig 6	41%	
	5.3	Fine aggregate content		1775*0.41=727.5 kg/m3	
	5.4	Coarse aggregate		1775-727.5=1047.25kg/m3	

APPENDIX 3.SPECIFICATION OF VIRGIN TYRE STEEL CORD

A- 3-1: Typical steel cord constructions for truck tyres

Construction	Lay mm	Diameter mm	Breaking force min. N	Linear density (g/m)
3+9+15x0,175+0,15 NT	5/10/16/3,5/SSZS	1,34	1670	5,42
3+9+15x0,22+0,15 NT	6,3/12,5/18/3,5/SSZS	1,62	2600	8,50
3+9x0,22+0,15 NT	6,3/12,5/3,5/SSZ	1,170	1290	3,850
0,22+18x0,20 cc NT	12,5/Z	1,02	1565	4,84
0,22+18x0,20 HT	12,5/Z	1,02	1840	4,84
0,25+18x0,225 NT	16/S	1,18	2050	6,36
3x7x0,22 HE	4,5/8/SS	1,52	1720	6,95
4x4x0,22 HE	3,5/5/SS	1,32	1150	5,40
5x0,38 HI	14/S	1,34	1185	4,63

A- 3-2 Typical steel cord constructions for Radial off the road (OTR) tyres

Construction	Lay mm	Diameter mm	Breaking force min. N	Linear density (g/m)
3+9+15x0,22+0,15 NT	6,3/12,5/18/3,5/SSZS	1,620	2750	8,500
7x7x0,22+0,15 NT	12,5/20/5/SZS	2,24	4650	15,20
7x7x0,25+0,15 HT	12,5/20/5/SZS	2,52	6350	19,80
7x(3+9+15x0,245)+0,245 HT	6,3/12,5/18/55/5/ZZZSZ	4,84	24200	73,90

A- 3-3 Typical steel cord constructions for passenger car (PCR)tyres

Construction	Lay mm	Diameter mm	Breaking force min. N	Linear density (g/m)	
2x0.30 NT	14/S	0,60	365	1,12	
2x0.30 HT	14/S	0,60	445	1,12	
2+1x0.28 HT	oo/16/S	0,70	740	1,47	
2+1x0.30 HT	oo/16/S	0,75	615	1,68	
2+2x0.30 NT	oo/16/S	0,78	715	2,23	
2+2x0.30 HT	oo/16/16/-S	0,78	825	2,23	
3x0.30 OC NT	16/S	0,64	510	1,67	
3x0.30 OC HT	16/S	0,64	620	1,67	
3x0.30 HT Betru	16/S	0,65	610	1,68	
5x0.22 ST Betru	9,5/S	0,60	580	1,51	

A- 3-4Typical steel cord constructions for Sport Utility Vehicle (SUV) and Light Truck (LT) tyres

Construction	Lay mm	Diameter mm	Breaking force min. N	Linear density (g/m)
2+7x0.22	6,3/12,5/SS	0,83	1000	2,74
2+2x0.30 HT	oo/16/16/-S	0,78	890	2,23
5x0.30 HT Betru	16/S	0,81	970	2,80
0.315+6x0.30 HT Betru	16/S	0,92	1480	3,99
0.365+6x0.35 HT Betru	18/S	1,08	1865	5,42
3x0.15+6x0.27 NT	9/10/SZ	0,85	1025	3,17

(The Goodyear Tire and Rubber product Company, 2015)

APPENDIX 4.COMPRESSIVE STRENGTH TEST RESULTS

A-4.1: 7Th day Compressive strength results

	cube No	Dimension (mm)	Weight(g)	volume (cm3)	unit weight (g/cm3)	Failure laod (KN)	Comp. strength (Mpa)
CRO	C1	150X150X150	8,267.50	3,375.00	2.45	557.04	24.76
	C2	150X150X151	8,164.00	3,375.00	2.42	569.6	25.32
	C3	150X150X152	8,025.60	3,375.00	2.38	579.5	25.76
	MEAN	150X150X153	**Mix design**	3,375.00	2.42	568.71	**25.28**
CR5	C1	150X150X150	8,173.20	3,375.00	2.42	543.05	24.14
	C2	150X150X151	8,200.70	3,375.00	2.43	552.8	24.57
	C3	150X150X152	7,989.63	3,375.00	2.37	529.09	23.52
	MEAN	150X150X153	8,121.18	3,375.00	2.41	541.65	**24.07**
CR10	C1	150X150X154	7,989.30	3,375.00	2.37	502.3	22.32
	C2	150X150X155	8,069.00	3,375.00	2.39	497.25	22.1
	C3	150X150X156	8,156.20	3,375.00	2.42	478.21	21.25
	MEAN	150X150X157	8,071.50	3,375.00	2.39	492.59	**21.89**
CR12.5	C1	150X150X158	7,989.23	3,375.00	2.37	457.89	20.35
	C2	150X150X159	8,091.30	3,375.00	2.4	476.5	21.18
	C3	150X150X160	7,974.80	3,375.00	2.36	433.3	19.26
	MEAN	150X150X161	8,018.44	3,375.00	2.38	455.9	**20.26**
CR15	C1	150X150X162	7,968.15	3,375.00	2.36	402.6	17.89
	C2	150X150X163	7,992.30	3,375.00	2.37	443.72	19.72
	C3	150X150X164	7,974.00	3,375.00	2.36	422.3	18.77
	MEAN	150X150X165	7,978.15	3,375.00	2.36	422.87	**18.79**
CR20	C1	150X150X166	7,602.05	3,375.00	2.25	334.1	14.85
	C2	150X150X167	7,554.33	3,375.00	2.24	353.06	15.69
	C3	150X150X168	7,462.00	3,375.00	2.21	318.3	14.15
	MEAN	150X150X169	7,539.46	3,375.00	2.23	335.15	**14.9**
CR12.5-V0.3L60	C1	150X150X170	7,910.70	3,375.00	2.34	449.2	19.96
	C2	150X150X171	8,198.30	3,375.00	2.43	427.07	18.98

	C3	150X150X172	8,209.89	3,375.00	2.43	469	20.84
	MEAN	150X150X173	8,106.30	3,375.00	2.4	448.42	**19.93**
CR12.5-V0.6L6	C1	150X150X174	7,881.00	3,375.00	2.34	472.05	20.98
	C2	150X150X175	8,020.60	3,375.00	2.38	477.2	21.21
	C3	150X150X176	8,461.60	3,375.00	2.51	469.41	20.86
	MEAN	150X150X177	8,121.07	3,375.00	2.41	472.89	**21.02**
CR12.5-V0.9L60	C1	150X150X178	8,223.11	3,375.00	2.44	500.3	22.24
	C2	150X150X179	8,173.02	3,375.00	2.42	486.33	21.61
	C3	150X150X180	8,293.60	3,375.00	2.46	491.36	21.84
CR12.5-V1.2L60	MEAN	150X150X181	8,229.91	3,375.00	2.44	492.66	**21.9**
	C1	150X150X182	8,094.10	3,375.00	2.4	517.9	23.02
	C2	150X150X183	8,119.10	3,375.00	2.41	518.2	23.03
	C3	150X150X184	8,068.90	3,375.00	2.39	521.1	23.16
	MEAN	150X150X185	8,094.03	3,375.00	2.4	519.07	**23.07**
CR12.5-V1.2L40	C1	150X150X182	8,054.30	3,375.00	2.39	521.36	23.17
	C2	150X150X183	8,140.10	3,375.00	2.41	530.7	23.59
	C3	150X150X184	8,165.90	3,375.00	2.42	514.3	22.86
	MEAN	150X150X185	8,120.10	3,375.00	2.41	522.12	**23.21**
CR12.5-V1.2L20	C1	150X150X182	8,254.41	3,375.00	2.45	488.29	21.7
	C2	150X150X183	7,889.78	3,375.00	2.34	479	21.29
	C3	150X150X184	8,078.19	3,375.00	2.39	466.7	20.74
	MEAN	150X150X185	8,074.13	3,375.00	2.39	478	**21.24**

A- 4.2: 28[Th] day Compressive strength results

Mix design	cube No	Dimension	Weight(g)	volume (cm3)	unit weight (g/cm3)	Failure laod (KN)	Comp. strength (Mpa)
CRO	C1	150X150X150	8,467.50	3,375.00	2.51	887.90	39.46
	C2	150X150X151	8,361.00	3,375.00	2.48	848.50	37.71
	C3	150X150X152	8,165.10	3,375.00	2.42	909.90	40.44
	MEAN	150X150X153	8,219.40	3,375.00	2.44	882.10	**39.20**
CR5	C1	150X150X150	8,266.20	3,375.00	2.45	837.30	37.21
	C2	150X150X151	8,161.20	3,375.00	2.42	843.50	37.49
	C3	150X150X152	8,145.70	3,375.00	2.41	839.10	37.29
	MEAN	150X150X153	8,191.03	3,375.00	2.43	839.97	**37.33**
CR10	C1	150X150X154	7,999.00	3,375.00	2.37	742.60	33.00
	C2	150X150X155	8,030.20	3,375.00	2.38	753.70	33.50
	C3	150X150X156	7,954.00	3,375.00	2.36	738.50	32.82
	MEAN	150X150X157	7,994.40	3,375.00	2.37	744.93	**33.11**
CR12.5	C1	150X150X158	8,040.50	3,375.00	2.38	702.20	31.21
	C2	150X150X159	7,792.30	3,375.00	2.31	675.03	30.00
	C3	150X150X160	7,854.00	3,375.00	2.33	699.74	31.10
	MEAN	150X150X161	7,895.60	3,375.00	2.34	692.32	**30.77**
CR15	C1	150X150X162	7,598.50	3,375.00	2.25	591.28	26.28
	C2	150X150X163	7,792.30	3,375.00	2.31	599.80	26.66
	C3	150X150X164	7,854.00	3,375.00	2.33	605.00	26.89
	MEAN	150X150X165	7,895.60	3,375.00	2.34	598.69	**26.61**
CR20	C1	150X150X166	7,702.00	3,375.00	2.28	505.80	22.48
	C2	150X150X167	7,854.00	3,375.00	2.33	511.00	22.71
	C3	150X150X168	7,562.00	3,375.00	2.24	499.90	22.22
	MEAN	150X150X169	7,706.00	3,375.00	2.28	505.57	**22.47**
CR12.5-V0.3L60	C1	150X150X170	8,110.30	3,375.00	2.40	683.60	30.38
	C2	150X150X171	7,998.30	3,375.00	2.37	668.19	29.70
	C3	150X150X172	8,287.30	3,375.00	2.46	699.50	31.09
	MEAN	150X150X173	8,131.97	3,375.00	2.41	683.76	**30.39**
CR12.5-V0.6L6	C1	150X150X174	8,381.00	3,375.00	2.48	737.90	32.80
	C2	150X150X175	7,920.60	3,375.00	2.35	729.30	32.41

	C3	150X150X176	8,073.60	3,375.00	2.39	719.00	31.96
	MEAN	150X150X177	8,125.07	3,375.00	2.41	728.73	**32.39**
CR12.5-V0.9L60	C1	150X150X178	8,089.00	3,375.00	2.40	768.60	34.16
	C2	150X150X179	8,360.20	3,375.00	2.48	748.02	33.25
	C3	150X150X180	8,209.00	3,375.00	2.43	778.00	34.58
CR12.5-V1.2L60	MEAN	150X150X181	8,219.40	3,375.00	2.44	764.87	**33.99**
	C1	150X150X182	8,354.10	3,375.00	2.48	787.32	34.99
	C2	150X150X183	8,229.10	3,375.00	2.44	791.58	35.18
	C3	150X150X184	8,098.90	3,375.00	2.40	792.65	35.23
	MEAN	150X150X185	8,227.37	3,375.00	2.44	790.52	**35.13**
CR12.5-V1.2L40	C1	150X150X182	8,054.30	3,375.00	2.39	792.60	35.23
	C2	150X150X183	8,198.10	3,375.00	2.43	789.70	35.10
	C3	150X150X184	8,465.90	3,375.00	2.51	797.40	35.44
	MEAN	150X150X185	8,239.43	3,375.00	2.44	793.23	**35.25**
CR12.5-V1.2L20	C1	150X150X182	8,254.10	3,375.00	2.45	762.60	33.89
	C2	150X150X183	8,129.10	3,375.00	2.41	779.70	34.65
	C3	150X150X184	7,998.90	3,375.00	2.37	752.40	33.44
	MEAN	150X150X185	8,127.37	3,375.00	2.41	764.90	**34.00**

APPENDIX 5.SPLIT TENSILE STRENGTH TEST RESULTS

A- 5.1: 7Th day Split tensile strength results

Mix design	**Cylinder No**	**Dimension (Heightxdiametr)**	**Weight(g)**	**volume (cm3)**	**unit weight (g/cm3)**	**Failure laod (KN)**	**Split Tens. strength (Mpa)**
CRO	C1	200X100	3,715.25	1,570.00	2.37	68.50	2.18
	C2	200X100	3,813.50	1,570.00	2.43	70.41	2.24
	C3	200X100	3,822.03	1,570.00	2.43	69.08	2.20
	MEAN	200X100	3,783.59	1,570.00	2.41	69.33	**2.21**
CR5	C1	200X100	3,615.25	1,570.00	2.30	64.77	2.06
	C2	200X100	3,833.30	1,570.00	2.44	67.80	2.16
	C3	200X100	3,771.50	1,570.00	2.40	68.39	2.18
	MEAN	200X100	3,740.02	1,570.00	2.38	66.99	**2.13**
CR10	C1	200X100	3,872.80	1,570.00	2.47	61.36	1.95
	C2	200X100	3,683.00	1,570.00	2.35	60.90	1.94
	C3	200X100	3,656.20	1,570.00	2.33	64.30	2.05
	MEAN	200X100	3,737.33	1,570.00	2.38	62.19	**1.98**
CR12.5	C1	200X100	3,707.09	1,570.00	2.36	55.89	1.78
	C2	200X100	3,900.71	1,570.00	2.48	56.89	1.81
	C3	200X100	3,618.30	1,570.00	2.30	59.21	1.89
	MEAN	200X100	3,742.03	1,570.00	2.38	57.33	**1.83**
CR15	C1	200X100	3,712.20	1,570.00	2.36	53.60	1.71
	C2	200X100	3,861.32	1,570.00	2.46	52.99	1.69
	C3	200X100	3,545.02	1,570.00	2.26	55.60	1.77
	MEAN	200X100	3,706.18	1,570.00	2.36	54.06	**1.72**
CR20	C1	200X100	3,520.23	1,570.00	2.24	48.27	1.54
	C2	200X100	3,608.54	1,570.00	2.30	45.99	1.46
	C3	200X100	3,439.87	1,570.00	2.19	47.80	1.52
	MEAN	200X100	3,522.88	1,570.00	2.24	47.35	**1.51**
CR12.5-V0.3L60	C1	200X100	3,837.00	1,570.00	2.44	57.08	1.82
	C2	200X100	3,772.30	1,570.00	2.40	60.00	1.91
	C3	200X100	3,764.90	1,570.00	2.40	59.20	1.89
	MEAN	200X100	3,791.40	1,570.00	2.41	58.76	**1.87**

CR12.5-V0.6L6	C1	200X100	3,826.30	1,570.00	2.44	60.11	1.91
	C2	200X100	3,697.50	1,570.00	2.36	63.20	2.01
	C3	200X100	3,782.66	1,570.00	2.41	69.22	2.20
	MEAN	200X100	3,768.82	1,570.00	2.40	64.18	**2.04**
CR12.5-V0.9L60	C1	200X100	3,822.20	1,570.00	2.43	71.23	2.27
	C2	200X100	3,819.05	1,570.00	2.43	69.12	2.20
	C3	200X100	3,589.73	1,570.00	2.29	65.21	2.08
	MEAN	200X100	3,743.66	1,570.00	2.38	68.52	**2.18**
CR12.5-V1.2L60	C1	200X100	3,674.20	1,570.00	2.34	69.22	2.20
	C2	200X100	3,765.00	1,570.00	2.40	71.90	2.29
	C3	200X100	3,744.07	1,570.00	2.38	66.25	2.11
	MEAN	200X100	3,727.76	1,570.00	2.37	69.12	**2.20**
CR12.5-V1.2L40	C1	200X100	3,793.00	1,570.00	2.42	66.70	2.12
	C2	200X100	3,615.36	1,570.00	2.30	69.78	2.22
	C3	200X100	3,784.05	1,570.00	2.41	68.90	2.19
	MEAN	200X100	3,730.80	1,570.00	2.38	68.46	**2.18**
CR12.5-V1.2L20	C1	200X100	3,694.20	1,570.00	2.35	63.08	2.01
	C2	200X100	3,785.00	1,570.00	2.41	59.50	1.89
	C3	200X100	3,728.70	1,570.00	2.37	61.77	1.97
	MEAN	200X100	3,735.97	1,570.00	2.38	61.45	**1.96**

A- 5.2: 28Th day Split tensile strength results

Mix design	Cylinder No	Dimension (Heightxdiametr)	Weight(g)	volume (cm3)	unit weight (g/cm3)	Failure laod (KN)	Split Tens. strength (Mpa)
CRO	C1	200X100	3,815.50	1,570.00	2.43	97.72	5.47
	C2	200X100	3,837.00	1,570.00	2.44	101.83	5.39
	C3	200X100	3,831.50	1,570.00	2.44	93.05	5.64
	MEAN	200X100	3,828.00	1,570.00	2.44	97.53	**5.50**
CR5	C1	200X100	3,615.50	1,570.00	2.30	96.30	4.52
	C2	200X100	3,737.30	1,570.00	2.38	95.80	4.66
	C3	200X100	3,572.50	1,570.00	2.28	97.00	4.35
	MEAN	200X100	3,641.77	1,570.00	2.32	96.37	**4.51**
CR10	C1	200X100	3,599.80	1,570.00	2.29	84.01	4.16
	C2	200X100	3,707.50	1,570.00	2.36	87.30	4.41
	C3	200X100	3,645.10	1,570.00	2.32	89.78	4.30
	MEAN	200X100	3,650.80	1,570.00	2.33	87.03	**4.29**
CR12.5	C1	200X100	3,596.20	1,570.00	2.29	81.80	4.54
	C2	200X100	3,578.37	1,570.00	2.28	80.70	4.42
	C3	200X100	3,697.30	1,570.00	2.35	79.07	4.60
	MEAN	200X100	3,623.96	1,570.00	2.31	80.52	**4.52**
CR15	C1	200X100	3,704.00	1,570.00	2.36	72.90	4.76
	C2	200X100	3,528.00	1,570.00	2.25	74.15	4.65
	C3	200X100	3,614.50	1,570.00	2.30	76.05	4.69
	MEAN	200X100	3,615.50	1,570.00	2.30	74.37	**4.70**
CR20	C1	200X100	3,617.90	1,570.00	2.30	65.70	5.75
	C2	200X100	3,549.30	1,570.00	2.26	61.99	5.79
	C3	200X100	3,656.70	1,570.00	2.33	67.30	5.68
	MEAN	200X100	3,607.97	1,570.00	2.30	65.00	**5.74**
CR12.5-V0.3L60	C1	200X100	3,823.00	1,570.00	2.44	79.20	5.27
	C2	200X100	3,794.00	1,570.00	2.42	87.30	5.19
	C3	200X100	3,765.00	1,570.00	2.40	82.30	5.35
	MEAN	200X100	3,794.00	1,570.00	2.42	82.93	**5.27**
CR12.5-V0.6L6	C1	200X100	3,811.00	1,570.00	2.43	87.02	4.25
	C2	200X100	3,699.50	1,570.00	2.36	84.79	4.36

	C3	200X100	3,782.00	1,570.00	2.41	90.30	4.41
	MEAN	200X100	3,764.17	1,570.00	2.40	87.37	**4.34**
CR12.5-V0.9L60	C1	200X100	3,822.00	1,570.00	2.43	91.80	5.47
	C2	200X100	3,715.00	1,570.00	2.37	94.60	5.39
	C3	200X100	3,789.30	1,570.00	2.41	89.95	5.64
	MEAN	200X100	3,775.43	1,570.00	2.40	92.12	**5.50**
CR12.5-V1.2L60	C1	200X100	3,614.20	1,570.00	2.30	100.30	4.52
	C2	200X100	3,745.00	1,570.00	2.39	97.20	4.66
	C3	200X100	3,654.70	1,570.00	2.33	94.30	4.35
	MEAN	200X100	3,671.30	1,570.00	2.34	97.27	**4.51**
CR12.5-V1.2L40	C1	200X100	3,723.00	1,570.00	2.37	94.80	4.16
	C2	200X100	3,615.00	1,570.00	2.30	95.60	4.41
	C3	200X100	3,789.05	1,570.00	2.41	93.00	4.30
	MEAN	200X100	3,709.02	1,570.00	2.36	94.47	**4.29**
CR12.5-V1.2L20	C1	200X100	3,822.00	1,570.00	2.43	91.80	4.54
	C2	200X100	3,715.00	1,570.00	2.37	94.60	4.42
	C3	200X100	3,789.30	1,570.00	2.41	89.95	4.60
	MEAN	200X100	3,775.43	1,570.00	2.40	92.12	**4.52**

APPENDIX 6.FLEXURAL STRENGTH TEST RESULTS

A- 6.1: 28Th day Flexural strength results

Mix design	**Beam No**	**beam size (mm)**	**P (KN)**	**M (KN-mm)**	**I (cm4)**	**Y (mm)**	σ_f(Mpa)
CRO	B1	500x150x150	41.03	3,076.88	4,218.75	75.00	5.47
	B2	500x150x151	40.43	3,031.88	4,218.75	75.00	5.39
	B3	500x150x152	42.30	3,172.50	4,218.75	75.00	5.64
	MEAN		41.28	3,096.00	4,218.75	75.00	**5.50**
CR12.5	B1	500x150x154	33.90	2,542.50	4,218.75	75.00	4.52
	B2	500x150x155	34.95	2,621.25	4,218.75	75.00	4.66
	B3	500x150x156	32.63	2,446.88	4,218.75	75.00	4.35
	MEAN		33.80	2,535.00	4,218.75	75.00	**4.51**
CR12.5-V0.3L60	B1	500x150x158	31.20	2,340.00	4,218.75	75.00	4.16
	B2	500x150x159	33.08	2,480.63	4,218.75	75.00	4.41

	B3	500x150x160	32.25	2,418.75	4,218.75	75.00	4.30
	MEAN		32.21	2,415.60	4,218.75	75.00	**4.29**
CR12.5-V0.6L6	B1	500x150x162	34.05	2,553.75	4,218.75	75.00	4.54
	B2	500x150x163	33.15	2,486.25	4,218.75	75.00	4.42
	B3	500x150x164	34.50	2,587.50	4,218.75	75.00	4.60
	MEAN		33.92	2,544.00	4,218.75	75.00	**4.52**
CR12.5-V0.9L60	B1	500x150x166	35.70	2,677.50	4,218.75	75.00	4.76
	B2	500x150x167	34.88	2,615.63	4,218.75	75.00	4.65
	B3	500x150x168	35.18	2,638.13	4,218.75	75.00	4.69
	MEAN		35.28	2,646.00	4,218.75	75.00	**4.70**
CR12.5-V1.2L60	B1	500x150x170	43.13	3,234.38	4,218.75	75.00	5.75
	B2	500x150x171	43.43	3,256.88	4,218.75	75.00	5.79
	B3	500x150x172	42.60	3,195.00	4,218.75	75.00	5.68
	MEAN		43.04	3,228.00	4,218.75	75.00	**5.74**
CR12.5-V1.2L40	B1	500x150x174	39.53	2,964.38	4,218.75	75.00	5.27
	B2	500x150x175	38.93	2,919.38	4,218.75	75.00	5.19
	B3	500x150x176	40.13	3,009.38	4,218.75	75.00	5.35
	MEAN		39.50	2,962.50	4,218.75	75.00	**5.27**
CR12.5-V1.2L20	B1	500x150x178	31.88	2,390.63	4,218.75	75.00	4.25
	B2	500x150x179	32.70	2,452.50	4,218.75	75.00	4.36
	B3	500x150x180	33.08	2,480.63	4,218.75	75.00	4.41
	MEAN		32.57	2,442.75	4,218.75	75.00	**4.34**

APPENDIX 7. FLEXURAL TOUGHNESS TEST RESULTS

Mix	First crack deflection (mm)	First crack load(N)	Deflection up to 1/150 span (mm)	Ultimate flexural load(N)	Flexural stiffness (KN/mm)	Toughness (KNmm)	Relative gain in Toughness (%)
CR0	1.01	41280	1.01	41280	40.87	20.85	-
CR12.5	1.25	30800	1.3	33800	24.64	22.08	5.90
CR12.5-V0.3L60	0.91	28010	6.71	32208	30.78	46.76	124.27
CR12.5-V0.6L60	0.82	28900	8.45	33920	35.24	52.5	151.80
CR12.5-V0.9L60	0.68	30001	9.09	35280	44.12	61.51	195.01
CR12.5-V1.2L60	0.55	37000	11.14	43040	67.27	74.8	258.75
CR12.5-V0.9L60	0.68	30001	9.09	35280	44.12	61.51	195.01
CR12.5-V1.2L40	0.71	36600	8.54	39500	51.55	55.6	166.67
CR12.5-V1.2L20	0.87	31300	5.23	32570	44.12	37.5	79.86

APPENDIX 8.IMPACT RESISTANCE RESULTS

Mix designation	Disk No	sample size(d*t) (mm)	Number of blows for first visible crack	Standard deviation	Number of blows for Ultimate failure	Standard deviation
CR0	1	65*150	10.00		14.00	
	2	65*150	14.00		17.00	
	3	65*150	16.00		21.00	
	4	65*150	13.00		16.00	
	Mean	**65*150**	**13.25**	**2.19**	**17.00**	**2.66**
CR12.5	1	65*150	19.00		26.00	
	2	65*150	15.00		22.00	
	3	65*150	11.00		23.00	
	4	65*150	23.00		37.00	
	Mean	**65*150**	**17.00**	**4.47**	**27.00**	**5.95**

CR12.5-V0.3L60	1	65*150	21.00		37.00	
	2	65*150	14.00		30.00	
	3	65*150	19.00		34.00	
	4	65*150	23.00		40.00	
	Mean	**65*150**	**19.25**	**3.35**	**35.25**	**3.69**
CR12.5-V0.6L60	1	65*150	17.00		49.00	
	2	65*150	29.00		59.00	
	3	65*150	45.00		53.00	
	4	65*150	13.00		61.00	
	Mean	**65*150**	**26.00**	**12.44**	**55.50**	**4.76**
CR12.5-V0.9L60	1	65*150	29.00		87.00	
	2	65*150	22.00		79.00	
	3	65*150	24.00		70.00	
	4	65*150	33.00		77.00	
	Mean	65*150	**27.00**	**4.30**	**78.25**	**5.99**
CR12.5-V1.2L60	1	65*150	34.00		181.00	
	2	65*150	57.00		105.00	
	3	65*150	39.00		138.00	
	4	65*150	49.00		148.00	
	Mean	65*150	**44.75**	**8.90**	**143.00**	**33**
CR12.5-V1.2L40	1	65*150	22.00		82.00	
	2	65*150	18.00		81.00	
	3	65*150	31.00		102.00	
	4	65*150	77.00		151.00	
	Mean	65*150	**37.00**	**27.24**	**104.00**	**28.3**
CR12.5-V1.2L20	1	65*150	29.00		80.00	
	2	65*150	19.00		79.00	
	3	65*150	23.00		78.00	
	4	65*150	18.00		97.00	
	Mean	65*150	**22.25**	**4.32**	**83.50**	**7.82**

APPENDIX 9.PRESENTATION OF TEST PHOTOGRAPHS

Fig.A-9-1. Pyrolysis plant at Athi-river

Fig.A-9-2. Recycled Steel tyre cords

Fig.A-9-3. Arrangement of Recycled Steel tyre cords to be cut.

Fig.A-9-4. Ready cut Recycled Steel tyre fibres

Fig.A-9-5. Cutting of RTSF

Fig.A-9-6. Cut RTSF in different 3 lengths

Fig.A-9-7. Crumb rubber

Fig.A-9-8. Sieving of Crumb rubber

Fig.A-9-9. Coarse aggregate

Fig.A-9-10. Adding RTSF in a mix

Fig.A-9-11. Slump test of plain mix

Fig.A-9-12. Slump test of RTSFRC mix

Fig.A-9-13. Adding Crumb rubber in a mix

Fig.A-9-14. Adding the steel fibre in a mix

Fig.A-9-15. Distribution of RTSF in a mix

Fig.A-9-16. Concrete cubes and cylinders

Fig.A-9-17. Demolding of cubes and cylinders

Fig.A-9-18. Curing of cubes and cylinders

Fig.A-9-19. Weighing of the samples

Fig.A-9-20. Casting of cubes and cylinders

Fig.A-9-21. Split tensile Strength test

Fig.A-9-22. Compressive strength test

Fig.A-9-23. Coarse. Aggregate Impact test equipment

Fig.A-9-24. Casting of concrete beams

Fig.A-9-25. Drying of concrete beams to be tested

Fig.A-9-26. Placing Concrete beams in curing tank

Fig.A-9-27. Concrete beams in curing tank

Fig.A-9-28. Arrangement of beam sample for flexural strength test

Fig.A-9-29. Flexural test of the beam

Fig.A-9-30. Installation of LVDTs

Fig.A-9-31. Recording of Load-deflection data

Fig.A-9-32. Data logger for recording Load-deflection data

Fig.A-9-33. tested beams

Fig.A-9-34. Flexural failure mode of RTSFRC

Fig.A-9-35. Cylinders to be cut for impact test samples

Fig.A-9-36. Cutting of Cylinders for impact test samples

Fig.A-9-37. Cutting of Cylinders for impact test samples

Fig.A-9-38. Cutting of Cylinders for impact test samples

Fig.A-9-39. Impact test specimens

Fig.A-9-40. Smearing white paint on impact test specimens surface

Fig.A-9-41. Impact test equipment

Fig.A-9-42. Ultimate failure mode of impact teste specimens

Fig.A-9-43. Ultimate failure mode of impact test specimens

Fig.A-9-44. Ultimate failure mode of RTSFRC vs Plain mix

Fig.A-9-45. Impact tested samples

Fig.A-9-45. Impact testing