University of Southern Queensland Faculty of Health, Engineering & Science

The role of steel fibres on the compressive and tensile properties of concrete

A dissertation submitted by

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In fulfilment of

Course ENG4111 Research Project part 1 &

ENG4112 Research Project part 2

Towards the degree of

Bachelor of Engineering (Honours) (Civil)

Submitted: 15th October, 2020

ABSTRACT

Concrete being a widely used structural material due to its good compressive strength and versatility under harsh conditions; it does suffer from weak tensile strength. Concrete tends to develop cracks which weakens its structural performance and leads to a reduction of its durability and failure in some cases. One of the ways to sort out this problem is to incorporate reinforcement bars and fibers. This study is on steel fiber reinforced concrete and the role of those steel fibers in the strength of concrete and which dosage level is both appropriate and economical in concrete production. The study has followed an experimental approach guided by the outcome of the comprehensive literature review. Cylindrical specimens of size 100mm diameter and 200 mm high are utilized. Uniaxial comprehensive and splitting tensile strength were investigated through test of 72 concrete cylinders. The tests were conducted for plain concrete 3 cylinders which are tested at 7 days, 14 days and 28 days; the same is repeated for 0.5% steel fibers, 1% steel fibres and 2% steel fibres both for compressive and splitting tensile tests. Regressions are done in MS-Excel and linear models developed which can be used to predict compressive and tensile strength of concrete with different dosages of steel fibres. It is established that the steel fibres have an effect on concrete strength development whereby they contribute 36.5% at 2% steel fibres and 81.2% for splitting tensile strength enhancement.

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ENG4111/ENG4112 Research Project

Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusion set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged. I further certify that the work is original and has not been previously submitted for any award, except where otherwise acknowledged.

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Signature Date

Signature of candidate.

Signature Date

Signature of Principal Supervisor.

ACKNOWLEDGEMENTS

First, I thank the Almighty Father in Heaven for giving me robust health and for His grace. This project was undertaken under the guidance of Prof Allan Manalo of the University of Southern Queensland. I am grateful Professor Allan, for your supervision while undertaking the research for this dissertation.

I thank all the rest of academic staff in the Faculty of Health, Engineering and Sciences in the University of Southern Queensland for teaching me theory units prior to the research project. I sincerely thank Ronel my study partner and University of Southern Queensland generally for offering me a study opportunity. I also thank Jomo Kenyatta University of Agriculture and Technology for offering me the opportunity to conduct my experiments in this great institution.

I wish to thank my family especially my wife and children for their persistent but important concerns while studying.

Endeavour has been made to present facts as accurately as possible in the academic discourse leading to this dissertation; the author hereby takes full responsibility for any errors and for that matter USQ is absolved from any action arising from this work.

TABLE OF CONTENTS

Contents

CHAPTER ONE: INTRODUCTION

1.1 Project Background

The construction industry is very important to economies globally. It is responsible for developing structures in which other industries depend on. Some manufacturing industries like manufacturers of construction materials such as cement, providers of services and transport providers are directly and indirectly impacted. One of the materials widely used in the industry is concrete because of its high compressive strength, easy of manufacture and its resistance to aggressive environmental conditions. Its most serious weakness is in low tensile strength. Other materials used in civil engineering structures include steel, timber and composite materials. Concrete is usually reinforced with steel to take care of tensile forces. For the last fifty years fibres have been investigated in form of fibre reinforced concrete by various researchers among them steel fibers. Some countries have developed codes to assist in design using these materials while other countries have remained conservative only embracing normal reinforced concrete and prestressed concrete with conventional reinforcement. This research shall consider the steel fibers, role and contribution to concrete strength performance at different steel dosages.

Concrete being a widely used structural material due to its high compressive strength has one weakness in that its tensile strength is low. It has a tendency to develop cracks and affect structures constructed with concrete leading to reduced durability and failure in extreme cases when used where tensile stresses are high. To mitigate against the tensile weaknesses in concrete steel reinforcement or steel fibres are incorporated to take over the tensile forces. When steel is incorporated a material called reinforced concrete is obtained while a fibre reinforced concrete is obtained if fibers are incorporated. According to (Zollo 1997) studies in this area began more than 50 years ago and lasts to this day. Some codes such as AS3600-2018 (Standards Australia 2018) have dedicated a section to fibre reinforced concrete. Fibres can be of different types of materials and sizes. In the construction industry steel fibres are most commonly used, but there are other fibres such as glass fibres, polypropylene (PP) fibre, graphite fibres or kevlar fibres in use (Shah & Ribakov 2011). Since fibres are now with us there is need to come up with models of their behaviour when used in concrete manufacture.

Effectiveness and materials properties of fibre reinforced concrete are influenced by fibre material properties, bonding, dosage and concrete manufacture process. Shape and proportions are the other factors affecting the concrete strength. The most important parameters that are used to describe the geometric proportions of the fibres are their length and diameter ratio (Martinie et.al. 2010). Fibre anchorage is another important factor to consider. It is preferable to use fibres with hooks to overcome being pulled out challenge (Shah & Rabakov 2011).

Use of fibres in concrete enhances its useful beneficial effects; namely flexural and tensile strengths, resistance to dynamic effects, durability and cracks resistance (Mohammadi et al. 2008). Fibres act mainly to bridge cracks appearing in the internal structure of the concrete. Figure 1.1 below gives an illustration of the behaviour of concrete members with or without fibres.

Fibres are useful at micro and macro scales of crack prevention.

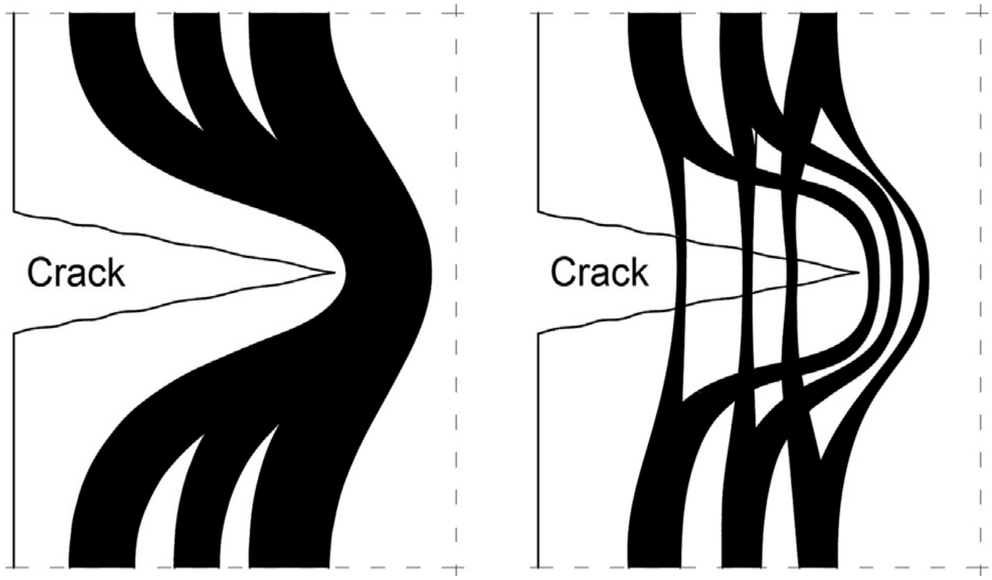

Figure 1.1: An illustration of members without and with fibres on a cracked section (Mohammadi et al. 2008)

Fibre reinforced concrete element failure is prevented by debonding and by the pulling out of the fibres from the concrete matrix thereby improving energy absorption during further resistance to dynamic loads, (Wang, L. P. Wu, et al. 2010). Fibres exhibit apparent advantages in case of high-speed impacts whereby energy absorption capacity is enhanced in concrete (Luo et al. 2000). Performance of typical fibre reinforced concrete is different from high performance fibre reinforced concrete (HPFRC) composites when typical elements are subjected to tension. After first cracking in fibre reinforced concrete less of tensile load is carried while in HPFRC there is enhanced load bearing capacity due to strain hardening (Naaman 2008).

Fibres are known to contribute to a reduction of concrete shrinkage and deformations albeit without consensus (Bywalski & Kamiinski 2013). Some fibres are also shown to improve rheological properties of concrete such as polypropylene (PP) fibres in which case design considerations are taken into place. Although some studies confirm the beneficial effect of such fibres on some materials' properties such as crack resistance and impact strength; no considerations are taken in design on all other mechanical parameters of concrete (Alhozaimy et al. 1996; Manolis et al. 1997).

In some cases, some researchers have argued for increased or reduced comprehensive strength of concrete due to presence of fibres. The current study aims to establish whether indeed steel fibres do contribute or otherwise to compressive and tensile strength of concrete; given lack of consensus in the area. The world currently is grappling with the issue of sustainable construction. As part of these efforts is about recycling of materials. Recycling can be from building materials or externally from other sources. Steel fibres can also be used to manage waste especially when waste recycling is done. Some studies have justified the use of such recycled fibres due to reduced costs and the improved mechanical properties of arising concrete (Nataraja et al. 1999; Martinelli et al. 2015 & Caggiano et al. 2015). Others like Zamanzadeh et al. 2015 have argued on the advantages of exclusively using steel fibres recovered from tyres. Polyethylene (PET) as another recycled material improves elasticity and delays micro cracking in concrete (Kim et al. 2010). It has been shown that the presence of PET and PP minimize cracks development in concrete (Borg et al. 2016).

Fibre Reinforced Concrete (FRC) has been in use for more than 50 years now. Its application has been in construction industrial and non-industrial elements of concrete members. Fibres have been established to enhance concrete properties like toughness, ductility, tensile strength, shear strength and fatigue resistance. Other studies have found out that for concrete to gain significant ductility and strength; then fibre content (Vf) must be high in ranges of $0.5\% < V_f < 1\%$. Other studies have confirmed that 0.75% are equivalent to shear reinforcement in reinforced concrete beams (Sahoo & Sharma 2014). Fibres do also play a role in concrete performance at service by preventing excessive deformation (Meda et al. 2012). Based on the foregoing there is increased development of structures utilizing fibres for superior concrete quality members (Destree 2006; Salehian et al. 2014). Use of fibres has led to reduced reinforcement usage and in some cases retaining only needed reinforcements along the columns to prevent progressive failure. Studies have shown that concrete performance depends on fibre parameters such as time, shape, bond strength, aspect ratio and volume fraction (Singh & Jain 2014). For FRC tensile characteristics key considerations are strain softening and hardening which may be further defined based on behaviour in bending (Naaman & Reinhardt 2006). Around the globe several countries have developed FRC design codes. AS 3600-2018 (Standards Australia 2018) code has provided a whole section dealing with this. Other times there is a combination of fibres with steel reinforcement to make hybrid reinforced concrete; which has bar reinforcement combined with fibres. Models existing on FRC (Taheri et al. 2011; Vandewalle et al. 2003); require that a strain compatibility analysis of the layered beam section be done in order to obtain moment capacity an impracticability for general users. There is therefore a need to model FRC behaviour under different steel dosages.

While studying tensile behaviour of FRC; simulations have been conducted in either a stress-strain (r-e) post-cracking relationship in a smeared crack continuum model or a stress-crack width (r-x) analysis. There was an initial study by Hillerborg et al. 1976 which has since been modified by many researchers on discrete crack approach (Zhang & Stang 1998; Denneman et al. 2011). Mier (1997) uses a stress-crack width (r-x) response in his study. Figure 1.2 below gives an illustration of beam performance in a cracked beam section; it has compression and tension zones. Using simulation, the stresses carried by the fibres across the crack intention can be expressed as a function of crack opening (Di Prisco et al. 2009; Minnelli & Plizzari 2015). These models mainly rely on the characteristic length parameter defined as LP, which prevents mesh dependence of the results infinite element models as it relates the crack width with strain (Di Prisco et al. 2013; Di

Prisco et al. 1999). Due to the expectation of crack distribution and tension stiffening then r-e approach is more suitable. Another approach is to use analytical equations for selection of variables based on designs automation procedures. Some researchers have used parametric material, tensile and compression constitutive models to derive analytical flexural load-deflection behaviour from closed form moment-curvature expressions. Inverse analysis of load-deflection response is then used to derive constitutive properties of elements under consideration (Soranakom & Mobasher 2007; Soronakom & Mobasher 2008).

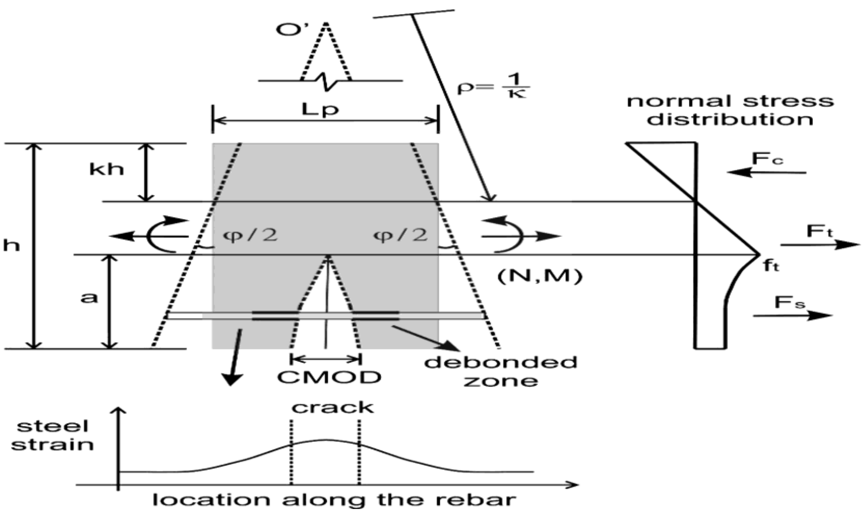

Fig. 1.2 Cracked beam presentation (Taheri et al. 2011)

The advances in materials technology including concrete; have seen its performance being continuously improved. It is possible to get well over 60MPa grade of concrete. But with increased comprehensive strength there are concerns that it becomes more brittle, less ductile making it liable to sudden failure. Steel fibres and reinforcement bars are incorporated to improve concrete's ability to absorb more energy and deformation before failure. The added steel fibres and reinforcement bars also make concrete more ductile. Studies have shown that tensile steel fibres also improve tensile strength and also enhance flexural behaviour of concrete. Among other contributing factors the extent of improvement in ductility is influenced by several parameters such as the type, shape, aspect ratio, distribution of fibres and volume. The geometry and quantity of steel fibres used have been shown to have a direct influence on the workability of the fresh concrete. It is therefore necessary and very important to conduct such a study in Kenya to develop necessary models which will guide designs in future. It is also useful to note that despite the popularity and usefulness of steel fibres in the construction industry over the last 50 years; there is little interest in embracing the use of steel fibres in Kenya. The steel fibres used for this research were imported although initially the empirical study was to be conducted at USQ but had to change due to Covid-19 situation.

1.2 Statement of the Problem

Concrete is a popular composite structural material that is widely used for construction of structures due to its good compressive strength, ease of manufacture and resistance to aggressive environmental conditions. Despite the foregoing it is weak in tensile strength hence tends to develop cracks which are a big issue compromising its durability and in extreme situations leading to failure. This shortcoming can be mitigated by the use of reinforcement bars, use of steel fibres or a combination of both. There are several studies done on the behavior of steel fibre reinforced concrete (SFRC) but with limited structural applications. For instance in Kenya we do not have any code to deal with this. We also do not have enough mechanical models that describe the behaviour of SFRC members failing in shear, measure the actual contribution to compressive strength and role in flexural behaviour in real life applications. Despite global interest and research in steel fibre reinforced concrete, many countries Kenya included are yet to conduct sufficient research in this area to inform policy and design principles using this material. This study focuses on analysis, failure and mechanical behavior of cylindrical specimens of plain concrete, FRC with

0.5% steel fibres, 1% steel fibres and 2% steel fibres. Specifically, an investigation on the role of fibres in compressive strength and splitting tensile test are conducted experimentally to develop models on the role of fibres in enhancing the structural performance of concrete.

1.3 Project Aim

To investigate the role of steel fibres on the compressive and tensile strength of concrete; with a view of optimization of designs in terms of cost, quality, strength and performance. The key focus shall be mainly in the role of steel fibres dosage against compressive and splitting tensile strength of cylindrical specimens.

1.4 Project Objectives

Main Objective: To investigate the role of steel fibres on the compressive and tensile properties of concrete.

Specific objectives:

1.0 To compare the compressive strength behaviour of SFRC of cylinders without steel fibres and those with steel fibres at different dosages.

2.0 To investigate contribution of steel fibres to tensile structural performance of concrete at different dosages.

3.0 To determine the most optimal steel fibre combination in concrete manufacture and come up with a model.

Research questions

1.0 How does plain concrete compare with steel fibre reinforced concrete at different dosages for compressive strength?

2.0 How do steel fibres affect splitting tensile strength in concrete?

3.0 What is the optimal combination of steel fibres in FRC manufacture?

1.5 Research Hypothesis

Null hypothesis: Use of steel fibres has no effect on concrete strength in reinforced concrete members.

$$HO: \beta 0 = \beta 1 = \beta 1 = \beta 2$$

Whereby β relates to steel fibres and its effects on contribution to concrete strength in the concrete manufacture at various dosages.

Alternate hypothesis: Use of steel fibres has an effect on concrete performance in fibre reinforced concrete cylinders.

$$H1: \beta 0 \neq \beta 1 \neq \beta 1 \neq \beta 2$$

For

Whereby β relates to steel fibres contribution to concrete performance in the concrete manufacture of various dosage at various measurement parameters.

The null hypothesis can be stated as follows:

$$Ho: b2 = b3 = \ldots = bn = 0$$

This posits that steel fibres do not have any significant influence on concrete strength development.

The research hypothesis is that: -

$$H1: bj \neq 0 \quad For\ at\ least\ one\ j, j = 1, \ldots, n$$

By rejecting the null hypothesis, it means that at least one of the experimental study variables, *S*1, *S*2…*S*n, contributes significantly to concrete strength development and crack prevention. An appropriate statistical test shall be used to test this hypothesis at a level of significance α=0.05.

The research seeks to find out if the addition of certain independent variables of interest (steel fibres at different dosages) add significantly to the prediction of concrete compressive and tensile strengths, *f'c.* This study is on an investigation of whether an addition of steel fibres as an additional variable to the 'traditional' ones, (water-cement ratio and quantities of coarse and fine aggregates) does increase concrete strength prediction model efficiency.

1.6 Significance

Despite the introduction and use of fibre reinforced concrete, little has been done in this regard in advancing design, usage and development of this product in Kenya. This study is useful in the sense of contributing and exciting academic discourse in this regard but also in contributing towards handling some of recycled products containing steel fibres like rubber tyres and the related. This will improve disposal and contribute towards a clean environment. Specifically a model on behaviour of concrete in terms of compressive and tensile strengths is developed.

1.7 Scope and delimitation

Employers in the construction industry fall into two broad categories either public or private sector clients in Kenya. Any research aimed at improving performance of the construction industry will be very useful. In this regard it would have been prudent to cover a range of fibres since these have never been used extensively in Kenya, but due to financial and time limitations, this research shall only focus on steel fibres. Other fibres can be investigated by other researchers' later, to build on this one. It would have been also nice to cover the range of all fine aggregates in use in Kenya other than river sand but time will not allow. Due to the current Covid-19 situation the study focused only on compressive and splitting tensile strength evaluation. In normal circumstances the study could have been extended to steel fibre reinforced concrete structural members especially on three point and four-point beam structural performance evaluation which could not be done in the current situation.

1.6 Justification

This research is on an investigation of steel fibre usage in the manufacture of concrete processes to determine the key mechanical properties, structural strength in terms of compressive and tensile splitting that are performed experimentally. The dosage of steel fibres is investigated to determine the optimum usage starting with 0%, 0.5%, 1% and 2% steel dosage against experimental parameters.

The findings of this study shall be useful as follows:

- To all the players in the construction industry namely clients, consultants and contractors through new information on construction materials especially steel fibres in Kenya. For civil and structural engineers, information on this material so that they can consider it in their designs.

- The study will be useful to future researchers in this area especially in civil engineering structures and materials.
- An optimal steel fibres usage framework/model to guide the design for steel fibre reinforced concrete in Kenya is developed.

1.7 Conceptual framework

The study shall utilize a conceptual framework as captured under figure 1.3 below.
All testing will be conducted with reference to all the relevant standards listed.

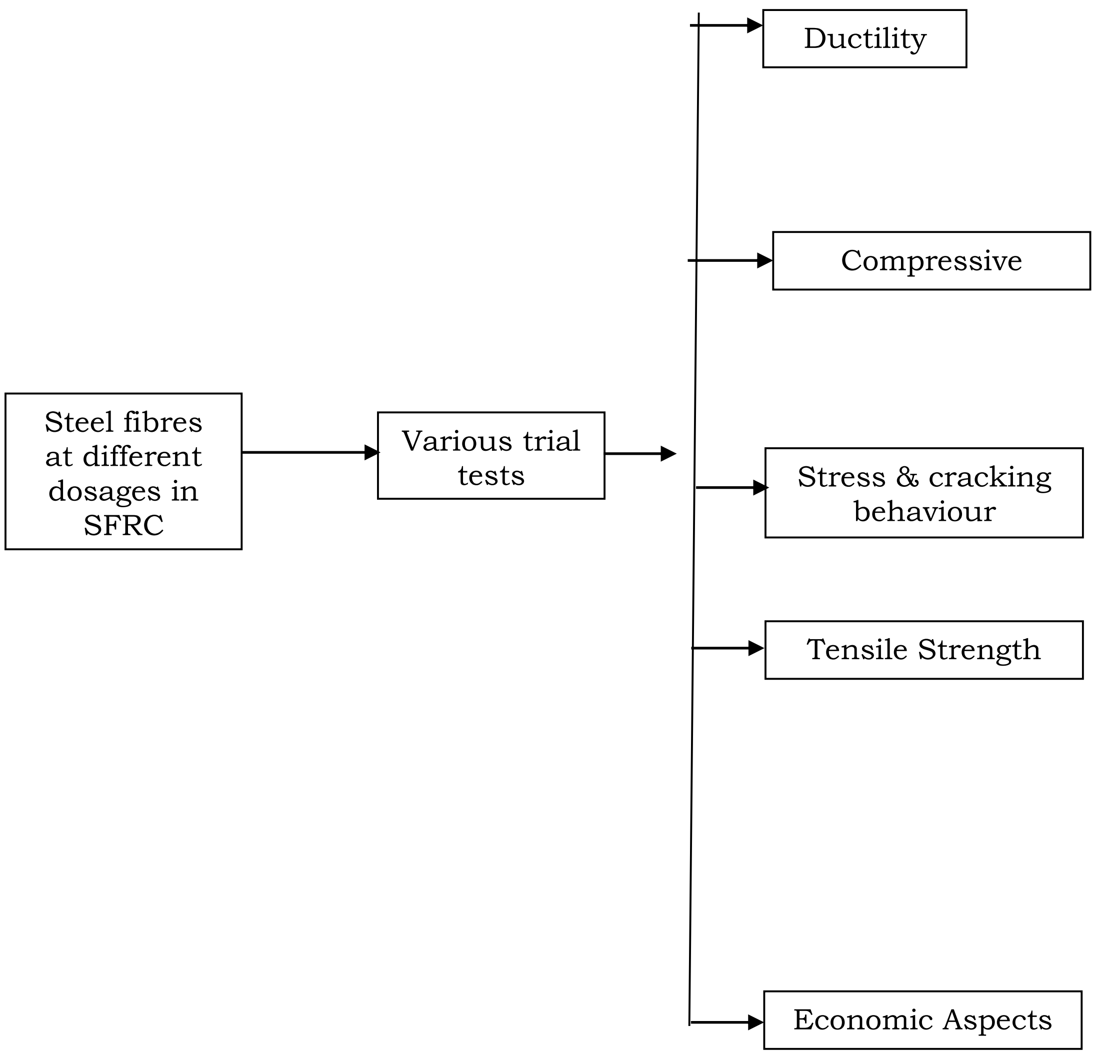

Fig 1.3: Conceptual framework for the study

1.10 Dissertation overview

The dissertation is organized into chapters for clarity and orderly presentation of the research objectives, testing and discussion of results. In a nutshell the dissertation is organized as follows:

Chapter one: Introduction

This discusses the introduction, statement of the problem, study objectives, aim, research hypotheses, justification and significance of the study. It is identified that over fifty years since the introduction of fibre reinforced concrete, the market in Kenya is yet to pick this construction product up, investigate it and use. A conceptual framework to guide the research process is presented under this Chapter.

Chapter two: Literature review

This chapter contains reviewed literature on the content appropriate to the study topic. Some of the reviewed works as *interlia*: influence of steel fibres on the flexural behaviour of concrete, investigation of steel fibres on shear crack opening, a new bond model for reinforcing bars in steel fibre reinforced concrete, evaluation of various fibres in comparison with steel on impact resistance of concrete, role of steel fibres in compressive, flexural and tensile strength of concrete culminating in research gap in literature

Chapter three: Research methods and materials

In Chapter three I have discussed extensively on how the work in research project was undertaken including the experimental design, the testing procedures, design variables, where the work was carried out, how risks and ethics were carried out for the research project. Research planning, design and risk analysis are presented here. The experimental design, tests carried out for results which are presented and discussed in the next chapter.

Chapter four: Results and observations

This chapter is on results and observations. Results based on different specimens are presented including observations on 0%, 0.5%, 1% and 2% dosages of steel fibres on reinforced concrete cylindrical test results for compressive and splitting tensile strength. The chapter concludes with a summary leading to the next chapter on discussion of results. More details will be found on the particular chapter within the thesis.

Chapter five: Discussion of results and modelling

In this chapter results are discussed including effect of steel fibre dosage on compressive and splitting tensile strength. A discussion on developed linear models and validation. Finally, the chapter concludes with hypothesis testing using Chi-Square and Kruskal-Wallis non-parametric statistics.

Chapter six: Conclusions and recommendations

The final chapter presents conclusions and recommendations arising from the study. The conclusions are based on the presented research objectives in line with experimental study findings from the experiment and discussed in Chapters four and five dealing with results and discussion respectively. Recommendations are on further studies as addressed at the end of the chapter.

CHAPTER 2: REVIEW OF RELATED LITERATURE

2.1 Introduction

In this chapter, review of related literature is presented. The importance of Steel fibres in fibre reinforced concrete is discussed followed by mechanical properties of Fibre Reinforced Concrete, then contributions of steel fibres in tensile, flexural and compressive strength, types of fibres, dosage of fibres, studies done in the area and research gap in literature which is being addressed in the current study. Finally, a summary of the chapter is presented.

2.2 Importance of steel fibres

Concrete is a widely used structural material with adequate compressive strength but poor tensile strength of usually less than 10MPa. To cure the problem of low tensile strength either reinforcement bars or fibres are used. The current study is aimed at studying the role of steel fibers in the performance of concrete at doses of 0%, 0.5%, 1% and 2% percentage of steel fibers. A comparison in terms of key performance variables over this range of fibre dosages is presented. Reinforcement can be done either using reinforcement bars or fibres. Fibres are in turn of various types including steel fibres, natural fibres, synthetic fibres, carbon, glass fibres among others. This research focuses on steel fibres. Changing world dynamics in loading mechanisms have resulted into different force impacts and therefore concrete which can withstand extreme loading tendencies. Under normal circumstances Vibrated reinforced concrete and prestressed concrete are adequate and have been used under static conditions successfully but these have been found to be inadequate under sudden and extreme loading mechanisms. Researchers have contributed in providing solutions to the noted drawbacks of plain concrete performance deficiencies, for instance (Yoo et al. 2016; Yoo & Yoon 2014; Bentur & Mindess 2006), have advocated for concrete to be strengthened with fibres. Other countries are still doing things the conventional way; many countries have no codes defining the procedures and rules guiding the design of FRC materials; but research is ongoing in this area for 50 years now. Listed hereunder are advantages of using fibres:

(1) That they mix easily in concrete,

(2) that they enhance concrete performance due to fibre bridging and

(3) that they are economical as compared with other methods of reinforcements.

Fibre bond performance affects concrete post-cracking ductility which is in turn is influenced by factors such as fibre dosage per area, fibre shapes, orientation, aspect ratio and strength of concrete. Research in other countries, Kenya included has been slow in the area of use of steel fibres. Materials for this study had to be imported from Bahrain because steel fibres are not manufactured in the Kenyan market. Sensitivity of both plain and reinforced concrete is affected by loading rates. This study in a small way contributes to this especially on the effect of steel fibres of different dosages on the performance of concrete.

2.3 Dynamic crack growth resistance of FRC

FRCs has been shown to exhibit a more complex fracture process and it, therefore, requires a sophisticated model to simulate it properly. Research in the area done previously has resulted into a cohesive crack model (Hillerborg 1980) and earlier a J-integral model (Mindess et al. 1977). This study will be an attempt to understand better the behaviour of concrete under different fibre content in a range of performance parameters as discussed under aims and objectives. (Bindiganavile & Banthia 2005; Bindiganavile 2003) established several useful findings as hereunder:

(1) that a higher crack growth resistance is maintained even at larger crack length as a result of inclusion of fibres;

(2) that the crack grow resistance increases with increase in the magnitude of input energy and rate of loading;

(3) that a higher impact rate leads to an increased rate of crack extension; and

(4) that crack growth decreases due to the existence of fibres.

The current study shall be mainly geared towards investigation of the role of steel fibres in compressive strength and splitting tensile test of concrete towards improving the body of knowledge in this regard.

2.4 Impact resistance of various types of FRC

Concrete structures are mainly loaded in two main ways; via dead loads and live loads. The mode of loading also is an important determinant of design considerations; whether static, dynamic or impact. Behaviour of plain concrete and reinforced concrete is different under these loading mechanisms. Research has shown that FRC is very good in compressive strength and is able to resist impacts, both static and dynamic in nature. But plain concrete is brittle and has been shown to fail suddenly. Due to this it is important to consider mode of loading and it is in this regard that FRC has been found to be very useful. Various types of fibres are discussed hereunder and how they offer impact resistance.

2.5 Fibre pullout behavior of steel fibres

One area to be considered is the behaviour of steel fibres when it comes to bond strength with concrete. Different fiber sizes and shapes have significant influence on bond strength of fibre reinforced concrete; which in turn influences overall performance of the concrete matrix. Besides the size and shape; the quantity also plays a role; that is why the current study is important so that a modelling is developed on this behaviour in relation to the different steel dosages. Several studies have shown slightly improved bond strength of straight fibres (Dinh et al. 2010, Teng et al. 2008 & Banthia et al, 1999). Fibre pullout behaviour is one of the key areas to be considered in fibre reinforced concrete. Fibres' contribution to concrete performance is a function of bond strength which is in turn influenced by fibre dosage, type, shape and size. There are several types of fibres in use but this study shall focus primarily on steel fibres.

2.6 Flexural behaviors of steel FRC

Flexural performance of concrete is another measure of concrete properties. Among other measures; reinforcement is meant to improve the flexural strength. The fibres do also contribute to enhancing this concrete quality and several studies have been conducted in this area as discussed under this section. For instance in their study (Suaris & Shah 1982) reported that the flexural strength of FRC with straight steel fibres greatly increased with loading rates while another study by (Naaman & Gopalaratnam 1983) indicated an almost threefold increase in flexural strength of straight steel FRC beams. For instance, when the straight steel fibres are inclined, mechanical bond components in addition to the frictional bond component are obtained, due to the bearing of fibre on the concrete. Based on previous studies, fibre reinforcement plays a more influential role on the flexural strength and behaviour of concrete compared to its influence on concrete compressive strength. According to the findings from a study by (Kooiman 2000), the flexural strength of the concrete is increased as the fibres create a softening effect which redistributes the stresses. Increase in flexural strength of concrete is also caused by the transfer of loads and stresses across formed cracks. In another study it was noted that when steel fibres were incorporated into a concrete mix at dosages of 0.5%, 1.0%, 1.5% and 2.0%, it significantly improved the flexural strength of the concrete. Ductility was also significantly improved as noted in the same study.

2.7 Tensile behavior of steel fibers

Compression and tensile forces are some of the major items considered as part of concrete properties which affect performance, determine failure mechanisms, crushing load of concrete. So tensile forces are evaluated often in concrete performance. The source of and major contributors of tensile strength of concrete are reinforcement bars and steel fibers. Studies have been carried out in this area before for instance a study by (Banthia et al. 1996) which evaluated the effects of matrix strength (38–90 MPa) and deformed steel fibre geometry (hooked, crimped, and twin-cone) on the resistance of concrete under tensile impacts; it was established that at the rate of 40 kg/m^3, tensile strengths and fracture energies were higher for SFRC under both impact and static loads compared with plain concrete. Steel fibres improve performance of concrete under static and impact loading conditions.

This research shall investigate tensile splitting test experimentally using 36 No. cylinders of 100mm diameter and 200mm height. No such research has been carried out in Kenya and all other concrete ingredients shall be kept as a constant pending only steel fibres dosages. Then modelling shall be done. This is one of the major research dimensions adopted in this research to compare with results from other studies conducted from elsewhere globally. Because the fibres can carry tension after the tensile strength of concrete is reached and cracking occurs, the improved tensile strength of SFRC and post-cracking behavior is its most notable significant mechanical property (Singh & Jain 2014; Heek et al. 2017) .

The current study shall extend on this research by filling the gap of modelling tensile behaviour from a situation of 0%, steel fibers reinforcement then 0.5%, 1% and finally at 2%. The reason why I am stopping at 2% is that studies have indicated some marked loss of ductility when the steel fiber dosage exceeds 2%. Tensile splitting test is one of the parameters that the experimental study shall investigate.

2.8 Compressive behavior of steel fibers

Concrete is known to be very strong in compression necessitating its wide usage in civil engineering projects. Many studies on concrete must also investigate on compressive behaviour of concrete. So previously studies done in this area, have ended up not indicating clearly or identifying the level and modelling contribution of steel fibers from dosage of one level to the other, or whether discrete or continuous. Equally some argue that steel fibers contribute to compressive strength while others have argued that negligible or no contribution to compressive strength results from addition of steel fibres. This study will aim at developing a model for this and clarifying whether indeed steel fibers have an effect on the performance properties of concrete.

Studies have indicated that adding steel fibres does not significantly increase the compressive strength of concrete (Thomas & Ramaswamy 2007; Lee et al. 2015) , but the post-peak rate of strength loss is smaller due to the role of fibres in mitigating post-peak splitting cracks (Lee et al. 2016; Dinh et al. 2010). Concrete cylinders of 100mm diameter and 200mm height shall be cast and tested for this property on 0%, 0.5%, 1% and 2% fibre dosage. Even though studies have been done elsewhere, no such a study has been done in Kenya to concur or otherwise disagree with studies done in other countries.

2.9 Projectile impact resistance

Concrete structures sometimes are subjected to projectile impact types of loading especially the slabs. There is no consensus yet on how plain and FRC behave under repeated hitting via projectile impact (Teng et al. 2008). But some studies done previously show improved resistance to perforations by FRC due to repeated impacts as opposed to plain concrete. There is no conclusive study on whether and how FRC contributes to projectile impact resistance.

2.10 Comparative evaluation of various fibers used on FRCs

Fibre Reinforced Concrete can be manufactured using different fibres. Discussed below is a comparison of steel fibres with other commonly used fibres under impact loading conditions.

2.10.1 Steel fibres vs. polymeric fibres

Apart from Steel fibres, there are other different fibres in use. One of the fibres is polymeric fibres. Previous studies in this area indicated that polymeric fibres are better than steel fibres at higher loading rates which are likely to fracture the steel fibres in concrete (Banthia et al. 1999). But steel fibres were found to be better than Polyolefin fibres. Of the three polymeric fibres were found to be the best followed in pullout resistance by steel fibres and finally polyolefin fibres. The reason why steel fibres were second best is because with high loading rates they tend to fracture but there is need to investigate at what levels of loading they fracture and model the behaviour for a better understanding of this structural material.

2.10.2 Steel fibres vs. carbon fibres

Research has been done to determine the behaviour of steel fibres and carbon fibres in impact resistance. Studies have shown that using steel fibers on impact resistance of wet-mix shotcrete using deformed steel fibers was much higher than that with micro carbon fibers (Banthia et al. 1999). So it is important to develop a better understanding of steel fibre reinforced concrete for a more robust application in concrete manufacture and in construction of structures.

2.11 **Steel fibres and shear failure**

Shear failure is one of the ways in which concrete members fail. Steel fibres play a role in mitigating against shear failure. Researchers have established that one barrier to the structural use of SFRC is the lack of mechanical models that describe the behaviour of SFRC members failing in shear and other mechanisms (Lee et al. 2016; Slater et al. 2012). Use of steel fibres can lead to reduced reinforcement bar usage thereby with a resultant reduction in construction time and costs (Singh & Jain 2014). This study will come up with a model to predict behaviour of steel fibre reinforced concrete over different dosages. The study will utilize cylindrical specimens to investigate and model for steel reinforced concrete performance.

2.12 Source and characteristics of steel fibres used in this research.

The steel used in this research was imported from Bahrain at AU $ of 1,000.00 (one thousand only) for a consignment of 20kgs although not all of it was utilized for this study. It is important to note that the actual cost of the fibres was approximately AU$ 50, the rest of costs was in freight charges. The reason for ordering a higher quantity is because it is better to have a surplus than a deficit. The characteristics of the imported fibres are discussed briefly below (www.forcetech.wll.com, Viewed 27 April 2020).

The steel fibres used were sourced from Bahrain with the following technical data:

That they are of 3X shape which is the most popular commercial shape of the end hooked steel fiber and it is the ideal product for standard industrial flooring system for both regular and dynamic loads.

Specifications of 3X shape include:

1.0 Deformable single end hooked.

2.0 Glued fiber, lower or high L/D ratio.

3.0 High tensile wire for standard concrete.

Notes given as follows

1.0 The longer the length of fiber steel the better the anchorage

2.0 The thinner the diameter of fibre steel the more fiber in cubic metres and the denser the network.

3.0 The higher the L/D ratio the better the performance of steel fibre reinforced concrete.

TABLE 2.1: CHARACTERISTICS OF 3X SHAPE

Element	**1.05/60**	**0.9/60**	**0.75/60**
Length	60mm	60mm	60mm
Diameter	1.05mm	0.9mm	0.75mm
Aspect ratio	57	67	80
Min. Dosage	21kg/M3	15kg/M3	10.57kg/M3
Fibers/kg	2314/kg	3257/kg	4690/kg

Wire strength

The strength of the 3X steel fiber has to increase in parallel with the strength of its anchorage. The fiber can resist the forces acting upon it only by using this way. 3X steel fiber combines high tensile strength with a very specific elongation capacity.

Wire Elongation

3X steel fiber creates concrete ductility by slow deformation of its hooks during the pullout procedure.

SAFETY AND STORAGE

(i)Head and eye protection and gloves must be used at all times.

(ii) Keep materials dry

(iii) No stacking.

The materials are supplied in 25kg boxes whereby 48boxes weigh 1200kg as net weight.

Material characteristics are as follows for FIBMix 3X/BL 1.05/60

(i) Tensile strength for drawn wire is 1115 N/mm2

(ii) Modulus of elasticity is approximately 200,000 MPa.

(iii) Number of fibers per Kg is approximately 2314.

Material characteristics are as follows for FIBMix 3X/BL 0.9/60

(i) Tensile strength of drawn wire 1160N/mm2

(ii) Modulus of elasticity is approximately 200,000 MPa.

(iii) Number of fibers per Kg is approximately 3257.

Material characteristics are as follows for FIBMix 3X/BL 0.75/60

(i) Tensile strength of drawn wire 1225N/mm2

(ii) Modulus of elasticity is approximately 200,000 MPa.

(iii) Number of fibers per Kg is approximately 4690.

For the experiment only one set of steel fibers have been used of type FIBMix 3X/BL 0.75/60.

2.13 Mechanical properties of SFRC

2.13.1 Introduction

Since fibre-reinforced concrete is concrete that contains fibrous material that increases the structural properties of the concrete; for good results these fibres are required to be evenly distributed throughout the concrete mix in order to work effectively. There are many types of fibres that exist for this purpose and according to Maccaferi, 2015 the main types of fibres that are used for FRC are as follows:

- Metallic fibres.
- Natural fibres.
- Synthetic fibres.

2.13.2 Types of Fibres

This study shall focus on steel fibres which are steel products geometrically characterized by one dimension prevailing onto the others (Maccaferi 2015). Fibres are geometrically characterized by the length (L), the shape and the equivalent diameter (De). The ratio between the length (L) and the equivalent diameter (De) provides the aspect ratio, or shape ratio (1=L/De); the steel fibre types act and perform differently to enhance the bond between the concrete and the reinforcement under the loadings experienced by the concrete.

Based on a study by Maccaferi, 2015, synthetic fibres are an alternative to steel reinforcement fibre in concrete. The synthetic fibres commonly used in concretes can be grouped as either polypropylene, Vinylal, Mordarcrylic, Polyamide and Aramid; whereby polypropylene fibres are composed of linear macromolecules made up of saturated alphatic hydrocarbon units in which one carbon atom in two carries a methyl side group, generally in an isotactic configuration and without further substitution (Maccaferi 2015). Mordarcrylic fibres are composed of linear macromolecules having in the chain at least 50% and less than 85% by mass of acrylonitrile while plyamide fibres are composed of linear macromolecules having in the chain recurring amide linkages, at least 85% of which are joined to aliphatic cycloaliphatic units. Aramid fibres are composed of linear macromolecules made up of aromatic groups joined directly to two aromatic rings and the number of imide linkage, if the latter are present, not exceeding the number of aramide linkages (Maccaferi 2015).

2.13.3 Mechanical Behaviour of Fibre Reinforced Concrete

When different fibres are incorporated into a concrete mix this will cause the concrete to experience different physical and mechanical characteristics as compared to non-fibre reinforced concrete. According to (Maccaferi 2015) the FRC performance are influenced by the fibre characteristics such as geometry, aspect ratio, contents, orientation and distribution; the matrix itself that is in resistance and maximum dimension of the aggregates and the interface fibre-matrix. The fibres geometry, aspect ratio and contents affect mechanical properties of the FRC because they determine how the individual fibres will carry the load while the strength of each fibre will also have an influence. The matrix of the aggregate interacting with reinforcing fibres is known as the interface fibre matrix which is influential as it will contribute to how load transfer through fibres will occur thus potentially preventing/ delaying any crack propagation, therefore essentially increasing the strength of the concrete.

2.13.4 Fibre Bridging

Because fibre reinforcement is spaced much more closely in the concrete than steel reinforcement normally it controls and manages crack propagation more efficiently. Incorporation of reinforcing fibres is able to take care of cracks which form in the concrete hence taking care of arising weaknesses due to a disruption of the path of stress/loading. This is so due to fibre bridging which is possible when the fibres are generally able to continue to transfer these stresses and forces across the crack along into the concrete. When fibre bridging occurs one of the following may happen:

I. Fibre fracture may occur.

II. Post-debonding may arise.

III. Fibre-matrix interface debonding may develop

IV. Matrix fracture and matrix spalling can occur

V. Fibre abrasion and plastic deformation of fibre may obtain.

The incorporation of reinforcing fibres in a concrete mix will result in the particular concrete to form a fibre matrix when a bond is made between the concrete and the fibre. This implies that loadings applied to the concrete will have direct effects on the fibres within the concrete. Cracking in concrete is witnessed due to many various loadings (Yassir et al. 2016). Because of different behaviour patterns of concrete and different loadings; debonding of fibre and the concrete cracking develop over several stages. Because it is already known that concrete is weak under tensile forces the cement matrix formed within the concrete will experience cracking prior to fibre failure (Yasir & Abbas 2016). Cracks occur before fibre failure necessitating the fibres to carry the load though the cement-matrix crack before total failure. It is assumed that initially loadings to the fibre and the concrete matrix behave elastically (Gambhir 2009). According to a study done by Gambhir (2009), there will be further matrix cracking after the initial crack has formed, therefore the bond between the fibre and the concrete will determine whether effective fibre-bridging occurs, thereby allowing the load of initial cracking to be carried by the fibre but once the concrete reaches its ultimate load it will commence to fail. It has been established that failure of the fibre-matrix and post cracking is usually as a result of fibre pull-out which in turn is determined by the bond of the fibre with the concrete, number of fibres bridging the crack, as well as the geometry of the fibre. The strength of the bond of the fibre and the concrete is essential for controlling cracking and effective fibre-bridging. A balance must be struck between bond strength and ductility of concrete;

whereas, a high bond strength is considered desirable; it is essential that the bond strength does not exceed limits that will impede on the ductility of the concrete (Gambhir 2009). The three types of fibre bonding that usually occur include:

- Elastic Bonding where fibres adhere to the Matrix
- Frictional Bonding where friction between the fibres and the matrix causes resistance to pull-out
- Mechanical Bonding where fibres are deformed along their lengths to enhance bond through interlocking with the matrix.

It is important to understand the fibre-matrix interaction as this will provide evidence and explanation regarding the failure experienced by the specimens during testing. This study utilizes cylinders to study the role of steel fibres in compressive, flexural and tensile splitting test.

2.13.6 Mechanics of Cracks Formation and Propagations

Incorporating fibres into the mix of concrete enhances the concrete's ability to transfer stresses across formed cracks, achieved through fibre bridging. Fibre bridging has the potential to increase the toughness and ductility of the concrete as well as the absorption capacity under impact (Clarke, Vollum et al 2007). Concrete is known as a heterogeneous material with pores and micro-cracks caused by shrinkage and thermal strains (Dossland 2008) but due to the incorporation of the fibres these cracks can potentially be limited, furthermore the width and extent of macro-cracking can be controlled through effective fibre bridging. Three ways in which fibres work to mitigate the formation of cracks include:

- Fibre-matrix debonding whereby fibres act indirectly as crack stoppers.
- Crack stabilization through fibre-bridging
- Crack suppression whereby fibres that are dispersed evenly will increase the force required to initial cracking.

2.13.7 Orientation and Distribution of Fibres

The physical and Mechanical characteristics of fibre reinforced concrete is mainly dependent on the distribution and orientation of the fibre which are in turn determined by the casting and mixing process; a major factor affecting the distribution and orientation of the fibres within the concrete batch. Other influencing factors include the size and geometry of the fibre which do have effects on the positioning fibres. According to Kooiman and Barragan 2002, fibre reinforced concrete that has been compacted through vibration should achieve planar-randomly distributed fibres nature. But according to Dupont, 2003, concrete that only experiences a short period of vibration will not have sufficient vibration to significantly alter the fibre orientation and it should be noted that the incorporation of fibres in concrete mixture has the potential to cause voids. The voids are caused by fibres that are orientated parallel to the direction of force application (Neves & Fernandez de Almeida, 2005).

2.13.8 Fibres Mechanical Properties

The behavior in which a fibre performs under loading is dependent upon the fibres mechanical properties which calls for an understanding of these properties. Steel and polypropylene fibres are the most commonly used fibres due to their availability and low cost (Brandhaus, 2016). Table 2.1 displays various fibres and their mechanical properties.

Table 2.2 Various fibres used for Fibre reinforced concrete and their mechanical properties (Beaudoin 1990).

Fibre Type	**Specific Gravity**	**Modulus of Elasticity**	**Tensile Strength**	**Failure Strain**
Steel	7.8	200.0	1.0-3.0	3.0-4.0
Glass	2.6	80.0	2.0-4.0	2.0-35.
Asbestos	3.4	196.0	3.5	2.0-3.0
Nylon	1.1	4.0	0.9	13.0-15.0
Carbon	1.9	380.0	1.8	0.5
Polypropylene	0.9	5.0	0.5	20.0
Polyester	1.4	8.2	0.7-0.9	11.0-13.0
Polyethylene	0.9	0.1-0.4	0.7	10.0

One of the most important properties of a fibre is its modulus of elasticity; a high modulus of elasticity would directly improve the fibre-concrete matrix elasticity, as such this would allow the matrix to transfer greater loads through formed cracks. The other important property of a potential reinforcing fibre is its tensile strength which should complement concrete's weakness in tension (Brandhaus, 2016).

2.14 Fatigue Behaviour

Fatigue behaviour is among mechanical properties to be considered for SFRC elements. Fatigue behaviour is different for seismic conditions and those occasioned by repeated loadings like from traffic passing through a given road or bridge. Steel fibre reinforced concrete outperforms normal concrete under seismic loadings, cyclic loadings and when considering life cycle costing as it was found out by (Carnovale & Vecchio 2014).

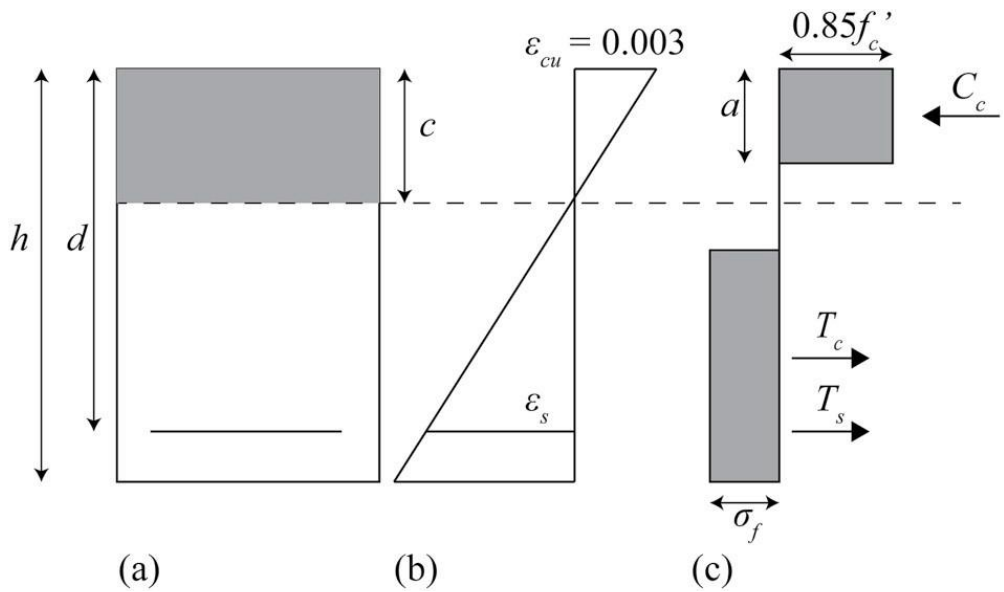

Fig. 2.3. Sectional analysis of SFRC: (a) cross-section; (b)strains; (c)stresses and resultant forces.
Figure 2.3 above shows a beam cross sections, strains and resultant forces. Studies have also been done for beams and it has been found out by previous researchers that steel fibres improve concrete performance over a range of different loading conditions.

2.15 Creep and shrinkage

Curing conditions do affect creep and shrinkage as investigated by (Garas et al. 2009). To deal with the issue of creep and ensure it is reduced, thermal treatment should be used. Another way of reducing creep is through the use of steel fibres because creep reduced in the UHPC mixes with fibres as compared to the mixes without fibres as per these studies (Garas et al. 2009; Kaprielov et al. 2018). To minimize these all specimens shall be kept in water as per labelled drums in accordance with experimental design discussed under chapter three.

2.16 Fibre Volume Dosage

Fibre dosage rates will also play an important role in determining the concrete physical and mechanical properties; fibres are usually introduced into a concrete mix by a percentage of the concrete's volume. Fibres are introduced by a percentage of the concrete's volume as this will ensure that an even ratio between fibre count and dispersion is achieved and increase the chances of creating an even fibre matrix throughout the concrete. According to (Naaman 2000) fibre volume dosage for typical fibre reinforced concrete is normally less than 2% and one would assume that higher number of fibres incorporated within a mix would increase the chances of crack being bridged. But it is important to note that there is a limit beyond which increased fibres dosages will also increase the chances of a fibre aligning with the direction of the load, thus potentially causing voids within the concrete matrix (Neves & Gonualves 2000). So a balance must be struck in terms of careful consideration when deciding on fibre dosage rates in terms of contribution to increased strength against the formation of additional voids.

2.17 Modelling in steel fibres

A number of models exist to predict concrete strength, but those utilizing steel fibres in modelling are very few. We do have the Abram's model which predicts using w/c ratio, the Bolomey's model which utilizes water cement ratio but predicts for 28 days only and the ACI which is a linear model but not on steel fibres. There is need to develop steel fibre predicting models for use in future. In this research a regression model shall be developed to predict strength of concrete at different dosages.

2.18 Research Gap in literature

Even though the structural behavior of steel fibre reinforced concrete (SFRC) has been extensively researched, structural applications are still limited. One barrier to its implementation is the lack of mechanical models that describe the behaviour of SFRC members. Despite global interest and research in Steel Fibre reinforced concrete, many countries Kenya included are yet to conduct sufficient research in this area to inform policy and design principles using this material. This study focusses on analysis, failure and mechanical behavior of cylindrical steel fibre reinforced concrete members. Despite several studies in this area around the globe, none has been done in Kenya. There is no code to guide the design using this product in Kenya, the study will therefore utilize the other concrete materials with imported steel fibres to model behaviour of concrete with a view of comparing the results with other studies from other countries and secondly a modelling to inform behaviour of concrete under different steel fibres dosages as a contribution to knowledge in this area. In structures such as beams or elevated slabs, fibres are generally used in combination with conventional reinforcement. In this work, the results of an extensive experimental research shall be carried out at the Laboratory of Civil engineering of the Jomo Kenyatta University of Agriculture and Technology. This research shall focus on FRC cylinders with different fibre contents at 0%, 0.5%, 1% and 2%. Specifically, compressive, flexural and tensile splitting tests shall be carried using 72 cylinders of size 100mm diameter and 200mm high. No such research has been done in Kenya previously so it was necessary to conduct this study here to compare with other studies in the area globally.

2.19 SUMMARY

In this chapter, a discussion has been done on fibre reinforced concrete including mechanical properties, behavior under impact loads, previous studies in the study area and fibre use dosages. In this chapter fibre reinforced concrete has been discussed including importance of fibres, role of fibres in dynamic crack control, impact resistance of fibre reinforced concrete and mechanical properties of fibres. Flexural and compressive behaviour of fibre reinforced concrete has been discussed as well.

What other researchers have done in comparative studies in impact resistance of various fibres is discussed. Mechanical behaviour of fibre reinforced concrete has been presented. Orientation and distribution of fibres is discussed. Fibre volume usage has been discussed and how it can be used in concrete manufacture. Flexural design solutions have been presented and existing models in this area. There remains a research gap which has to be addressed in literature by not fully studying and appreciating results from material characterization of concrete incorporating SFRC which is being addressed in this study via cylinders with steel fibre reinforcement of different dosages. Many countries Kenya included are yet to embrace and fully appreciate design codes including SFRC in their engineering applications. The next chapter presents the methods and materials used to conduct the experiments.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Introduction

This chapter discusses the materials and methods used in achieving the set-out objectives in the study. It discusses the materials and resources used as well as the experimental design, set up, mixing, curing and testing procedures adopted. This research follows a quantitative experimental approach with data collected empirically based on the research objectives and hypotheses. Tested and obtained results shall be used in the strength prediction models.

3.2 Research design

This research attempts to explore the suitability of steel fibres and optimum mix in the manufacture of concrete. It would have been desirable to explore all sands used in the construction industry in Nairobi based on different fine aggregates in Nairobi Metropolitan sourced in Machakos, Mwingi, Kajiado, Mlolongo and Naivasha. For the purpose of this study, the research approach adopted is quantitative in nature using an experimental study with fine aggregate and coarse aggregates obtained from same sources to avoid variations due to these two crucial concrete materials ingredients.

Steel fibre reinforced concrete is an essential material in civil/structural engineering design and materials and it has pre-occupied researchers and scholars for a while; over 50 years, with each scholar contributing in one way or the other. However, in Kenya this area has not received enough attention and most of the structures are designed in the conventional reinforced concrete system. The experimental programme will be conducted in two parallel ways:

Study 1 will cover 36 cylinders of size 100mm diameter and 200mm height, nine each with plain concrete, 0.5% fibres, 1% steel fibres and 2% steel fibres steel fibre reinforced concrete respectively. The cylinders shall be crushed at 7 days, 14 days and 28 days for compressive strength determination.

Study 2: 36 cylinders shall be cast for tensile splitting test and shall include steel fibres of 0%, 0.5%, 1% and 2%. The following tabulated tables 3.1 and 3.2 show the parameters to be tested and in turn other research variables shall be derived. In each of the readings the three tests shall be averaged to get a governing result.

TABLE 3.1: COMPRESSIVE STRENGTH

TEST PARAMETERS	SPECIMEN: CYLINDER	7 DAYS	14 DAYS	28 DAYS	TOTALS	STANDARD
Steel fibres at 0%	100mm Dia and 200mm high	3	3	3	9	ASTM C39
Steel fibres at 0.5%	100mm Dia and 200mm high	3	3	3	9	ASTM C39
Steel fibres at 1%	100mm Dia and 200mm high	3	3	3	9	ASTM C39
Steel fibres at 2%	100mm Dia and 200mm high	3	3	3	9	ASTM C39
TOTALS		**12**	**12**	**12**	**36**	

TABLE 3.2: TENSILE SPLITTING TEST STRENGTH

TEST PARAMETERS	SPECIMEN: CYLINDER	7 DAYS	14 DAYS	28 DAYS	TOTALS	STANDARD
Steel fibres at 0%	100mm Diameter and 200mm high	3	3	3	9	ASTM C496/496M-17
Steel fibres at 0.5%	100mm Diameter and 200mm high	3	3	3	9	ASTM C496/496M-17
Steel fibres at 1%	100mm Diameter and 200mm high	3	3	3	9	ASTM C496/496M-17
Steel fibres at 2%	100mm Diameter and 200mm high	3	3	3	9	ASTM C496/496M-17
TOTALS		**12**	**12**	**12**	**36**	

3.3 Target population

Population refers to a set of elements that a research focuses on, and to which the results of the study obtained by testing samples are generalized. The target population of the research project shall be the commonly used sands within Nairobi Metropolitan. In particular, the research targeted sands from Mwingi, Machakos, Kajiado, Naivasha and Mlolongo. Some of the extraction points for the sands for natural river sands are mapped as Mwingi (00^0 58' 4.36" S, 38^0 03' 35.66" E), Machakos (01^0 20' 29.4 "S, 37^0 26' 15.2" E) and Kajiado (02^0 02' 28.9" S, 37^0 06' 43.7" E), with rock sand being sourced from Mlolongo (01^0 23' 11.1" S, 36^0 50' 31.5" E). I elect to keep fine aggregate and coarse aggregates as constants otherwise, I will be forced to do 144cylinders or more if I use the four commonly used fine aggregates, incorporating crushed rock and quarry dust will take the cylinders to 216. In this study Kajiado river sand was used.

Table 3.3 shows the locations of fine aggregates sources in Nairobi.

Table 3.3 Sampling stations and their coordinates

Sample	Station location	Latitude	Longitude
Source 1	Mwingi sand	00^0 58' 4.36" S	38^0 03' 35.66" E
Source 2	Kajiado sand	02^0 02' 28.9" S	37^0 06' 43.7" E
Source 3	Mlolongo sand	01^0 23' 11.1" S	36^0 50' 31.5" E
Source 4	Machakos sand	01^0 20' 29.4" S	37^0 26' 15.2" E

3.3.1 Project planning

This section is aimed at defining the goals, determining an appropriate methodology, is geared towards establishing a realistic schedule and the resource requirements for the execution of the research project. The key study steps are covered in table 3.4 below. It covers tasks involved; specifically, the body of practices, procedures and rules for conducting the experimental research project. The detailed study procedure is discussed hereunder:

Table3.4: Project phases

PHASE	DESCRIPTION	DURATION
1	PROJECT PROBLEM AGREEMENT	14 DAYS
2	SPECIFICATION GENERATION	28 DAYS
3	INITIAL ASSESSMENT REPORT SUBMISSION	35 DAYS
4A	CONDUCT OF EXPERIMENT	33 DAYS
4B	DATA ANALYSIS AND PRESENTATION	14 DAYS
5	PARTIAL THESIS SUBMISSION	21 DAYS
6	FINAL THESIS SUBMISSION	14 DAYS

Below are the experimental tables set up for recording the results as detailed from table 3.5 to 3.8. The experiment was conducted from 11th July to 10th August 2020. Then thesis draft was sent out in mid-September with final thesis submitted on 15th October,2020.

Experimental test set up.			
Table 3.5: Test one 0% fibers (Plain concrete)			
No. specimens tested	After 7 days (MPa)	After 14 days (MPa)	After 28 days (MPa)
3No In each Case			
Results Compressive test			
Results for splitting tensile			

Table 3.6: Test two 0.5 % fibers (Fiber reinforced concrete)

No. specimens tested **3No In each Case**	After 7 days (MPa)	After 14 days (MPa)	After 28 days (MPa)
Results Compressive test Results splitting tensile			

Table 3.7: Test three 1.0 % fibers (Fiber reinforced concrete)

No. specimens tested **3No In each Case**	After 7 days (MPa)	After 14 days (MPa)	After 28 days (MPa)
Results Compressive test Results splitting tensile			

Table 3.8: Test four 2% fibers (Fiber reinforced concrete)

No. specimens tested **3No In each Case**	After 7 days (MPa)	After 14 days (MPa)	After 28 days (MPa)
Results Compressive test Results splitting tensile			

3.4 Quality assurance

To check or mitigate against errors and or inaccuracies; the following generally accepted practices were used:

(i) Concrete test procedures was carried out within established practices and in 7 days, 14 days and 28 days after casting.

(ii) Each measurement was based on at least three test specimens.

(iii) Concrete mixing was conducted in an established concrete lab within JKUAT

(iv) Testing was conducted using equipment and machines and in accordance with test manuals.

(v) Data analysis was done using accepted statistical and scientific methods.

3.5 Quantitative Analysis

3.5.1 Identification and Collection of Material

3.5.1.1 Cement

The cement used in the experiment was treated as a constant and purchased from Bamburi Cement. The cement was normal setting Portland Cement class 42.5, designated as CEM I (EAS-KS, 2001).

3.5.1.2 Coarse Aggregate

The coarse aggregate used in the experiment shall be purchased from Mlolongo quarry, which produces crushed aggregate. It is important to use coarse aggregate from one source for all the specimens to ensure there are no extraneous variations brought about in the experiment due to coarse aggregate. The aggregate was purchased from the same supplier in separate batches with maximum aggregate size of 10mm and 20mm in the ratio 1:2 in line with the requirements of the concrete mix design using the Department of Environment/ British method (D.O.E). The aggregate was checked for particle shape, size and cleanliness after which it was mixed accordingly.

3.5.1.3 Fine Aggregate

The fine aggregate shall be sourced from one of the six locations that popularly supply the Nairobi Metropolitan area. The exact coordinates of the quarry from which these fine aggregate shall be collected will be captured through Global Positioning System (GPS). This is to ensure that it is possible to describe the general geological and environmental phenomena occurring in the area, and the effect on the fine aggregate being sourced. The coarse aggregate source shall be kept constant and the geological composition of the material shall be described. For this experiment the fine aggregate is also kept as a constant and Kajiado river sand was used. Cost of a full tipper with 18 tonnes costs AU$ 500.00, Ballast of 14 tonnes costs AU$ 400.00 while a bag of cement costs AU$ 7.00/ 50kg bag. The steel fibres were imported at a cost of AU$ 1,000.00.

3.5.2 Storage of Material

3.5.2.1 Cement

The cement bags were kept in a space within the lab storage area at a clear raised dry place, stacked neatly (maximum of 10 bags) and stored on a raised platform. The bags were protected from puncture and great care taken to keep them free of moisture. The piles of cement shall be clear off the walls and adequate space was provided between individual piles to allow for easy access (about 1,000mm). PVC gauge 500 paper was used to cover the top of the cement stack to avoid moisture getting in.

3.5.2.2 Coarse Aggregate

The ballast was stored in the open but near the lab as guided because it doesn't suffer from the vagaries of the weather. Care was exercised to ensure the different maximum aggregate size heaps are not mixed to ensure consistency in the experiment, procedure and results achieved. For reliable results, the coarse aggregate shall be washed at least 24 hours before mixing and casting in order to remove any foreign material to achieve saturated surface dry (SSD) conditions. Below under figure 3.1 is an illustration on storage plans of the coarse aggregates that was used in the study.

Figure 3.1 Storage of coarse aggregates

3.5.2.3 Fine Aggregate

The different fine aggregates available in Nairobi are captured below, in the study Kajiado sand was used as per figure 3.2 below.

Figure 3.2 Some of the fine aggregates available in Nairobi.

3.6 Sampling for Testing

As per proper random sampling techniques; fine aggregates from the piles was done by taking approximately equal amounts from different points over the complete stock pile.

3.6.1 Material Testing

Cement was not to be subjected to testing since it is treated as a fixed variable to tests in this research as it is produced under controlled factory conditions, Bamburi Cement was used. However, a sample was sent to the State Department of Mining for material properties composition just for confirmation. Coarse aggregates was considered to be a standard since they are from a coarse aggregate manufacturer in Mlolongo, a cosmopolitan area in Nairobi which is common to all samples and it shall only be tested for aggregate crushing value to assess the strength. The variable in this study is a range of different doses of steel fibres percentage which are required to undergo testing.

3.6.3 Testing of Fine Aggregate

There are already done tests on fine aggregates in Kenya for the sand to be used. A simple confirmation along physical, chemical and material composition properties shall be done to compare with the recent study and results compared before the main experiment.

3.7 Concrete Mix design

The fine aggregate physical properties shall be used in the determination of the various proportions in the mix design. Generally the batch mixes shall be as per table 3.9 below. The key parameters taken into account shall be grade designation, type of cement, maximum nominal size of aggregate, maximum water-cement ratio, minimum cement content, slump test and steel fibre dosage. For this experiment a cement water ration of 0.5 shall be used. Target mix is 30MPa minimum.

These quantities included 50% extra material to accommodate for losses during mixing.

Table 3.9: Batch Quantities	
Material	Quantity (kg)
OPC (Bamburi 42.5)	14.74 kg
Water	7.37 kg
Fine Aggregate	26.22 kg
Course Aggregate	26.22 kg

Should there be an issue with workability then a super-plasticizer shall be considered.

3.7.1 Concrete batching, mixing and Placement

Weight batching was used to proportion the concrete mixes; concrete mix design ratios adopted for the production of concrete are generally accepted but not very accurate. Batching by weight is more accurate than batching by volume since weight batching avoids the problem created by bulking of damp sand and that is what will be used in the test.

The mixing was carried out following the guidelines prescribed in the design standards. The concrete volume for each cylindrical sample is estimated as follows:

Concrete volume; $\frac{0.1}{2} \times \frac{0.1}{2} \times \frac{0.20x22}{7} = 0.00157 + 50\%\% \, Shrinkage = 0.00471 \, m^3$. A total of 72 cylinders was manufactured and tested for universal compression and splitting tensile strength.

The concrete was poured into the moulds by hand using a shovel and care was taken to avoid dropping the concrete through a height of more than 0.5m or throwing across a distance sufficiently large to cause segregation. Compaction of the concrete was done with the use of a poker vibrator. Each mould was stored carefully to avoid mixing the cylinders and allow for marking after they harden. The cast cylinders were kept hydrated from the second day until all are tested but in separate plastic drums.

3.8 Steel Fibres

The steel fibers used in the study were ordered from Forcetech W.L.L limited, a company based in Bahrain. More details are included in chapter two about steel fibres used.

3.9 Curing of Concrete

For lack of a curing incubator, plastic drums were used to cure the concrete cylinders due to their relatively high capacity, durability and availability. From the market; the drums have dimensions of 880mm height and 570mm diameter. One drum was used to hold only one set of cylinders prepared from one type of steel fibre content, to prevent any accidental mixing and provide redundancy should the marking on the cubes become unclear. Four drums were used for this experiment. The concrete made from the samples was moist cured for 28 days.

Sample	S1	S2	S3	S4
C30/20				

Figure 3.3 Drums for curing of concrete cylinders

3.10 Concrete Testing

The concrete cylinders were tested for compressive strength using the universal testing machine (UTM) in the laboratory. To achieve reliability, three cylinders for each sample were crushed on the 7^{th}, 14^{th} and 28^{th} days and the mean of the values of strength from the three cylinders taken as the compressive strength for that particular batch. It has been established from studies that flexural strength approximates to 10% of compressive strength. The compressive strength of the concrete cylinders shall be tested in accordance to (BSI, 2009). The strength development curves for concrete with each type of steel fibre shall then be drawn. The validity of the compressive strength tests shall be checked using the already available values for the compressive strength measured at different intervals from relevant sources.

Figure 3-4 Compressive strength testing in the laboratory

3.11 Concrete strength prediction

Statistical modeling was used in the formulation of a strength prediction model utilizing inferential statistics. Multiple linear regression analysis was conducted on the data sets using MS-Excel. This method was used because of the flexibility and ability of formulating datasets that have more than one explanatory variable with one dependent variable whose values are continuous and or discrete. The dependent variable was concrete strength at different ages. The independent (explanatory) variables included quantities of steel fibers, fine aggregates, coarse aggregates, water and cement used in concrete production. Regression coefficients were obtained and checked against the minimum allowable confidence intervals to ascertain validity of the model.

3.12 Data Analysis

After recording experimental results appropriate analysis was done using descriptive and inferential statistics and later modelling.

3.12.1 Data Reliability and Validity

For reliability in this research, the results obtained were compared with established standards. A minimum of three samples was used to measure each parameter. The data collected was checked in terms of sufficiency, competence and relevance as per the Australian AS3600-2018 for concrete manufacture and testing.

Reliability in modelling was achieved by using sample strength results obtained from the concrete cast to formulate the model then validation of the finally developed model carried out using similar studies done elsewhere in related topics.

3.13 Range of steel fibre dosage for concrete SFRC

The second part of the experiment was to investigate influence of Steel Fibres on concrete properties at SF content of 0%, 0.5%, 1% and 2% on cylinders to calculate the splitting tensile test and shear. Each dosage rate included three tensile tests. A total of 36 cylinders was tested. Ductility was also evaluated.

Slump tests were conducted for each dosage batch in order to compare the concretes' workability. This experiment aimed to determine the optimum fibre dosage which will mostly improve the concrete's mechanical properties in addition to structural performance and economical use of steel reinforcement.

3.14 Mixing of Concrete Batches

3.14.1 Apparatus

The following apparatus were required for the mixing of the concrete batches.

- Mixer; rotating drum mixer,
- Appropriate bags
- Buckets for carrying measured materials
- Wheel Barrow to carry wet mix

3.14.2 The following procedures was adopted while mixing concrete:

- The materials were weighed in accordance to the mix proportions as designed.
- The water and the cement was added to the mixer first based on designed quantities.
- Steel fibres were then added according to dosage.
- The last materials to be added were fine and coarse aggregates in that order. This was done so that the fibres are spaced and bonded correctly with the concrete for a consistent homogenous mix.
- Once uniformity of mix was achieved the concrete was poured into wheel barrows ready for casting into labelled moulds.

3.15 Preparation of Specimens

3.15.1 Apparatus

The following apparatus were used in order to prepare the specimens:

- Cylindrical moulds/formwork (100mm diameter 200mm height) 72 number in total being for different fibre dosages; being 9 cylinders for plain concrete, same number for 0.5%, 1% and 2% repeated twice to cover compressive and tensile tests.
- Spade or appropriate scooper
- Porker vibrator
- Drums, four number for curing

- Concrete mixers; drum rotating type.

3.15.2 Preparation Process

The following procedure was adopted when it was time to cast the concrete samples:

- The green cast concrete were poured in the moulds in three equal layers. The samples were compacted using a porker vibrator.

- The cast concrete was placed on a vibrating table for at least 25 seconds to ensure that all air voids are removed from the concrete. Appropriate measures were undertaken to ensure no spillages take place.

- The formwork was removed not less than 24 hours after casting and specimens cured continuously for a total of 28 days. For this to happen well, all cylinders were kept in drums, separate from each other, a total of 4 number to hold labelled different fibre levels samples.

- The compressive samples were left in the mould to allow the concrete to be placed.

    - Water and concrete were mixed in mixers until workable.

    - The top surface of the sample were kept clean to ensure a good bond.

    - Once the wet concrete was levelled on the side, a dump sack was placed on top to ensure no accelerated moisture loss overnight until the following day.

    - The formwork was removed and the samples placed in the plastic drums filled with water and left in place for curing until 28 days were over for final tests. Samples for crushing at 7 days and 14 days were picked from the drums and the last samples were picked at the end of 28 days for crushing.

3.16 Slump Test

The cast concrete was subjected to slump tests in accordance to AS1012.3.1 2014. Slump tests were conducted on all the four batches of concrete mixed in order to evaluate the workability of the fresh mix. The slump test measures the consistency of concrete in a specific batch. Concrete workability refers to how easily the concrete is placed, also it gives a measure of the batches' strength and durability. Factors affecting workability include water content, aggregate grading, particle shape and size which must be checked. If a low slump test obtains it can be assumed that the batch tested has a stiff consistency. An excessive wet mix may however, have issues such as fluid segregation and honeycombing arising out of a fluid concrete. Despite various improvements in the mechanical properties of hardened concrete, the use of fibre reduces the fluidity of the material, which can cause negative impacts on the workability of the concrete but this may be corrected with a super-plasticizer. Factors affecting workability must be taken into consideration when conducting the slump test, however if the fibres within the mix are correctly portioned the FRC will compact easily with the use of vibration. Another use for the data obtained from the slump test will be to compare the effects of the dosage rates on the consistency of the mix. So that there are no mixing issues a super-plasticizer shall be used to improve the mixing and workability of the concrete.

3.16.1 Apparatus

The following apparatus were used to conduct a slump test:

- A Mould – hollow cone with a bottom diameter of 200 with a deviation of 5mm either way, top diameter of 100mm with a deviation of 5mm either way and a vertical height of 300mm also with a deviation of 5mm either way.
- Rod – metal rod of 16 mm in diameter and length of 600mm, one end must be tapered for a distance of 25mm to a spherical shape having a radius of about 5mm
- Conical collar – to facilitate filling the mould
- Spade or something to use in scooping
- Baseplate
- Ruler for measurement.

3.16.2 Test procedure

The following procedure shall be adopted to conduct the slump tests:

- The formwork (mould) was internally cleaned and moistened with a damp cloth preferably a towel before each test.

- The mould was placed on the baseplate and held in place by standing on the foot plates.
- The mould shall be filled in three evenly placed layers.
- Each layer was rodded with 25 evenly distributed strokes of the rounded end of the rod.
- On the third layer the concrete was heaped above the top of the cone after rodding the final level and more concrete was added/removed so that the concrete is maintained level with the mould.
- The mould was removed by vertically raising it slowly and carefully
- Immediately the slump was measured through calculating the difference between the height of the mould and the average height of the top surface of concrete.

3.17 Compressive Strength Test

The compressive strength of concrete is the most common performance measure used by engineers. Compressive strength is the concrete ability to resist compressive loading and since concrete is designed to withstand compressive loads, compressive strength is determined as the most important property of concrete. The compressive test that shall be conducted to determine the effect of steel fibres on the concrete and how reinforcing fibres might improve these characteristics.

The procedure set out by ASTM C39 (2015) was adopted to conduct the compression tests. ASTM C39 is the standard test procedure for conducting compression tests on cylindrical samples. This test applies a compressive axial load to the concrete cylinders at a determined rate until the sample fails and calculations are then made to determine the compressive strength (MPa) of the sample (Load/cross-section area). Compressive tests will be conducted in the engineering laboratory of Jomo Kenyatta University of agriculture and technology.

3.17.1 Test Setup

This test consists of hydraulic loading machine. There was a rubber capping on each of the samples to be tested.

3.11.2 Test Procedure

The following procedure is outline in ASTM C39 (2015).

1. The specimens were tested immediately after removal from the curing drums as discussed above.
2. The specimens were kept free of moisture prior to testing
3. The mass of each specimen was measured and recorded
4. The lower bearing plate was placed on the plate of the testing machine directly under the upper spherical bearing block.
5. The axis of the specimen was aligned with the centre of thrust of the spherically seated block.
6. The load indicator for readings must be at zero prior to commencing the test.
7. The load was applied without shock at a rate corresponding to a stress rate on the sample of 0.5MPa/s
8. The load was applied until the load indicator shows that the load is decreasing steadily and the specimen displays a well-defined fracture pattern.

3.18 Procedure of Splitting Tensile Test

- I took the wet specimen from water after 7,14 and 28 days of curing to measure tensile strength.
- I ensured all the water on surfaces is wiped out from the test specimen
- Then I drew diametrical lines on the two ends of the specimen to ensure that they are on the same axial plane.
- I then recorded the weight and dimension of the specimen.
- After that I set the compression testing machine for the required range.
- Then I placed plywood strip on the lower plate and place the specimen.
- I ensured I align the specimen so that the lines marked on the ends are vertical and centered over the bottom plate.
- Then I placed the other plywood strip above the specimen.

- I brought down the upper plate so that it just touched the plywood strip.
- I conducted the test by applying the load continuously without shock at a rate within the range 0.7 to 1.4 MPa/min.
- Finally, I recorded the breaking load (P)

3.19 Risk assessment

Like in all other engineering projects; the research project has some element of risk which must be discussed. The risk mainly implies the potential threat to personal or public safety and requires a risk management plan. Risk management is very crucial not only for me as a student but for other people and Jomo Kenyatta University of Agriculture and technology premises. So the major consideration here is the emphasis on proper duty of care by each and every individual in the workplace myself included.

In my risk assessment preparation I have considered the risks during execution of the research project and what happens immediately after. Risks do occur due to existence of hazards which can be defined as sources of physical harm. In the research project machines and equipment shall be used and safety considerations in terms of operation and use are key. So risk is the likelihood of harm occurring following presence of hazards.

Risk types in the project

There are two identified types of risks duration the duration of the project. The two risks include personal risk with varying degrees during the duration of the project and secondly project risk occurring during the different phases of the project resulting in incomplete project due to various reasons.

3.19.1 Personal risk

The project was done within the established milestones as done in the project specification, namely Problem identification, specification generation, initial assessment report submission, partial thesis submission and final thesis submission.

The following are the potential risk sources:

1.0 Covid-19 issues:

To mitigate against this requires observing government directives. The experiment was initially to be carried out at USQ- Toowoomba campus; then air travel ban happened so an alternative had to be sought out. In this regard the experiment was conducted at Jomo Kenyatta University of Agriculture and Technology. Social distancing, washing of hands, use of sanitizers and wearing of masks throughout the experiment time and while in public places and the laboratory was observed.

2.0 Fatigue to the eyes due to long hours working using the computer; the mitigation measure is 15 minutes break after every two hours during the times that I will be using the computer continuously.

I have discussed the risk in the research project following possibility of occurrence as follows:

Extremely slight (not likely to occur)

Very slight (there is some minute possibility of occurring)

Slight (Slim chances of occurring)

Significant (May occur)

Substantial (most likely to occur)

Sources of risk include the following

1.0 Personal sources of risks

2.0 Lab environment risks sources.

3.0 Adverse weather risks sources

4.0 Materials handling risks sources

The risk level and minimization have been discussed under table 3.11 below:

3.19.2 Then the significance of its occurrence:

Here the exposure levels and consequences are considered. Exposure: exposure levels are measured based on very rarely, rarely, occasionally, regularly, frequently and continuously. Consequences are measured using minor (minor destruction of equipment), moderate (major destruction of equipment), minor injuries or illnesses, major injuries or illnesses and fatal where there is a possibility of death. Table 3.11 below represents the risk likelihood and consequences as a risk legend.

I followed the risk mitigation measures namely; risk identification, risk evaluation and risk control.

Table 3.11 : Likelihood and consequence matrix for personal risk					
(Risk legend)					
Risk likelihood	**Consequences**				
	A. Insignificant	**B. Minor**	**C. Moderate**	**D. Major**	**E. Critical**
1.0 Most likely	Medium	Medium	High	Extreme	Extreme
2.0 Likely	Low	Medium	High	High	Extreme
3.0 Possible	Low	Medium	High	High	High
4.0 Slightly likely	Low	Low	Medium	Medium	High
5.0 Very rare.	Low	Low	Low	Low	Medium

Based on risk matrix and definition legend under table 3.11 above, the potential risks levels and minimization measures are discussed under table 3.12 below.

TABLE 3.12 : ANTICIPATED PERSONAL RISK AND MITIGATION MEASURES			
RISK LEVEL	**PHASE**	**HAZARD**	**MINIMIZATION/MITIGATION MEASURES**
Medium, B2	4A	Due to vagaries of the weather from heat and rain	1. Keeping test specimens protected.
			2.0 Wash of coarse aggregates to remove any unwanted materials.
			3.0 Work during good weather.
Medium, C4	4A	Dust, flying objects and pricking risk, dropping of some materials.	1.0 Use personal protective equipment such as thick gloves, wearing protective masks, steel capped boots.
			2.0 Observing lab rules and regulations
			3.0 Working with lab technicians.
			4.0 Wear of protective glasses.
High, C3	4A	Fine particles inhalation.	Wear protective masks.
Medium, D4	4A	Laboratory environment testing.	1.0 Wearing PPE as per laboratory requirements.
			2.0 Do laboratory induction
			3.0 Follow procedures and I shall not operate equipment alone.
Medium, E4	4A & 4B	Working posture and body strain	To ensure safety postures and good working procedures are adopted.

3.20 Risk assessment and ethics

Since this is a localized project and it shall be done within university premises together with lab technicians, a research permit was not necessary. A letter authorizing me to use the laboratory was deemed sufficient from the university where the experiment was conducted. Below under table 3.13 project risks and minimization measures are discussed. Those experiments are deemed to be within normal lab work that is done in the university while training students.

Table 3.13: Anticipated project risks and minimization			
Phase	**Hazard**	**Risk**	**Minimization**
4A	Unable to obtain steel fibers due to unforeseen events.	High	Adopt and implement a contingency plan for alternative fibers in lieu of steel fibres
			Contact several suppliers with a view of importing.
4A	Injuries due to falling or flying objects	Medium	1.0 Use of appropriate PPE
			2.0 Observing laboratory rules.
			3.0 Working with technicians
4A & 4B	Unable to access USQ laboratory equipment	High	Arrangements with another university laboratory to undertake experiments.
3,4,5&6	Unable to complete experiments as a result of lack of resources.	Low	Make alternative contingency plans.
			Adequate resource mobilization in advance.
3 TO 6	Loss of data records or dissertation due to extraneous events	High	Ensure a well maintained back up is in place in the house.

3.21 Resource analysis

The research project required resources like fine aggregates, coarse aggregates, cement, steel fibres and tools for conducting the experiment. The rest are research equipment and lab materials which were procured from out. Table 3.14 below represents the evaluation of different resources used in the project.

In terms of resources the tabulated analysis is as under table below:

	Table 3.14: Evaluation of resource constraints				
Item	**Description**	**Fine aggregates**	**Coarse aggregates**	**Cement**	**Steel fibres**
1	Materials sources identification.	Identified.	Identified.	Identified.	Imported.
2	Availability assurance.	Yes	Yes	Yes	Yes
3	Direct cash costs involved.	Yes as discussed below.	Yes as discussed below.	Yes as discussed below.	Yes as discussed below.
4	Is the budget manageable/ acceptable?	Yes	Yes	Yes	Yes
5	Availability of necessary funds.	Yes	Yes	Yes	Yes
6	Purchasing arrangements.	Arranged	Arranged	Arranged	Arranged
7	Ex stock or likely delays.	No.	No.	No.	Yes, but alternative fiber can be used with the approval of supervisor.
8	Alternative suppliers if delivery problems are encountered.	Yes	Yes	Yes	Yes, alternative fiber can be used.

Steel fibres are not available and may threaten the viability of the whole project; arrangements were put in place to receive a consignment from Bahrain. The supplier supplied via DHL within days. The above supplier was arrived at after several false starts in form of false online suppliers and also a very slow response from others. As a mitigation measure an alternative fibre had been sought just in case but the concurrence of the supervisor had not been secured. I am lucky I did get these suppliers. The other materials are readily available.

3.22 Safety

Whilst conducting this study there are a few safety precautions that must be taken:

- Breathing mask when handling materials such as cement and fine sand
- Rubber gloves during casting
- Thick gloves when handling cured samples
- Safety glasses during testing

3.23 MATERIALS

This section discusses the material properties and tests carried out in the initial stages prior to the experiment, the material properties were critical for determining the design mix to be used in the experiment.

3.24 Tests done on cement

Bamburi 42.5 power plus cement was used in the study as part of the concrete mixed material. It usually has the manufacturer's broad brochure which describes contents. But to be sure a sample was sent to the government in the state department of mining for analysis. The test result is as per attached appendix at the end of this thesis. The percentage chemical composition is as per the attached table 3.15 below:

Table 3.15 Cement chemical test results

Composition	**SiO_2**	**AlO_3**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**TiO_2**	**MnO**	**Fe_2O_3**	**LOI**
Cement 42.5 Power Plus	16.33	4.18	39.56	ND	0.10	0.23	0.20	0.01	2.68	33.80

The test results are in percentage unless indicated

3.25 Material properties for fine aggregates (sand)

The tests done for fine aggregates were in two parts, chemical properties and physical properties, for physical properties I did them in JKUAT concrete laboratory and for chemical properties, it was done in the government ministry of mining laboratory because that was not available in JKUAT laboratory. I will present the chemical test results first then the physical test results. Table 3.16 shows the chemical composition of chemicals in percentages as tested.

3.25.1 Chemical properties for sand

Table 3.16 Sand chemical test results (Fine Aggregate)

Composition	**SiO_2**	**AlO_3**	**CaO**	**MgO**	**Na_2O**	**K_2O**	**TiO_2**	**MnO**	**Fe_2O_3**	**LOI**
Sand	69.50	14.00	3.38	ND	0.80	1.02	1.00	0.14	4.25	3.46

The test results are in percentage unless indicated

3.26 Testing for fine aggregates physical properties

The following investigations were carried out for physical properties of sand:

(1) Sieve analysis
(2) Specific gravity
(3) Silt content
(4) Moisture content

3.26.1 Sieve analysis

Sample of 2000g was used to carry out fine aggregate sieve analysis the test results are presented using the following two tables as presented under table 3.17 and table 3.18 below:

Table 3.17 : Sieve Analysis

Sieve No	Sieve Wgt (g)	Sieve + Material	Retained material	%age passing
10	822.5	822.5	0	100.00
5	838.5	855	16.5	99.17
2.36	810.5	902	91.5	94.60
1.2	784	1381.5	597.5	64.71
0.6	758	1225	467	41.35
0.3	709	1289.5	580.5	12.31
0.18	703.5	886.5	183	3.15
Pan	719	782	63	-
			1999	

Table 3.18: Sieve analysis for fine aggregate second test

Sieve No	Sieve Wgt (g)	Sieve + Material	Retained material	%age passing
10	822.5	827	4.5	99.77
5	838.5	859.5	21	98.72
2.36	810.5	902	91.5	94.15
1.2	784	1320	536	67.34
0.6	758	1242	484	43.14
0.3	709	1367.5	658.5	10.20
0.18	703.5	858	154.5	2.48
Pan	719	768.5	49.5	-
			1999.5	

3.26.2 Specific gravity for fine aggregates

Pycnometer was used for fine aggregate specific gravity testing.

The samples were washed, then soaked for 24 hours.

The sample was surface dried and later oven dried for 24 hours after being saturated. All air bubbles were removed. The results are as per table 3.19 below.

Table 3.19 Specific gravity of Sand

Item	Sample 1	Sample 2	Sample 3
Weight of Pycnometer (A)	670	670	670
Pycnometer + Sand (B)	1170	1170	1170
Pycnometer + Sand + Water (C)	1840	1843	1842
Pycnometer + Water (D)	1532.5	1532.5	1532.5
Specific gravity values (A-B/ (D-A)- (C-B)	2.60	2.64	2.62

Average **2.62**

3.26.3 Water absorption was calculated as per table 3.20 below.

Table 3.20 Water absorption calculation for fine sand

Description	Sample 1 (g)	Sample 2 (g)	Sample 3 (g)
Weight of saturated surface dry sample W1(g)	500	500	500
Weight of oven dry sample W2 (g)	480.5	481	483
Water absorption (W1-W2)/W2	4.06%	3.95%	3.52%

Average **3.84%**

3.26.4 Silt content determination in fine aggregate

10 grams of salt was mixed in 1000ml potable water and sand mixed in. Silt content was measured the following day. Water in cylinders were mixed to roughly 250ml in each cylinder. Tabulated under 3.21 below are the results:

Table 3.21 Silt content calculation

Description	Sample 1 (mm)	Sample 2 (mm)	Sample 3 (mm)
The whole fine aggregate level L1	134	155	163
Good sand level L2	129	149.5	157
Silt content in percentage (L1-L2)/L1	3.73%	3.55%	3.68%

Average **3.65%**

3.27 Coarse aggregates

For coarse aggregates a number of investigations on material properties were done as follows:

(i) Sieve analysis
(ii) Aggregate crushing value
(iii) Flakiness index
(iv) Specific gravity
(v) Aggregate impact value
(vi) Water absorption

3.27.1 Sieve analysis

Table 3.22 and 3.23 show results from sieve analysis

Table 3.22 Sieve analysis for coarse aggregates

Sieve No	Sieve Wgt (g)	Sieve + Material	Retained material	%age passing
37	928.5	928.5	0	100.00
31	1003.5	1003.5	0	100.00
25	1097.5	1097.5	467.5	76.62
20	985	1007	738.5	39.68
14	1085	2291.5	623.5	8.50
10	822.5	1462	151	0.95
5	838.5	963.5	15	0.20
2.36	810.5	811.5	0.5	0.18
Pan	719	724.5	3.5	-
			1999.5	

Table 3.23 Coarse aggregate sieve analysis

Sieve No	Sieve Wgt (g)	Sieve + Material	Retained material (g)	%age passing
37	928.5	928.5	0	100.00
31	1003.5	1003.5	0	100.00
25	1097.5	1097.5	0	100.00
20	985	1007	22	98.90
14	1085	2291.5	1206.5	38.56
10	822.5	1462	639.5	6.58
5	838.5	963.5	125	0.33
2.36	810.5	811.5	1	0.28
Pan	719	724.5	5.5	-
			1999.5	

3.27.2 Aggregate Crushing Value

This test is performed to determine a relative measure of how an aggregate resists crushing under gradually applied load. It is better to obtain or have aggregate with a lower crushed fracture under load for a longer service performance. The tabulated results are in table 3.24 below.

The materials were filled in three equal layers into the cone each layer receiving 25 blows. The weight of tamping load was 1320grams, diameter of 20mms and height of 650mm.

How the procedure was done:

(i) First the cone was weighed.

(ii) Then cone with material.

(iii) Then material passing 14mm sieve but retained by 10mm sieve was crushed to 400kN in a period of 10mins.

(iv) The material was then carefully put through the 2.36 sieve.

(v) Weight of material passing and pan were measured and net weight of material in pan calculated.

(vi) That was done for three samples and mean aggregate crushing values calculated as shown in the table below

Table 3.24 Aggregate Crushing Value determination

Parameter	Sample 1	Sample 2	Sample 3
Total weight of dry sample taken w1g	2314.5	2383.5	2358.5
Weight of portion passing 2.36mm sieve = w2g	478.5	480	489
Aggregate crushing value w2/w1*100%	20.67%	20.14%	20.73%
Mean aggregate crushing value	20.52%		

The aggregate used had a mean crushing value of 20.52% which is not bad.

3.27.3 Flakiness index

This determines the aggregate roundness and shape. The test was carried out by counting 200 particles, randomly sampled from a sample of 2000g. The result is under table 3.25 below.

Procedure

1.0 We took a sample of 2kilograms and sieved it through the various sieves.

2.0 Then picked 200 pieces randomly

3.0 Checked for the samples elongated samples that passed through the various gauges.

4.0 The width appropriate slot would be 0.6 times the average range of sizes.

5.0 The flaky materials were added and weighed.

6.0 This weight is then dived by the total weight of sample and ratio expressed in percentages.

Table 3.25 Flakiness Index

Total weight of sample is 2000g

Passing through IS Sieves	Retained on IS Sieves	Thickness gauge	Weight passing on thickness gauge 1	Weight passing on thickness gauge 2	Weight passing on thickness gauge 3	Average
25mm	20mm	13.5	28	10.5	20	19.5
20mm	16mm	10.8	21	29.5	19	23.16667
16mm	12.5mm	8.55	71.5	44	39	51.5
12.5mm	10mm	6.75	55.5	115.5	123	98
10mm	6.3mm	4.89	25.5	55.5	17	32.66667
		Total	201.5	255	218	224.8333

Flakiness index **11.24%**

3.27.4 Aggregate Impact Value

This property determines the toughness of a material. For coarse aggregate I investigated this property. Impact value is a measure of resistance to gradually applied compressive load. A machine called Mami from Japan is installed in the laboratory and was used for testing. Materials were filled in three layers each layer receiving 15 blows of the rod. The following table 3.26 shows the results.

Table 3.26 Aggregate Impact test for aggregate

Description	Test 1	Test 2	Test 3
Weight of sample (W1)g	546.5	544	548
Weight of retained on 2.36mm sieve (W2)g	499.5	506.5	507
Weight of fraction passing through 2.36mm sieve (W3)= (W1-W2) g	47	37.5	41
Aggregate Impact Value (W3/W1)*100	8.60%	6.89%	7.48%
Average	**7.66%**		

The lower the values the better, we obtained an average value of 7.66%.

3.27.5 Moisture absorption content
Moisture absorption was calculated as per table 3.27 below.

Table 3.27 Water absorption calculation for coarse aggregate

Description	Sample 1 (g)	Sample 2 (g)	Sample 3 (g)
Weight of saturated surface dry sample W1(g)	2000	2000	2000
Weight of oven dry sample W2 (g)	1900	1932	1939.5
Water absorption (W1-W2)/W2	5.26%	3.52%	3.12%

Average **3.97%**

3.27.6 Specific gravity

Specific gravity was calculated from three samples as per tabulated results under table 3.28 below.

Table 3.28 Specific gravity for coarse aggregates

		Observed values in g and numbers		
Item	Description	Sample 1	Sample 2	Sample 3
1	Weight of saturated aggregate and bucket in water W1g	1577	1571.5	1578.5
2	Weight of bucket in water W2g	387	390.5	390.5
3	Weight of saturated aggregate in air W3g	2000	2000	2000
4	Weight of oven dry aggregates in air W4g	1900	1932	1939.5
5	Apparent specific gravity W4/((W4-(W1-W2))	2.676	2.573	2.58
6	Bulk specific gravity W4/ ((W3-(W1-W2))	2.346	2.358	2.388
	Average specific gravity	**2.610**		

3.28 Summary

The chapter has outlined the materials and testing methods that will be used for conducting study. This study includes 2 parallel stages of experimentation;

- Testing of 36 cylinders for compressive strength
- Testing of 36 cylinders for splitting tensile strength
- Materials used in the study are presented with their properties

All testing was conducted with reference to all the relevant standards.

CHAPTER FOUR: RESULTS AND OBSREVATIONS

4.0 Introduction

In this chapter results and observations from experimental studies are discussed. The section begins with the tensile and compressive tests. Behaviour of plain concrete followed by 0.5% fibre reinforced concrete, 1% and finally 2% steel fibre reinforced concrete. The cylinders exhibited different failure modes with plain concrete having brittle single cracks while 2% had several cracks in the tested specimens. The failure was sudden in plain concrete specimens while it was gradual in the steel fibre reinforced specimens. Figure 4.1 shows some of the crushed cylinders with steel fibre reinforcement from 0.5%, 1% and 2%. Below we have figures 4.2(a) to (d) showing cracks and failure patterns for compressive specimens while figure 4.3 (a) to (d) shows the failure patterns for splitting tensile as tested.

Figure 4.1 some of the tested specimens showing failure behaviour

(a) 0.5% steel fibres

(b) 0 % steel fibres

(c) 1% steel fibres

(d) 2% steel fibres

Fig 4.2 Compressive testing for all four types of specimens

(a) 0% steel fibres

(b) 0.5% steel fibres

(c) 1% steel fibres

(d) 2% steel fibres

Figure 4.3 Splitting tensile testing for all specimens

4.1 Specimens with 0% steel fibres

Table 4.1 below shows the results of specimens with 0% steel fibres, strength increased with age in both cases of compression and splitting tensile. Figure 4.4 gives a better illustration using line graphs for the two strength parameters as shown below.

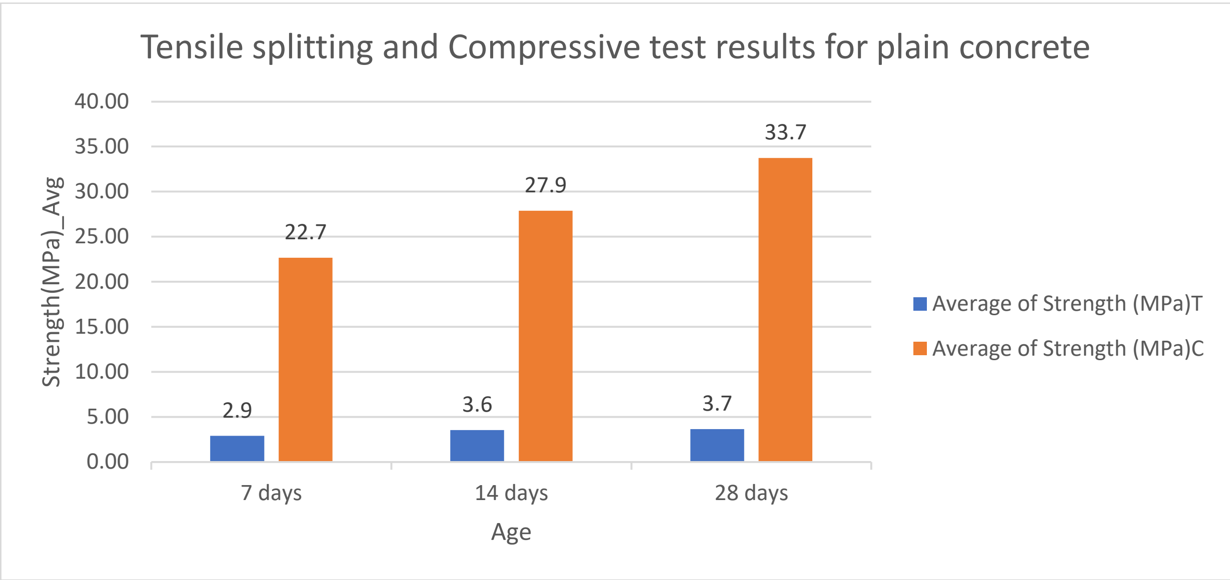

Figure 4.4 Compressive and splitting tensile strengths failure behaviour at 0% steel fibres

4.1.1 Compressive strength and failure behaviour

Table 4.1 below shows the test results from compressive testing. The results show gain in strength with age for all specimens tested. In each case three specimens were crushed at 7, 14 and 28 days. There is noted closer observations with little variability for 7 and 14 days. At 28 days the crushed cylinders showed a greater variability with observed values ranging from 32.0 to 34.2MPa. The results exhibit a linear function and this will help later in modelling. The test failure mode showed failure in terms of broken particles as shown in figure 4.2 (b) above.

Table 4.1: Compressive test results for plain concrete
Tested specimens: Cylinders of size 100mm diameter and 200mm high.

Date cast	Age	Number	Mass (g)	%age fibres	Maximum load (kN)	Strength (MPa)
9/8/2020	7 days	C/0/4	3685	0%	179.0	22.8
9/8/2020	7 days	C/0/5	3658	0%	178.8	22.8
9/8/2020	7 days	C/0/6	3628	0%	176.5	22.5
AVERAGE			**3657**		**178.1**	**22.7**
9/8/2020	14 days	C/0/7	3690	0%	215.4	27.4
9/8/2020	14 days	C/0/8	3651	0%	221.0	28.1
9/8/2020	14 days	C/0/9	3693	0%	220.6	28.1
AVERAGE			**3678**		**219.0**	**27.9**
9/8/2020	28 days	C/0/16	3677	0%	268.6	34.2
9/8/2020	28 days	C/0/17	3692	0%	275.5	35.1
9/8/2020	28 days	C/0/18	3623	0%	250.9	32.0
AVERAGE			**3664**		**265.0**	**33.7**

4.1.2 Splitting tensile strength and failure behaviour

For plain concrete the failure behaviour was more sudden with neat cracks and some specimens split into two after testing. The failure was also sudden. From figure 4.3 (a) it shows how the tested specimens looked like at failure. The achieved strength grew with age but with small values as shown in figure 4.4 above. It exhibits a linear function after plotting using the averages of strength gained. Table 4.2 below shows the average of 2.9 Mpa at 7 days to 3.7 MPa. Although this shows gain in strength the overall gain is less than 1.0MPa at 28 days, actual strength gain being 0.8MPa. There is also noted big variability at the beginning with specimens tested at 7 days, a closer result at 14 days while there is a big variability at 28 days. There is minimal strength gain from 14 days to 28 days.

Table 4.2 Splitting tensile test results for plain concrete
Tested specimens: Cylinders of size 100mm diameter and 200mm high.

Date cast	Age	Number	Mass (g)	%age fibres	Maximum load (kN)	Strength (MPa)
9/8/2020	7 days	C/0/1	3694	0%	77.0	2.5
9/8/2020	7 days	C/0/2	3688	0%	92.7	3.0
9/8/2020	7 days	C/0/3	3693	0%	102.8	3.3
AVERAGE			**3692**		**90.8**	**2.9**
9/8/2020	14 days	C/0/10	3670	0%	111.8	3.6
9/8/2020	14 days	C/0/11	3660	0%	110.0	3.5
9/8/2020	14 days	C/0/12	3668	0%	112.7	3.6
AVERAGE			**3666**		**111.5**	**3.6**
9/8/2020	28 days	C/0/13	3692	0%	107.0	3.4
9/8/2020	28 days	C/0/14	3691	0%	116.2	3.7
9/8/2020	28 days	C/0/15	3683	0%	121.4	3.9
AVERAGE			**3689**		**114.9**	**3.7**

4.2 Specimens with 0.5% steel fibres

Specimens with 0.5% showed slight improvement in gained strength over time as compared to plain concrete specimens (control). Again, they did not exhibit neat failure cracks instead the cracks were spread out for compressive strength while for splitting tensile the specimens showed more cracks but did not break off completely. Below in figure 4.5 we have the results showing the trends for compressive and splitting tensile strength behaviour over time in days.

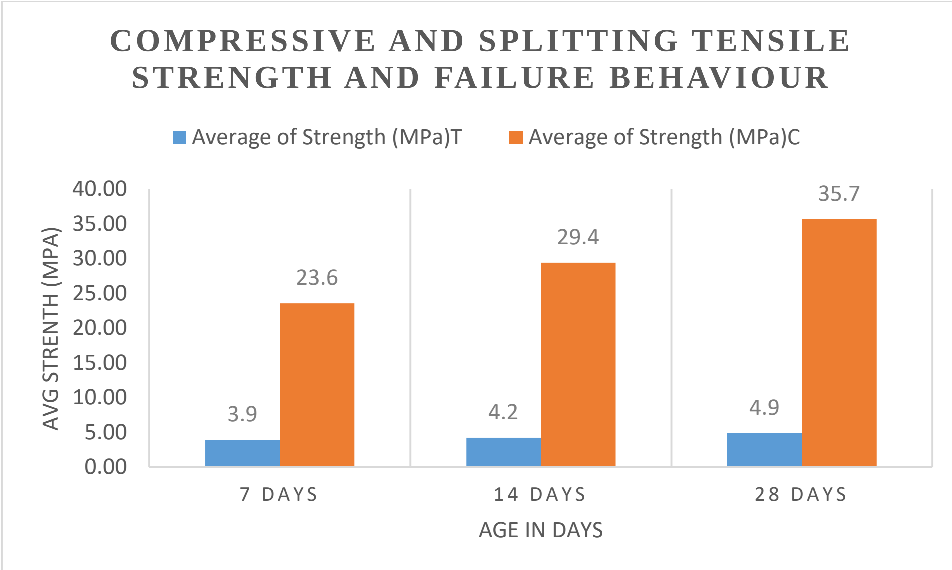

Figure 4.5: strength and failure pattern of 0.5% steel fibre reinforced concrete

4.2.1 Compressive strength and failure behaviour

Compressive testing behaviour for 0.5% steel fibre dosage is captured in figure 4.3 (a) above and table 4.3 below. In terms of physical look the crushed specimens showed more failure cracks as opposed to plain concrete but fewer than those of 1% steel fibres perhaps due to residual strength derived from the incorporated fibres. The strength gained increased with age as plotted in figure 4.7 above. Unlike in plain concrete there is a slightly higher variability in the tested specimens at all the three testing intervals as shown in table 4.3 below. The variability can be attributed to how the fibres spread out in the mixed concrete thereby affecting the expected consistency in the study results. However, the test results exhibit some linear function and the modelling can be tried using a linear function later.

Table 4.3: Compressive test results for 0.5%steel fibre reinforced concrete
Tested specimens: Cylinders of size 100mm diameter and 200mm high.

Date cast	Age	Number	Mass	%age fibres	Maximum load (kN)	Strength (MPa)
10/8/2020	7 days	S/0.5/07	3779	0.50%	180.0	22.9
10/8/2020	7 days	S/0.5/15	3761	0.50%	185.7	23.6
10/8/2020	7 days	S/0.5/13	3790	0.50%	189.5	24.1
AVERAGE			**3777**		**185.1**	**23.5**
10/8/2020	14 days	S/0.5/03	3820	0.50%	226.1	28.8
10/8/2020	14 days	S/0.5/02	3747	0.50%	237.4	30.2
10/8/2020	14 days	S/0.5/09	3775	0.50%	229.2	29.2
AVERAGE			**3781**		**230.9**	**29.4**
10/8/2020	28 days	S/0.5/05	3755	0.50%	274.6	35.0
10/8/2020	28 days	S/0.5/11	3764	0.50%	281.3	35.8
10/8/2020	28 days	S/0.5/10	3651	0.50%	284.5	36.2
AVERAGE			**3723**		**280.1**	**35.7**

4.2.2 Splitting tensile strength and failure behaviour

From the empirical study the splitting tensile strength for specimens with 0.5% steel fibre content also show a gain in strength over time but the overall strength gained from 7 days to 28 days is 1.0MPa. This may look insignificant but translating these figures to percentages may make the overall behaviour more robust and it can be noted that the gain in strength is highly significant at 25.6%. The crushed specimens also show a linear function behaviour. The tested specimens show more cracks from figure 4.3 (c). There is a bit of variability in test results at all the three levels and the average results are used to plot the trends. Table 4.4 presents the test results as hereunder.

Table 4.4: Splitting test results for 0.5% fibre reinforced concrete
Tested specimens: Cylinders of size 100mm diameter and 200mm high.

Date cast	Age	Number	Mass (g)	%age fibres	Maximum load (kN)	Strength (MPa)
10/8/2020	7 days	S/0.5/01	3754	0.50%	120.1	3.8
10/8/2020	7 days	S/0.5/12	3768	0.50%	125.3	4.0
10/8/2020	7 days	S/0.5/14	3753	0.50%	121.8	3.9
AVERAGE			**3758**		**122.4**	**3.9**
10/8/2020	14 days	S/0.5/04	3770	0.50%	132.4	4.2
10/8/2020	14 days	S/0.5/11	3760	0.50%	128.7	4.1
10/8/2020	14 days	S/0.5/06	3768	0.50%	137.3	4.4
AVERAGE			**3766**		**132.8**	**4.2**
10/8/2020	28 days	S/0.5/16	3792	0.50%	148.2	4.7
10/8/2020	28 days	S/0.5/17	3781	0.50%	152.2	4.8
10/8/2020	28 days	S/0.5/18	3773	0.50%	156.5	5.0
AVERAGE			**3782**		**152.3**	**4.8**

4.3 Specimens with 1.0% steel fibres

The specimens with 1.0% steel fibres had higher strengths when compared with plain concrete as well. They too showed a trend of increase in strength with age although the growth rate was not uniform. As for tensile strength they showed same trend but the overall gained strength was more than 1.0MPa from age 7 to 28 days as per figure 4.6 below. The overall gained strength is 14.4 MPa for compressive strength and 1.7MPa for splitting tensile. These translate to 56% and 40% respectively. Figure 4.2 (c) and 4.3 (c) above show that in both cases the failure cracks are more than those of plain concrete and 0.5% steel fibre reinforced concrete but less than those of 2% as per the tested specimens.

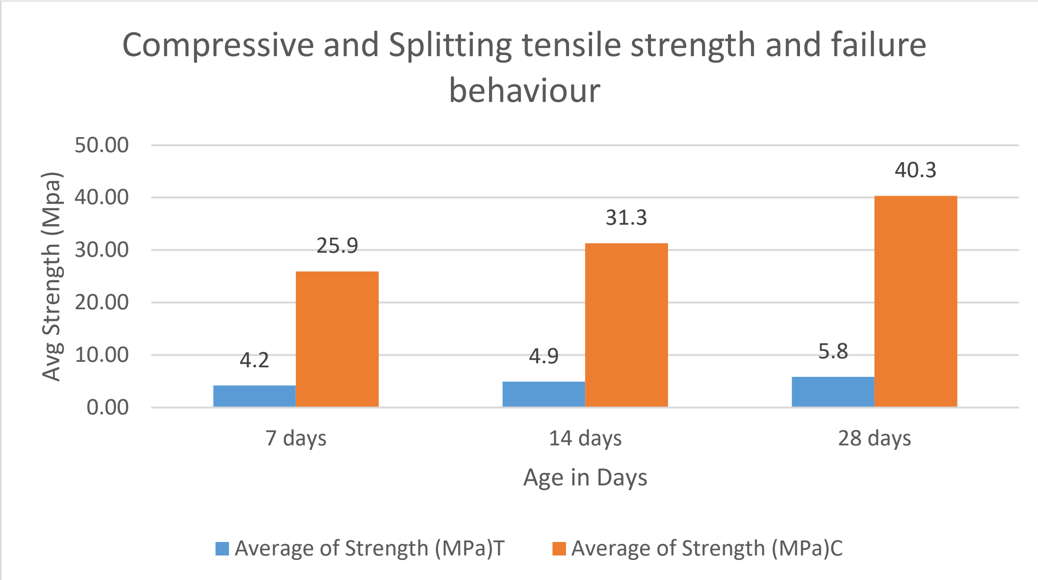

Figure 4.6 Compressive and splitting tensile strength and failure behaviour at 1% steel fibres

4.3.1 Compressive strength and failure behaviour

For 1% steel fibre reinforced concrete, compressive strengths were higher than those of plain concrete and 0.5% steel fibre reinforced concrete. It also showed an increasing trend with age. There was also variability in the tested specimens as per table 4.5 below requiring that the average result be used in modelling and discussion later.

Table 4.5: Compressive test results for 1% steel fibre reinforced concrete
Tested specimens: Cylinders of size 100mm diameter and 200mm high.

Date cast	Age	Number	Mass (g)	%age fibres	Maximum load (kN)	Strength (MPa)
10/8/2020	7 days	S/1/04	3769	1.00%	213.9	27.2
10/8/2020	7 days	S/1/15	3781	1.00%	199.5	25.4
10/8/2020	7 days	S/1/03	3772	1.00%	197.3	25.1
AVERAGE			**3774**		**203.6**	**25.9**
10/8/2020	14 days	S/1/07	3716	1.00%	238.2	30.3
10/8/2020	14 days	S/1/08	3865	1.00%	255.4	32.5
10/8/2020	14 days	S/1/17	3771	1.00%	243.6	31.0
AVERAGE			**3784**		**245.7**	**31.3**
10/8/2020	28 days	S/1/18	3763	1.00%	327.4	41.7
10/8/2020	28 days	S/1/02	3774	1.00%	308.2	39.2
10/8/2020	28 days	S/1/06	3754	1.00%	315.1	40.1
AVERAGE			**3764**		**316.9**	**40.3**

4.3.2 Splitting tensile strength and failure behaviour

The splitting tensile strength was higher than those of plain concrete and specimens with 0.5% steel fibres. It showed an increasing trend over time like the other two. So a linear function behaviour is exhibited. There was significant reduction in variability among the tested specimens. Table 4.6 below shows the summary of test results. Figure 4.6 above shows the trend. Table 4.6 below shows results for all tested specimens for this 1% steel fibre dosage.

Table 4.6: Splitting tensile test results for 1%steel fibre reinforced concrete
Tested specimens: Cylinders of size 100mm diameter and 200mm high.

Date cast	Age	Number	Mass	%age fibres	Maximum load (kN)	Strength (MPa)
10/8/2020	7 days	S/1/12	3774	1.00%	128.2	4.1
10/8/2020	7 days	S/1/10	3698	1.00%	126.2	4.0
10/8/2020	7 days	S/1/01	3783	1.00%	137.6	4.4
AVERAGE			**3752**		**130.7**	**4.2**
10/8/2020	14 days	S/1/11	3751	1.00%	150.0	4.8
10/8/2020	14 days	S/1/14	3770	1.00%	154.5	5.0
10/8/2020	14 days	S/1/13	3768	1.00%	159.0	5.0
AVERAGE			**3763**		**154.5**	**4.9**
10/8/2020	28 days	S/1/16	3722	1.00%	176.9	5.6
10/8/2020	28 days	S/1/09	3791	1.00%	183.4	5.8
10/8/2020	28 days	S/1/05	3781	1.00%	187.6	6.0
AVERAGE			**3765**		**182.6**	**5.8**

4.4 Specimens with 2.0% steel fibres

Specimens with 2% steel fibres showed the highest compressive and splitting tensile test results as per figure 4.7 below. A similar trend was established for growth over time just like for the previous test specimens. From figure 4.2 (d) and 4.3 (d) the tested specimens also showed numerous cracks for all tested specimens in both cases.

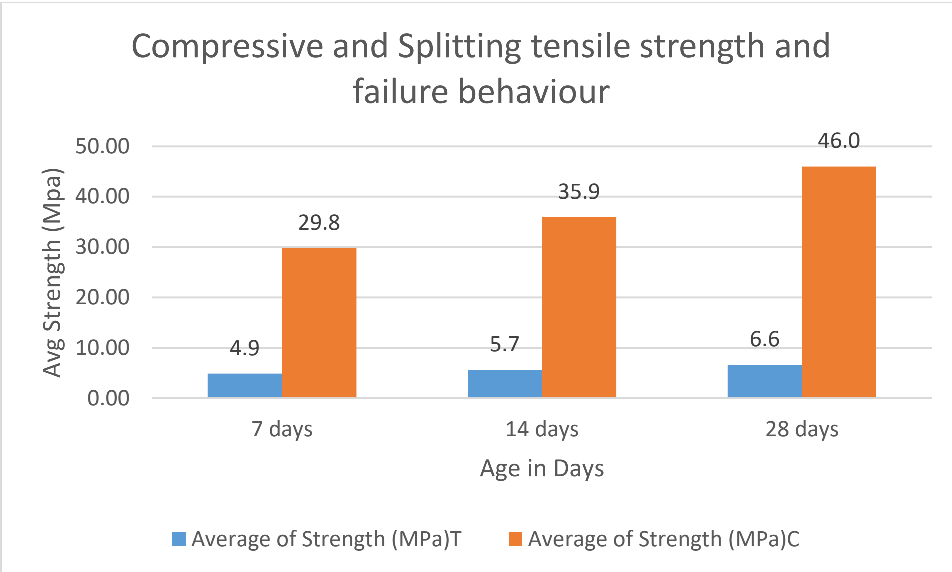

Figure 4.7 Compressive and splitting tensile strength behaviour for 2% steel fibres

4.4.1 Compressive strength and failure behaviour

For compressive strength the specimens with 2% recorded the highest strength as compared to previous specimens. It showed an increasing trend from a low of 29.8 MPa at 7 days to a high of 46.0MPa at 28 days. That is a gain of 16.2MPa translating to 54.4%. The increase in strength to 14 days and from 14 days to 28 days although linear is not uniform. From table 4.7 below there is little variability in the tested specimens for all cases.

Table 4.7: Compressive test results for 2% steel fibre reinforced concrete
Tested specimens: Cylinders of size 100mm diameter and
200mm high.

Date cast	Age	Number	Mass (g)	%age fibres	Maximum load (kN)	Strength (MPa)
10/8/2020	7 days	S/2/11	3791	2.00%	238.3	30.3
10/8/2020	7 days	S/2/14	3809	2.00%	229.1	29.2
10/8/2020	7 days	S/2/16	3758	2.00%	234.8	29.9
AVERAGE			**3786**		**234.1**	**29.8**
10/8/2020	14 days	S/2/10	3805	2.00%	282.6	36.0
10/8/2020	14 days	S/2/12	3770	2.00%	283.1	36.1
10/8/2020	14 days	S/2/15	3826	2.00%	281.1	35.8
AVERAGE			**3800**		**282.3**	**36.0**
10/8/2020	28 days	S/2/18	3844	2.00%	360.1	45.9
10/8/2020	28 days	S/2/05	3857	2.00%	361.0	46.0
10/8/2020	28 days	S/2/17	3860	2.00%	362.3	46.1
AVERAGE			**3854**		**361.1**	**46.0**

4.4.2 Splitting tensile strength and failure behaviour

For splitting tensile test this specimen series also recorded the highest strength figures at all levels as compared to the previous specimens. The overall gain in strength is 1.7MPa translating to 35%. The variability among the tested specimens were low as per table 4.8 below. More discussion on this is done under chapter 5.

Table 4.8: Splitting tensile test results for 2% steel fibre reinforced concrete
Tested specimens: Cylinders of size 100mm diameter and 200mm high.

Date cast	**Age**	**Number**	**Mass (g)**	**%age fibres**	**Maximum load (kN)**	**Strength (MPa)**
10/8/2020	7 days	S/2/09	3796	2.00%	149.5	4.8
10/8/2020	7 days	S/2/01	3779	2.00%	152.1	4.8
10/8/2020	7 days	S/2/06	3801	2.00%	161.2	5.1
AVERAGE			**3792**		**154.2**	**4.9**
10/8/2020	14 days	S/2/04	3811	2.00%	185.4	5.9
10/8/2020	14 days	S/2/13	3795	2.00%	174.9	5.6
10/8/2020	14 days	S/2/02	3774	2.00%	176.4	5.6
AVERAGE			**3793**		**178.9**	**5.7**
10/8/2020	28 days	S/2/08	3802	2.00%	204.7	6.5
10/8/2020	28 days	S/2/07	3789	2.00%	211.7	6.7
10/8/2020	28 days	S/2/03	3815	2.00%	208.0	6.6
AVERAGE			**3802**		**208.1**	**6.6**

4.5 Summary

In this chapter results and observations have been presented. All tested specimens including the control (0% steel fibres), 0.5%, 1% and 2% steel fibre reinforced concrete have been covered. Generally, in all cases the results indicate an increasing strength trend with age. The results also show an increasing trend with steel fibre dosage content. The number of cracks in tested specimens increased with increase in fibre content. The next chapter discusses these results and models developed.

CHAPTER FIVE: DISCUSSION

5.0 Introduction

In this chapter a discussion on the test results is done. The chapter begins with a discussion on the effect of steel fibre dosage on compressive strength, then the effect of fibre dosage on splitting tensile strength, model development, hypotheses testing using Chi-Square and Kruskal-Wallis and finally a summary on the chapter.

5.1 Effect of steel fibre dosage on compressive strength

Steel fibres have a positive effect on compressive strength by improving it. For instance, when monitored against plain concrete with a fibre dosage of 0.5% the improvement is noted at 7 days, 14 days and 28 days. At 7 days the improvement is 0.9 MPa (23.6-22.7); at 14 days the improvement is 1.5 MPa (29.4-27.9) while at 28 days it is 2.0 MPa (35.7-33.7). These exhibit a positive trend with age. The values of 0.9 – 2.0MPa look small but when presented more robustly in terms of percentages they become significant for instance the above can be stated as 4.0%, 5.4% and 5.9% respectively at 7,14 and 28 days. Using the same approach, the improvement in strength for 1% is 14.1%, 12.2% and 19.9% respectively at 7, 14 and 28 days. There is a noted reduction to strength improvement in terms of percentage at 14 days but it is again robust at 28 days which is a significant strength measure for structural engineers. When we take the same measurements again for steel fibres at 2% we get the percentage improvement to strength as follows: 7 days at 31.3%, 14 days at 28.7% and 28 days at 36.5%. These results are consistent with other studies which have put percentage contribution of steel fibres to compressive strength at between 14 – 40% even though for this study the range is between 4.0% and 36.5%. The lower values are observed for 0.5% steel fibres dosages.

There is consistent observation that strength increases with increased steel fibres but while conducting the experiment I observed some noted difficulty in workability challenges. I used a superplasticiser to improve workability while conducting this study. The contribution to compressive strength at 2% steel fibre dosage is up to 36.5% which is highly significant and there is need to consider this in concrete manufacture. Table 5.1 summarizes these observations and presents them in a more compact form.

Table 5.1 Summary of steel fibres on concrete compressive strength improvement

Age	Plain Strength (MPa)	With 0.5% Steel fibres (MPa)	With 1% Steel fibres (MPa)	With 2% Steel fibres (MPa)
7 days	22.7	23.6	25.9	29.8
% improvement	**0**	**4.0**	**14.1**	**31.3**
14 days	27.9	29.4	31.3	35.9
% improvement	**0**	**5.4**	**12.2**	**28.7**
28 days	33.7	35.7	40.4	46.0
% improvement	**0**	**5.9**	**19.9**	**36.5**

5.2 Effect of steel fibre dosage on splitting tensile strength

Like for compressive strength; addition of steel fibres also enhances the splitting tensile strength of concrete. For this to be clearly demonstrated we compare results of plain concrete with 0.5% steel fibre reinforced concrete; then again with 1% steel fibres and finally with 2% steel fibres. The strength for plain concrete= 2.9MPa as compared to 3.9MPa at 7 days. The additional strength is 1.0MPa; at 14 days it is 0.6MPa (4.2-3.6). At 28 days it is 1.1 MPa (4.8-3.7). The results show low figures but they should be presented in a more robust form. In terms of percentage it is 34.7%, 19.1% and 32.6% at 7, 14 and 28 days respectively in terms of strength improvement. That is very significant and perhaps the greatest benefit of steel fibres inclusion in concrete manufacture. When compared to 1% steel fibres and following the same workings principles, the percentage strength addition contributions are 1.3MPa, 1.4 and 2.2Mpa respectively which translates to 43.9%, 38.6% and 59.0% for 7, 14 and 28 days respectively. Finally, for 2% steel fibres, the percentage strength addition contributions are 69.8%, 60.4% and 81.2% for 7, 14 and 28 days respectively. The contribution of steel fibres to concrete strength in terms of splitting tensile is significantly higher as compared to contribution in compressive strength although splitting tensile strength figures are still low in terms of overall total values.

Table 5.2 Summary of steel fibres on concrete splitting tensile strength improvement

Age	**Plain Strength (MPa)**	**With 0.5% Steel fibres (MPa)**	**With 1% Steel fibres (MPa)**	**With 2% Steel fibres (MPa)**
7 days	2.9	3.9	4.2	4.9
% improvement	**0**	**34.7**	**43.9**	**69.8**
14 days	3.6	4.2	4.9	5.7
% improvement	**0**	**19.1**	**38.6**	**60.4**
28 days	3.7	4.8	5.8	6.6
% improvement	**0**	**32.6**	**59.0**	**81.2**

5.3 Model development and prediction

For the model development data was summarized as per table 5.3 below and linear regressions were done using MS-Excel. Table 5.4 represents the summary output for compressive regression model results whereas table 5.5 shows the splitting tensile model summary. Table 5.6 shows data used for compressive modelling.

Table 5.3. Compact data representation from the experiment

		Tensile Testing			*Compressive Testing*	
Age	***%age fibres***	***Maximum load (kN)***	***Strength (MPa)***		***Maximum load (kN)***	***Strength (MPa)***
7 days	***0%***	***90.8***	***2.9***		***178.1***	*22.7*
14 days	***0%***	***111.5***	***3.6***		***219.0***	*27.9*
28 days	***0%***	***114.9***	***3.7***		***265.0***	*33.7*
7 days	*0.50%*	***122.4***	***3.9***		***185.0***	***23.6***
14 days	*0.50%*	*132.8*	*4.2*		*230.9*	*29.4*
28 days	*0.50%*	*152.3*	*4.8*		*280.1*	*35.7*
7 days	*1.00%*	*130.7*	*4.2*		*203.6*	*25.9*
14 days	*1.00%*	*154.5*	*4.9*		*245.7*	*31.3*
28 days	*1.00%*	*182.7*	*5.8*		*316.9*	*40.3*
7 days	*2.00%*	*154.2*	*4.9*		*234.0*	*29.8*
14 days	*2.00%*	*178.9*	*5.7*		*282.3*	*35.9*
28 days	*2.00%*	*208.1*	*6.6*		*361.1*	*46.0*

TABLE 5.4 TENSILE SUMMARY OUTPUT								
Regression Statistics								
Multiple R	*1*							
R Square	*1*							
Adjusted R Square	*1*							
Standard Error	*2.83E-15*							
Observations	*12*							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	*4*	*12.77764*	*3.194410639*	*3.99345E+29*	*7.9E-103*			
Residual	*7*	*5.6E-29*	*7.99913E-30*					
Total	*11*	*12.77764*						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	*7.99E-15*	*7.22E-15*	*1.107493799*	*0.305*	*-9.1E-15*	*2.51E-14*	*-9.1E-15*	*2.51E-14*
P0	*0.031831*	*6.93E-17*	*4.59223E+14*	*0.000*	*0.031831*	*0.031831*	*0.031831*	*0.031831*
F0.005	*0.031831*	*5.4E-17*	*5.88979E+14*	*0.000*	*0.031831*	*0.031831*	*0.031831*	*0.031831*
F0.01	*0.031831*	*4.66E-17*	*6.8294E+14*	*0.000*	*0.031831*	*0.031831*	*0.031831*	*0.031831*
F0.02	*0.031831*	*4.04E-17*	*7.87326E+14*	*0.000*	*0.031831*	*0.031831*	*0.031831*	*0.031831*

TABLE 5.5: COMPRESSIVE MODEL SUMMARY OUTPUT								
Regression Statistics								
Multiple R	1							
R Square	1							
Adjusted R Square	1							
Standard Error	4.93E-15							
Observations	12							
ANOVA								
	df	SS	MS	F	Significance F			
Regression	4	521.0247	130.2562	5.36E+30	8.9E-107			
Residual	7	1.7E-28	2.43E-29					
Total	11	521.0247						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-5.3E-15	8.35E-15	-0.63792	0.543821	-2.5E-14	1.44E-14	-2.5E-14	1.44E-14
P0	0.127324	3.9E-17	3.26E+15	6.7E-107	0.127324	0.127324	0.127324	0.127324
F0.05	0.127324	3.71E-17	3.44E+15	4.7E-107	0.127324	0.127324	0.127324	0.127324
F0.01	0.127324	3.35E-17	3.8E+15	2.3E-107	0.127324	0.127324	0.127324	0.127324
F0.02	0.127324	2.93E-17	4.35E+15	9E-108	0.127324	0.127324	0.127324	0.127324

Table 5.6: Table Data for modelling compressive strength

Days	P_0%	F_0.5%	F_1%	F_2%
7	22.68	23.56	25.92	29.80
14	27.89	29.40	31.29	35.94
28	33.74	35.67	40.35	45.98

Regression models in MS-Excel were executed as per the above tables and then results presented using bar charts as presented in figures 5.1 and 5.4 below. Trial functions were done in linear and exponential functions with the best model with a higher R^2 being the linear functions. Also based on simplicity of use I have adopted them and developed predicted results to compare with the actual results.

Figures 5.1 and 5.2 represents the developed linear compressive splitting tensile strength respectively. Linear models give a good illustration with high R^2 values and are adopted.

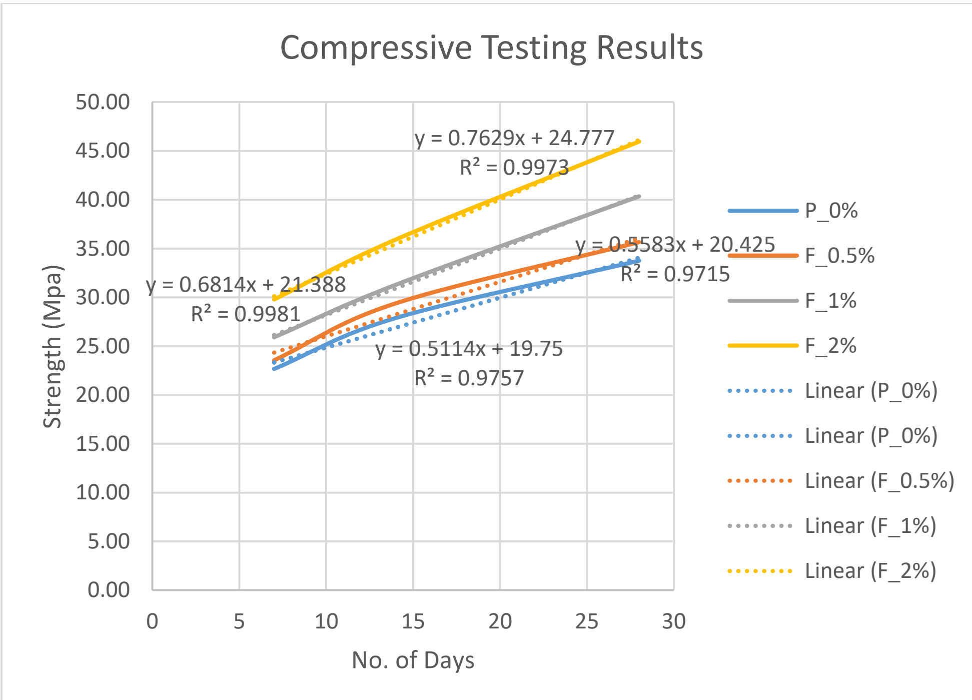

Figure 5.1: Linear predictive models for compressive strength

Data in table 5.7 was used to model splitting tensile functions.

Table 5.7 Splitting test results for plain concrete

Days	P_0%	F_0.5%	F_1%	F_2%
7	2.89	3.90	4.16	4.91
14	3.55	4.23	4.92	5.69
28	3.66	4.85	5.81	6.63

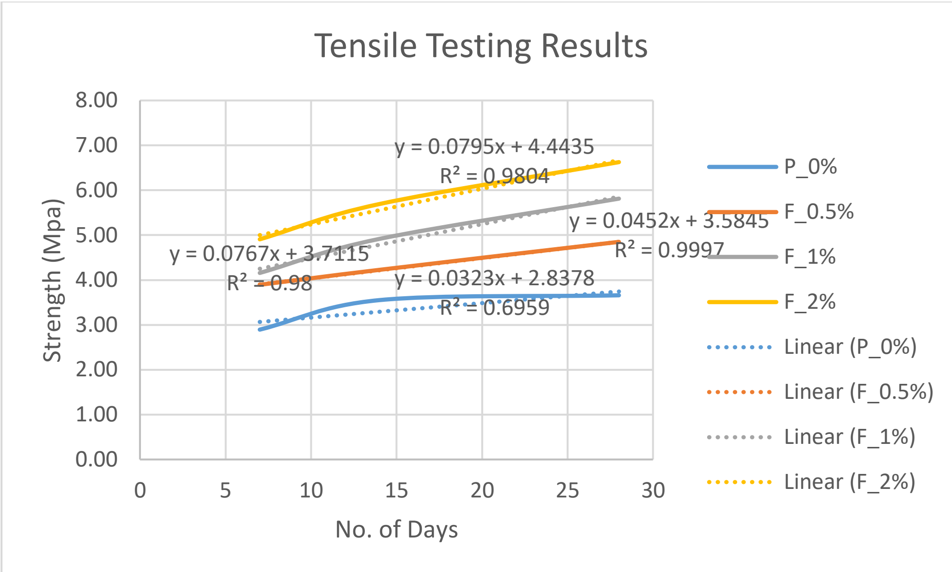

Figure 5.2: Linear predictive models for splitting tensile strength

5.4 Model validation

Tables 5. 8 and 5.9 below contains the results from the model validation. The extracted equations for modelling are as follows:

5.4.1 For compressive strength prediction.

Each of the specimens had a unique behaviour and four equations have been modelled in this regard to take care of 0%, 0.5%, 1% and 2% steel fibres respectively. The equations are as follows:

For 0%, $y=0.5114x + 19.75$

For 0.5%, $y= 0.5583x + 20.425$

For 1%, $y=0.6814x + 21.388$

For 2%, $y= 0.7629x + 24.777$

The generated results which are compared with the average results are presented in table 5.8 below. The standard deviation and variance are well within the experimental results.

5.4.2 For splitting tensile model prediction

Tensile model prediction is well within the actual with a variance of only 0.1. See more results on table 5.9 below. The equations generated for modelling splitting tensile are:

For 0% fibres, $y=0.0323x + 2.8378$

For 0.5% fibres, $y= 0.0452x + 3.5845$

For 1% fibres, $y=0.0767x + 3.7115$

For 2% fibres, $y=0.0795x + 4.4435$

Table 5.8 Validation results for compressive results as per model versus actual

Steel fibre	Age	Predicted (MPa)	Actual (MPa)	Deviation (P-A)	Variance
0%	7 days	23.3	22.7	0.6	0.36
0%	14 days	26.9	27.9	1.0	1.00
0%	28 days	34.1	33.7	0.4	0.16
0.50%	7 days	24.3	23.6	0.7	0.49
0.50%	14 days	28.2	29.4	-1.2	1.44
0.50%	28 days	36.1	35.7	0.4	0.16
1%	7 days	26.2	25.9	0.3	0.09
1%	14 days	30.9	31.3	-0.4	0.16
1%	28 days	40.5	40.3	0.2	0.04
2%	7 days	30.1	29.8	0.3	0.09
2%	14 days	35.5	36.0	-0.5	0.25
2%	28 days	46.2	46.0	0.2	0.04
				Calculated Variance	**0.36**
				std deviation	0.60

Table 5.9 Validation results for splitting tensile results as per model versus actual

Steel fibre	Age	Predicted (MPa)	Actual (MPa)	Deviation (P-A)	Variance
0%	7 days	3.0	2.9	0.1	0.01
0%	14 days	3.3	3.6	-0.3	0.09
0%	28 days	3.7	3.7	0.0	0.00
0.50%	7 days	3.9	3.9	0.00	0.00
0.50%	14 days	4.2	4.2	0.00	0.00
0.50%	28 days	4.9	4.9	0.0	0.00
1%	7 days	4.2	4.2	0.0	0.00
1%	14 days	4.8	4.9	-0.1	0.01
1%	28 days	5.9	5.8	0.1	0.01
2%	7 days	5	4.9	0.1	0.01
2%	14 days	5.6	5.7	-0.1	0.01
2%	28 days	6.7	6.6	0.1	0.01
				Calculated Variance	**0.01**
				std deviation	0.11

5.5 Hypothesis testing

Both Chi-Square and Kruskal-Wallis have been used for hypothesis testing. First Chi- Square is presented under table 5.10 and 5.11; then Kruskal-Wallis from table 5.12 -5.15.

Table 5.10: Compressive strength hypothesis testing

Days	P_0%	F_0.5%	F_1%	F_2%	Total
7	22.68	23.56	25.92	29.80	101.95
14	27.89	29.40	31.29	35.94	124.51
28	33.74	35.67	40.35	45.98	155.74
Total	**84.31**	**88.63**	**97.55**	**111.72**	**382.21**
Expected	22.4887	23.6417	26.0219	29.7997	
(O-E)	0.1889	-0.0817	-0.1052	-0.0021	
(O-E)^2	0.0357	0.0067	0.0111	0.0000	
(O-E)^2/E	0.0016	0.0003	0.0004	0.0000	0.0023
Expected	27.4654	28.8735	31.7804	36.3943	
(O-E)	0.4213	0.5258	-0.4911	-0.4560	
(O-E)^2	0.1775	0.2765	0.2412	0.2079	
(O-E)^2/E	0.0065	0.0096	0.0076	0.0057	0.0293
Expected	34.3532	36.1145	39.7504	45.5213	
(O-E)	-0.6102	-0.4441	0.5963	0.4580	
(O-E)^2	0.3724	0.1972	0.3556	0.2098	
(O-E)^2/E	0.0108	0.0055	0.0089	0.0046	0.0299

Chi Square	0.061
P value	0.80
df	6
Critical	12.592

Table 5.11: Splitting tensile hypothesis testing

Days	**P_0%**	**F_0.5%**	**F_1%**	**F_2%**	**Total**
7	2.89	3.90	4.16	4.91	15.86
14	3.55	4.23	4.92	5.69	18.39
28	3.66	4.85	5.81	6.63	20.94
Total	**10.10**	**12.97**	**14.89**	**17.23**	**55.19**
Expected	2.9006	3.7264	4.2786	4.9498	
(O-E)	-0.0092	0.1686	-0.1189	-0.0405	
(O-E)^2	0.0001	0.0284	0.0141	0.0016	
(O-E)^2/E	0.0000	0.0076	0.0033	0.0003	0.0113
Expected	3.3638	4.3215	4.9618	5.7403	
(O-E)	0.1849	-0.0945	-0.0438	-0.0466	
(O-E)^2	0.0342	0.0089	0.0019	0.0022	
(O-E)^2/E	0.0102	0.0021	0.0004	0.0004	0.0130
Expected	3.8314	4.9222	5.6516	6.5382	
(O-E)	-0.1757	-0.0742	0.1628	0.0871	
(O-E)^2	0.0309	0.0055	0.0265	0.0076	
(O-E)^2/E	0.0081	0.0011	0.0047	0.0012	0.0150

Chi Square	0.0393
P value	0.98
df	6
Critical	12.592

Using Chi-Square the critical value is 12.592 and it will easily pass that steel fibres have no significant effect on the strength of concrete. But we have to check the P value and see the range to which the results apply from the Chi- Square tables; in both cases the value calculated is considerably less than the acceptable value of 12.592 at 0.05 significance level. It therefore accepts the alternate hypothesis and rejects the null hypothesis as per the statements below.

If X^2 > CV reject the H0,

If P value < alpha Reject H0.

From the scenarios, the Ho is rejected because the corresponding alpha values are very high at 0.8 and 0.98 for compressive and splitting tensile strengths respectively; way above 0.05 set for this study.

5.6 Hypothesis testing using Kruskal-Wallis method

Kruskal-Wallis one-way analysis of variance is an extremely useful test for deciding whether k independent samples originate from different populations. It tests the null hypothesis that any k samples are not different with averages, assuming that the variable under study has an underlying continuous distribution. This method is the one best suited to test our hypotheses. The formula is given by:

$$T = 12/N(N+1)\sum_{J=1}^{k}\frac{Rj^2}{nj} - 3(N+1)$$

k=the number of samples.

n_j= The number of cases in the jth sample.

N= Σnj; the number of cases in all the combined samples combined.

R_j= Sum of ranks in the jth sample (or jth column).

Where more than two groups are involved Kruskal-Wallis non-parametric statistics is the best and the critical values read off from Chi-Square tables apply. However, I have access to some tables showing critical values which shall be adopted for this study.

Table 5.12 A summary of compressive strengths of different specimens

Age	Plain Strength (MPa)	With 0.5% Steel fibres (MPa)	With 1% Steel fibres (MPa)	With 2% Steel fibres (MPa)
7 days	22.678	23.56	25.917	29.798
14 days	27.887	29.399	31.289	35.938
28 days	33.743	35.67	40.347	45.979

Table 5.13A ranked summary of compressive strengths of different specimens

	1	2	3	6
	4	5	7	10
	8	9	11	12
SUM Rj	**13**	**16**	**21**	**28**

The first task is to check for compressive tests and rank them. Table 5.10above is reduced to table 5.11 by ranking. These are then used to calculate the T value which is crosschecked with the Critical value 12.592. The same exercise is carried out for splitting tensile test and the values ranked in table 5.14 and 5.15 below. In both cases the calculated T values of 3.3 and 4.5 are way below critical value of 12.592 thereby supporting the alternate hypotheses that steel fibres have an effect on strength. After that the table is arranged in ranked order and T value calculated generated using the above formula as hereunder.

$$T = 12/12(12+1)\sum_{J=1}^{12} \frac{13\text{^}2}{3} + \frac{16\text{^}2}{3} + \frac{21\text{^}2}{3} + \frac{28\text{^}2}{3} - 3(12+1) = 3.306$$

T= 3.306 While T critical is 12.592 since T critical is higher than T calculated then null hypothesis is rejected and alternate hypothesis accepted.

Equally for splitting tensile test the same formula is used and we get the following:

$$T = 12/12(12+1)\sum_{J=1}^{12} \frac{6\text{^}2}{3} + \frac{17\text{^}2}{3} + \frac{25\text{^}2}{3} + \frac{30\text{^}2}{3} - 3(12+1) = 8.434$$

Table 5.13 A summary of tensile splitting strengths of different specimens

Age	Plain Strength (Mpa)	With 0.5% Steel fibres (Mpa)	With 1% Steel fibres (Mpa)	With 2% Steel fibres (MPa)
7 days	2.9	3.9	4.2	4.9
14 days	3.6	4.2	4.9	5.7
28 days	3.7	4.9	5.8	6.6

Table 5.14 A ranked summary of tensile splitting strengths of different specimens

	1	4	5	8
	2	6	9	10
	3	7	11	12
SUM Rj	**6**	**17**	**25**	**30**

T= 8.434 While T critical is 12.592 since T critical is higher than T calculated then null hypothesis is rejected and alternate hypothesis accepted. So equally for tensile splitting addition of steel fibres has an effect on tensile splitting strength of concrete.

5.7 Summary

In this chapter the following have been discussed, effect of steel fibres on compressive strength whereby it was established that steel fibres contribute to strength enhancement from a low of 4.0% for steel fibres of 0.5%; to 36.5% for 2% steel fibres. The detailed strength enhancement is discussed at the beginning of the chapter. The effect of steel fibres on improving splitting tensile strength is also discussed. In this regard steel fibres improve splitting tensile strength up to 81.2% but strength values are still low of below 7.0MPa in all specimens tested. In terms of modelling linear models are developed as one of the key outputs of this study. Finally, on hypothesis testing the alternative hypothesis that steel fibres have an effect on concrete strength is supported.

CHAPTER SIX: CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

The aim of this research project was to investigate the role of steel fibres on the structural performance of steel fibre reinforced concrete members in form of cylinders of 100mm diameter and 200mm high as used. Studies on steel fibre reinforced concrete have been conducted over the last 50 years with little progress in this area for several countries. It is time different countries developed design codes to guide steel fibre reinforced concrete design. There is need to have a good grasp on mechanical properties of steel fibres reinforced concrete and the role of steel fibres in improving the compressive and splitting tensile strengths of concrete.

In order to appreciate the role of steel fibres in enhancing concrete performance as a construction material; knowledge in this area using local materials and imported steel fibres is required. An understanding of behaviour and failure mechanism of steel fibres reinforced concrete is essential to inform future designs and policy development. This was achieved by doing the following:

(1). Did a literature review in the subject area on:

- (i) Importance of steel fibres
- (ii) Dynamic crack growth and resistance of FRC
- (iii) Impact resistance of various types of FRC
- (iv) Fibre pull out behaviour of steel fibres reinforced concrete
- (v) Tensile behaviour of steel fibres reinforced concrete
- (vi) Compressive behaviour of steel fibres reinforced concrete
- (vii) Comparative evaluation of various fibres used on FRC.
- (viii) Source and characteristics of steel fibres used in this research.
- (ix) Mechanical properties of steel fibre reinforced concrete
- (x) Fibre bridging
- (xi) Fibre dosage determination

(2). Evaluating the physical and chemical properties of various concrete materials used in concrete manufacture including physical and chemical properties of cement, coarse and fine aggregates. This is detailed in chapter 3 under materials and methods.

(3). Conducting an experimental study on behaviour of concrete with various dosages of steel fibres.

(4). Development of regression models on behaviour and concrete strength predictions using linear and exponential functions.

The results of the study project have provided extra knowledge on the role and behaviour of concrete reinforced with steel fibres. The results regarding strength against different fibre dosages are discussed in detail under chapter 5. The study project met research objectives as outlined in project specifications.

6.2 Final conclusions

The project investigated the role of steel fibres on structural performance of concrete. The results were obtained through experimental study of various concrete cylinders specimens containing 0% fibres, 0.5% fibres, 1% fibres and 2% fibres.

6.2.1 Review of related literature

The review of related literature is covered under chapter 2, which provided a detailed knowledge regarding the study project. The following useful knowledge was gained:

(i) That steel fibres incorporation in concrete manufacture enhances compressive strength characteristics. This is mainly through fibre bridging and extra strength provided by the steel fibres.

(ii) That steel fibres did not have any significant effect on compressive strength whereas other researchers indicated that they have a significant contribution to compressive strength. So there is no consensus on this and a study to conclusively address this was necessary hence this study.

(iii) That splitting tensile strength for concrete is enhanced by addition of steel fibres and this was later established in the empirical study in chapters 4 and 5.

6.2.2 Effect of steel fibres on compressive strength

From the experimental study it was established as follows:

(i) That with steel fibres incorporation of 2% dosage the contribution to compressive strength increases up to 36.5%, a steel fibre dosage of 1% increases the compressive strength up to 19.9% while a dosage of 0.5% increases the compressive strength by up to 5.9%.

(ii) That workability is affected with increased steel fibres necessitating addition of superplasticizer.

(iii) That contribution to compressive strength is from a low of 4.0% at 7 days with 0.5% to a high of 36.5% at 28 days for 2% dosage of steel fibres.

6.2.3 Effect of steel fibre dosage on splitting tensile strength

Under this item it was established as follows:

(i) That contribution to splitting tensile strength as a result of steel fibres increases with age. At 0.5% dosage the increase in strength is 32.6%, at a dosage of 1% steel fibres it is 59.0% at 2% steel fibre dosage the increase is 81.2%.

(ii) That the strength contribution also increases with steel fibre dosage.

(iii) That percentage contribution ranges from 19.1% to 81.2%.

(iv) That the percentages contribution to strength enhancement looks high but actual strengths in terms of absolute MPa values are minimal and none of the specimens reaches a strength of 7.0MPa. The highest splitting tensile strength attained is 6.6MPa for 25 steel fibre reinforced concrete at 28 days while the lowest is 2.9MPa at seven days for plain concrete.

(v) That the failure modes and patterns differ with steel fibre dosage. Cracks intensity increase with increase in fibre dosage with fine least cracks in plain concrete to many cracks when steel fibre dosage is at 2%. The nature of failure is more brittle in plain concrete, then gradual failure with increased fibres up to 2% steel fibre content. More details can be found in chapter four.

6.3 Developed models

Using regressions linear and exponential models are generated. The adopted final models are linear in form and are specific to fibre dosage. They predict for both compressive and splitting tensile strengths at highly accepted range. The developed models were done based on the following:

(i) That there is an underlying theoretical believe that the variables of increase in strength as a result of steel fibres incorporation are related and follow a linear behavior.

(ii) That the other variables of type of aggregates and cement used are treated as constants. The cause of change is the steel fibre dosage.

(iii) That the strength gained over time exhibits a continuous growth function behaviuour in terms of strength over time until age 28 days

(iv) That the closer to 1.0 of our R^2 the better the predictive model developed.

In our case the R^2 for 0%, 0.5%, 1% and 2% steel fibres reinforced concrete model results are 0.976, 0.972, 0.998 and 0.998 respectively for compressive concrete strength linear predictive models. For splitting tensile the R^2 are, 0.696, 1.00, 0.98 and 0.98 respectively for 0%,0.5%, 1% and 2% steel fibre splitting tensile concrete strength linear predictive models. Based on R^2 values the developed models are reliable. The validation results lead to the same conclusion as done under chapter five. Initially the study was to cover real structures in terms of beams of size 150mm x 150mm x 600mm, 9No, for three point bending test and 150 x 300 x 2100mm, 9No, for four point bending test at USQ apart from the cylinders but due to Covid-19 situation the study was scaled down to cylinders only at an alternative laboratory.

6.3 Recommendations

From the study it can be established that steel fibres are still significant contributors to strength development both for compressive and splitting tensile. There is need for engineers and policy makers to embrace steel fibres as a construction material and come up with design codes for its use. Some countries like Australia have already developed design code sections addressing fibre reinforced concrete. There is need for a further investigation on steel fibres elements especially on actual construction members to establish the behaviour. Using all the wide variety of fine aggregates to understand the behaviour of manufactured concrete with different steel fibre dosages is important.

6.4 Areas for further study

There is need for research to further improve knowledge on the area of steel fibres and fibre usage generally in Kenya. Specific areas for further research are:

(i) Use other fibres to conduct research and compare with findings from this study with a view of determining useful optimal fibres and type for use in concrete manufacture.

(ii) Expand knowledge in this area by investigating the role of steel fibres in fibre pull – out resistance, impact resistance and contribution to flexural strength of concrete.

(iii) To investigate the role of steel fibres in shatter and shear failure of manufactured concrete elements.

(iv) Investigation of role of steel fibres in actual structural elements like slabs, walls, beams, roads and columns.

(v) Use of different fine aggregates range and steel fibres at different dosages to establish whether they exhibit same failure patterns. Only one fine aggregate in form of Kajiado river sand was used in the study. It is important to check the behaviour of fine aggregates sourced from other sources as used in Nairobi.

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APPENDICES

Appendix A: Project Specification

ENG4111/4112 RESEARCH PROJECT

For: Oswald Gwaya

Title: The role of steel fibres on the compressive and tensile properties of concrete

Major: Civil Engineering

Supervisor: Prof Allan Manalo

Enrolment: ENG4111 –Ext/online S1, 2020

ENG4112- Ext/online S2, 2020

1.3 Project Aim

To investigate the role of steel fibres on the compressive and tensile strength of concrete; with a view of optimization of designs in terms of cost, quality, strength and performance. The key focus shall be mainly in the role of steel fibres dosage against compressive and splitting tensile strength of cylindrical specimens.

Programme version 1, 25th March, 2020

1.0 Research background information relating to fibre reinforced concrete.

2.0 Do a thorough literature review on what others have done on the topic. Research and analyze documents on the role of steel fibres in enhancing compressive and splitting tensile strength of concrete specimens.

3.0 Prepare and test experimentally at the lab, concrete cylindrical specimens size 100mm diameter and 200mm high for compressive strength at steel fibre dosage of 0%, 0.5%, 1% and 2%. At each stage 3 cylinders are tested for each dosage at age 7, 14 and 28 days. Total cylindrical specimens tested equal to 36 for this test.

4.0 Prepare and test experimentally at the lab, concrete cylindrical specimens size 100mm diameter and 200mm high for splitting tensile strength at steel fibre dosage of 0%, 0.5%,1% and 2%. At each stage 3 cylinders are tested for each dosage at age 7, 14 and 28 days. Total cylindrical specimens tested equal to 36 for this test.

5.0 Present results and discuss observations

6.0 Do discussion of results and develop predictive concrete strength predictive models for both compressive and splitting tensile strengths.

7.0 Derive conclusions and make recommendations.

8.0 Writing and submission of research project.

Appendix B: Tests done at state department of mining

REPUBLIC OF KENYA

MINISTRY OF PETROLEUM AND MINING

STATE DEPARTMENT OF MINING

MADINI HOUSE
MACHAKOS ROAD
P.O. Box 30009-00100 GPO
NAIROBI

e-mail:cg@mining.go.ke

When replying please quote ref No & date

Ref. No.ORIGINAL CERT NO.2115/20

Date…24th August, 2020

ASSAY CERTIFICATE

SENDER'S NAME : ABEDNEGO GWAYA
DATE : 20.08.2020
SAMPLE TYPE : CEMENT
SAMPLE NO : 2115/20

RESULT

Sender's Ref.	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	Fe_2O_3	LOI
CEMENT 42.5 POWER PLUS	16.33	4.18	39.56	ND	0.10	0.23	0.20	0.01	2.68	33.80

The results are expressed in percentage (%) unless otherwise indicated.

FOR DIRECTOR OF GEOLOGICAL SURVEYS
24 AUG 2020
P. O. Box 30009-00100
NAIROBI

EDWARD MWANGI
FOR: DIRECTOR OF GEOLOGICAL SURVEYS.

The results are based on the test sample only.

Test result of cement from the government laboratory

REPUBLIC OF KENYA

MINISTRY OF PETROLEUM AND MINING

STATE DEPARTMENT OF MINING

e-mail:cg@mining.go.ke
When replying please quote ref No & date
Ref. No.ORIGINAL CERT NO.2116/20

MADINI HOUSE
MACHAKOS ROAD
P.O. Box 30009-00100 GPO
NAIROBI

Date…24th August, 2020

ASSAY CERTIFICATE

SENDER'S NAME : ABEDNEGO GWAYA
DATE : 20.08.2020
SAMPLE TYPE : SAND
SAMPLE NO : 2116/20

RESULT

Sender's Ref.	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	Fe_2O_3	LOI
SAND	69.50	14.00	3.38	ND	0.8	1.02	1.00	0.14	4.25	3.46

The results are expressed in percentage (%) unless otherwise indicated.

FOR DIRECTOR OF GEOLOGICAL SURVEYS
24 AUG 2020
P. O. Box 30009-00100
NAIROBI

EDWARD MWANGI
FOR: DIRECTOR OF GEOLOGICAL SURVEYS.
The results are based on the test sample only.

Test result of hemical composition of fine aggregates