# JIMMA UNIVERSITY
## SCHOOL OF GRADUATE STUDIES
## JIMMA INSTITUTE OF TECHNOLOGY
## FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
## STRUCTURAL ENGINEERING STREAM

# STUDY ON THE BEHAVIOR OF CONCRETE WITH WASTE TIRES WIRE AS FIBER

BY
ADDISALEM KASU

JANUARY, 2022
JIMMA, ETHIOPIA

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**ADDISALEM KASU**

A Thesis submitted to the School of Graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Master of Science in Structural Engineering

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## DECLARATION

This thesis is my original work and has not been presented for a degree in any other university

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As Master research Advisors, we hereby certify that we have read and evaluated this MSc. research prepared under our guidance, by **ADDISALEM KASU** entitled: ''**STUDY ON THE BEHAVIOR OF CONCRETE WITH WASTE TIRE WIRE AS FIBERS**'' We Recommend that it can be submitted as fulfilling the MSc Thesis requirements.

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***ABSTRACT***

*Steel fiber reinforced concrete (SFRC) is cement based composite material. Basically, the concrete has low tensile strength, low strain capacity, and it fails in brittle manner. Different types of steel fiber (industrially manufactured and recovered from different used materials) are used in concrete to modify the tensile strength of concrete. The addition of the fiber improves the mechanical properties of concrete, especially the post-cracking properties. It is known that fibers bridge the cracks and transfer the tensile stress across the cracked sections. Therefore, the concrete becomes more ductile and durable material in resisting tension.*

*In this research work, the effect of addition of recovered steel fiber (the Bead wire) from waste tire on the mechanical behavior of concrete was investigated to quantify the advantages obtained by the concept of SFRC with concrete. Experimental (compression, workability and split) and finite element analysis method (post cracking response in terms of load-displacement) was used for the investigation. The effect on flexure (on post cracking response in terms of Load-displacement) was analyzed by finite element method, using ABAQUS Software. For Modeling, the SFRC constitutive model proposed by Lok and Xiao (1999) was adopted. The stress and strain values for compressive and tensile behavior were calculated using the formula proposed by aforementioned model's formula. The values of* $f_t$ *for calculation, in formula were obtained from laboratory test result. The reliability of the FE numerical model predictions was ensured by calibrating it against existing experimental data. A total of twelve beams of 1.70 m length and 180mm x 100mm in cross-section were modeled and analyzed in ABAQUS for this study. For each grade of concrete one beam served as control beam (without fiber) and other three beams were modeled with different fiber volume fraction (1.0% 1.5%, & 2%). Also compressive and tensile strength test were performed experimentally. Different grade of concrete (C20, C25 and C30) and different steel fiber (bead wire having a diameter of 0.89 mm extracted from used tires with aspect ratio of 67) volume fractions (1.0% 1.5%, & 2%) were the principal parameters considered in this study. All the beams were analyzed under four-point bending in a loading.*

*The results showed that addition of RSF to concrete greatly reduces the workability of concrete, increased the compression in fewer amounts, maximum increment was observed in C-30-2.0 mix on third specimen (37.76%) and minimum increment was observed in C-30 -1.0 mix on third specimen (35.16%). The tensile strength of RSFC also highly increased as the ratio of RSF increased. Maximum increment of tensile strength was seeing on C-25-2.0 mix in the third specimen which is 140.49% and the minimum increase was observed in C-30-1.0 mix on the third specimen which is 60.07%. The post-crack were greatly increased with fold due to the presence of steel fibers.*

**ACKNOWLEDGEMENT**

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## ACRONYM

| | |
|---|---|
| ACI | American Concrete Institute |
| BC | Brittle Cracking |
| DP | Damaged Plastic |
| EBCS | Ethiopian Building Code Standard |
| Ec | Elastic modulus of concrete |
| Es | Elastic modulus of Steel |
| FEA | Finite Element Analysis |
| FRC | Fiber Reinforced Concrete |
| GFRC | Glass Fiber Reinforced Concrete |
| HSC | High Strength Concrete |
| NLFEA | Nonlinear Finite Element Analysis |
| P | Applied static load |
| RC | Reinforced Concrete |
| RSF | Recovered Steel Fiber |
| RSFRC | Recovered Steel Fiber Reinforced Concrete |
| SFRC | Steel Fiber Reinforced Concrete |
| SNFRC | Synthetic Fiber Reinforced Concrete |
| UHSC | Ultra-High Strength Concrete |
| Vf | Steel fiber content |
| $\delta$ | Stress |
| $\varepsilon$ | strain |

# CHAPTER ONE
# INTRODUCTION

## 1.1 Background of the Study

If concrete cannot be reinforced it will show low tensile strength and low strain capacity at the fracture point. When this unreinforced concrete is subjected to tension it deforms elastically at the initial and this elastic response is followed by micro-cracking, macro cracking, and finally fractured. To overcome this problem in the early stage in human civilization history, people have been using naturally available plant fibers. As civilization and technology advanced different types of fibers have been created.

Fiber is a small piece of reinforcing material possessing certain characteristic properties. They can be circular or flat. The fiber is often described by a convenient parameter called “aspect ratio”. The aspect ratio of the fiber is the ratio of its length to its diameter. The typical aspect ratio ranges from 30 to 150 [5]. Glass fiber is a predominantly used mineral fiber. Glass fibers are silica-based glass compounds that contain several metal oxides, which can be tailored to manufacture different types of glasses. They are quite economical and hence are the most commonly used fibers for structural applications. The use of glass fibers in Ethiopia is very much limited to the manufacturing of water tankers.

Synthetic fibers are man-made fibers resulting from research and development in the petrochemical and textile industries. They have become increasingly common in recent years. Limitation using this type of fiber is limited primarily due to their high cost compared to other fibers. This fiber is primarily used as a crack controlling additive for cementitious materials principally for concrete repairing. Natural fibers have existed naturally on the earth. These fibers are added to other fibers for usage where cost matters. Some of the best-known natural fibers such as sisal, coconut, sugarcane bagasse, elephant grass, palm, etc. These fibers are sufficiently strong in tension, but their modulus of elasticity is quite low. In Ethiopia agro stone is produced using sugarcane bagasse which is natural fiber together with fiber glass.

Introduction of fibers into the concrete results in post-elastic property changes, that range from subtle to substantial, depending upon several factors, including matrix strength, fiber type, fiber modulus, fiber aspect ratio, fiber strength, fiber surface bonding characteristics, fiber content, fiber orientation, and aggregate size effects. In recent years, the use of fibers for enhancing the mechanical properties of concrete increased significantly [2].The reinforcing fibers can be found in different shapes. Their cross-sections include circular, rectangular, half-round, and irregular or varying shapes. They may be straight or bent and come in various lengths [3].

In general, fiber length varies from 12.7 mm to 63.5 mm. The most common fiber diameters are in the range of 0.45–1.0 mm. For normal-weight concrete, fiber contents vary from as low as 30 kg /m3 to as high as 157 kg /m3, although the high range limit is usually about 95 to 118 kg /$m^3$ [4].The effect of fiber shapes and fiber volume fraction has been of great interest in recent years. Several studies led to the development of new fiber geometries to optimize the fiber concrete bond, reduced the rebound, and offer high toughness in shotcrete.

Considerable research, development, and applications of steel fiber reinforced concrete (SFRC) are currently taking place. The use of steel fibers in concrete, with different fiber volumes and aspect ratios, increases the compressive strength of the material. In general, the addition of fibers does not significantly increase the compressive strength but it does increase the compressive strain at ultimate load [4].

The influence on the other hand of steel fibers on the flexural strength of concrete and mortar is much greater than in the case of the tensile or compressive properties of these materials [3]. The use of steel fibers in concrete significantly increases the flexural strength of the material. Furthermore, the increase in the flexural strength of SFRC is significant. The behavior of steel fibered reinforced concrete at the material and the structural level was studied by different scholars.

### 1.2 Statement of the Problem

Using steel fiber extracted from the used tire in reinforced concrete is interesting in two ways. The first one is the environmental issue regarding the disposal of the used tire. The second and the important point is how much it is effective in the application as steel fiber in concrete.

A series of experimental tests on steel fibered reinforced concrete were performed to investigate the behavior or mechanical properties of SFRC. More recently, experimental and analytical researches were carried out on the mechanical property of concrete when steel fibers are used in different ways, amount of dosage, shape, and aspect ratio. Almost all experimental investigations on the Steel fiber reinforced concrete mainly focused on the virgin fiber.

Different models are proposed by researchers (Baros and figuiras, lok and pei 1998, Tlemat 2006, lok and xiao 1999, etc.) for numerical analysis of virgin steel fiber effect on the mechanical properties of concrete. Following this finding other researchers have tried to investigate the certainty of these models using nonlinear finite element analysis software like ABAQUS, ANSYS, etc. by validating the output of software with experimental tests and have got satisfactory results [10, 11, and 23].

However, those researchers had not used these models to investigate the mechanical effect of recovered steel fiber on concrete for analytical investigation. This study tried to investigate the effect of RSF, specifically from used tire on concrete by ABAQUS software using a model proposed by Lok and Xiao 1999. Analyses was carried out to fill the gaps; the effect of recovered steel fiber fraction from waste tires on the flexural capacity (post cracking stage in terms of load displacement) of concrete beam with different grades of concrete using ABAQUS software.

### 1.3 Objectives of the Study

The general objective of this study is to analyze the effect of steel wires (bead wire) extracted from used heavy duty truck tires (diameter 22.5" - 24.5") in concrete on concrete flexural capacity. And then using experimental study and finite element analysis provide comprehensive information on the flexural strength of steel fiber reinforced concrete beam considering significant parameters of both concrete and steel fibers extracted from used tire (RSF).

Specifically, this study sought the following objectives

- To investigate the effect of applying different volume of fractions of RSF on peak flexural load carrying capacity of concrete using different grades of concrete by FEA.
- To investigate the effect of RSF on compressive strength, workability and flexural capacity of concrete experimentally.

### 1.4 Research Question

1) What is the effect of the different volume fraction of steel fiber extracted from the used heavy duty truck tire on concrete in peak flexural load carrying capacity and post cracking stage?
2) Does Adding of RSF on concrete have effect on compressive strength, split strength and workability of concrete?

### 1.5 Significance of the Study

Results gained from this study are expected to contribute to the efforts made to characterize the mechanical properties of RSFRC structure and more application of recovered steel fiber in concrete structure will initiate in our country.

The use of SFRC has the advantage of increasing static and dynamic tensile strength, energy-absorbing characteristics, and better fatigue strength over conventional concrete.

The use of structure produced using this type of concrete, will reduce damage due to abrasion and impact in industrial floors, and reduce both thickness and cracking of highway and airport rigid pavements, good in the repair of concrete structures, best in producing of precast products like pipes, beams, manhole covers, etc.

- It will encourage other researchers to investigate the effect of RSF on concrete using this approach in detail.
- It will encourage tire factories to focus on business gained from the extraction of tire steel wire.
- It will encourage our country universities and their students to study in detail on RSFRC for future applicability.

## 1.6 Scope and Limitation of the Study

The recovered bead wire from used heavy duty truck tire were cut into 60mm length and these wires are used in three fraction dosage i.e. 1.0%, 1.5% and 2.0% alternatively for three grades of low strength concrete and their result were analyzed. The burning process to recover steel wires affects the ductility of wires which intern would influence the flexural capacity RSFC. In this investigation all studies were performed using constant aspect ratio and low strength concrete at material level.

# CHAPTER TWO
# REVIEW OF RELATED LITERATURE

Since ancient times, fibers have been used to reinforce brittle materials. Straw was used to reinforcing sun-baked bricks, and horsehair was used to reinforce masonry mortar and plaster. A pueblo house built around 1540, believed to be the oldest house in the U.S., is constructed of sun-baked adobe reinforced with straw [4, 12]. In more recent times, large scale commercial use of asbestos fibers in a cement paste matrix began with the invention of the Hatschek process in 1898. Asbestos cement construction products are widely used throughout the world today.

However, primarily due to health hazards associated with asbestos fibers, alternate fiber types were introduced throughout the 1960s and 1970s [4, 12]. Experimental trials and patents involving the use of discontinuous steel reinforcing elements -such as nails, wire segments, and metal chips - to improve the properties of concrete date from 1910. During the early 1960s in the United States, the first major investigation was made to evaluate the potential of steel fibers as reinforcement for concrete. Since then, a substantial amount of research, development, experimentation, and industrial application of steel fiber reinforced concrete has occurred [4, 12]. Use of glass fibers in concrete was first attempted in the former USSR in the late 1950s. It was quickly established that ordinary glass fibers, such as borosilicate E-glass fibers, are attacked and eventually destroyed by the alkali in the cement paste. Considerable development work was directed towards producing a form of alkali-resistant glass fibers containing zirconia. This led to a considerable number of commercialized products [4, 12].

Initial attempts at using synthetic fibers (nylon, polypropylene) were not as successful as those using glass or steel fibers. However, a better understanding of the concepts behind fiber reinforcement, new methods of fabrication, and new types of organic fibers have led researchers to conclude that both synthetic and natural fibers can successfully reinforce concrete [4,12]. Considerable research, development, and applications of FRC are taking place throughout the world. Industry interest and potential business opportunities are evidenced by continued new developments in fiber-reinforced construction materials. These new developments are reported in numerous research papers, international symposia, and state-of-the-art reports issued by professional societies [12].

## 2.1 Fibered reinforced concrete

The concept of using fibers in the matrix is not new. Initially, during the Egyptian and Babylonian civilizations, fibers had been used to reinforce brittle material.

There are different types of fibers used in concrete as mentioned in detail in chapter one of this article. It has been suggested that the U.S. Department of Defense was the initiator of interest in fiber-reinforced concrete in the late 1950s. Regardless of the historical responsibility, most of the market from that time has consisted of individual fibers from glass and sheet steel by-products or scraps. These were commonly known as fiberglass and steel shavings. The introduction of these fibers into the concrete became a problem due to handling, balling, and uneven dispersion. The benefits in the performance of the concrete were not significant enough in most cases to warrant the additional effort [13].

Today the improvement in using different types of fiber reinforced concrete is interesting in high strength concrete. According to the terminology adopted by the American Concrete Institute (ACI) Committee 544, Fiber Reinforced Concrete, there are four categories of FRC based on fiber material type. These are steel fiber reinforced concrete (SFRC), glass fiber reinforced concrete (GFRC), synthetic fiber reinforced concrete (SNFRC) including carbon fibers, and natural fiber reinforced concrete (NFRC) [14].

### 2.1.1 Areas of fiber reinforced concrete applications

There are many applications in which FRC may be required to act as a primary structural load-carrying component,( i.e Provides structural integrity). However, there are many more applications in which the fibers are intended principally to augment the integrity of the matrix material and in this way favorably affect the integrity of the structural system. In the latter case, the goal is to affect the non-structural serviceability aspects of the design. Confinement of an FRC matrix can either be from internal sources, such as conventional reinforcement, or from external structural support. Applications in the low fiber volume regime include slab on grade and composite deck as two examples. In these applications, the continued ability to transfer tensile stress, either through the matrix or through fibers that bridge cracks, improves the serviceability aspects of design such as durability and toughness. Applications of the cast in place and precast FRC in new construction and repair include a dam, bridge deck, mine, tunnel, canal, and reservoir lining, security and utility vaults, caisson, pile, and pile cap foundation elements, slope stabilization, refractory castables and precast, a modular panel including tilt-up and sheet, breakwaters, mine crib block, machine bases, pipe, and non-structural flatwork such as for highway, airport, composite deck, residential grade slab, and industrial floors. For the wide range of applications listed there is a correspondingly wide range of appropriate FRC formulations.

### 2.1.2 Volume of fiber in applications

Low fiber volume applications, using less than 0.5 - 1% fiber, have experienced commercial success. Within this category performance criteria will usually include a desire for a high degree of material integrity in the form of crack width and area reduction, i.e. Crack control, for both aesthetic and serviceability-related considerations. These are applications in which the stress due to loading is less important than control of the effects of volume change. The use of relatively low fiber volumes minimizes the effect of fibers in batching, mixing, and placing operations. Also, in these applications, the energy-absorbing capabilities of fibers and their effect on matrix integrity are realized at all stages of concrete maturity; including from the time the concrete is placed and is still in the plastic state. The effect of the fibers is more in the nature of energy absorption and crack control rather than in increased load transfer capacity. Although the fiber volume is relatively low the fibers are yet present in large numbers uniformly distributed throughout the concrete mass. So, that they are affecting crack propagation in both the immature and the mature concrete. The genesis of the design as to the specification of the number of fibers is empirically based. However, most field experience and reported research have been at fiber volume loadings of 0.5 -01% for steel fiber [14].

### 2.1.3 Steel fiber reinforced concrete, SFRC

Fiber-reinforced concrete (FRC) is a composite material made primarily from hydraulic cement, aggregates, and discrete reinforcing fibers. Steel fiber reinforced concrete (SFRC) was first introduced in the early 20th century. The earliest study on SFRC was published in 1910; in the United States, Porter envisaged the incorporation of short steel fibers into the concrete matrix to reinforce the concrete materials. Graham proposed the incorporation of steel fibers into ordinary reinforced concrete to improve its strength and volume stability in 1911 [15]. Throughout investigation and technology advancement the use of ultra-high-strength concrete is important for the construction of different heavy loads carrying RC structures. In the construction of high load-carrying structures, the use of steel fiber plays a great role in improving the flexural strength of reinforced concrete by controlling the crack width.

Steel fiber reinforced concrete (SFRC) during the few past decades has been found to possess many excellent dynamic performances such as high resistance to explosion and penetration, which has now attained acknowledgment in many engineering applications since it has several advantages. The randomly distributed short fibers are used to improve the physical properties of reinforced concrete structures due to resistance from crack initiation to crack propagation [16].

Lately, it has become more frequent to substitute steel reinforcement because adding fibers can overcome the brittleness of the concrete by improving the post-cracking behavior and enhancing ductility [16]. In particular, concrete is a unique composite material that is porous and highly heterogeneous. It is brittle in resisting tensile stresses, but the addition of discontinuous fibers leads to a dramatic improvement in its toughness during the fracture process. The randomly distributed short fibers can improve the physical properties of reinforced concrete structures. It is generally agreed that the fibers contribute primarily to the post-cracking response of the matrix, by providing resistance to the crack opening [16].

Numerous works for evaluating mechanical properties of SFRC have been reported, it now has been well accepted that incorporation of steel fiber can significantly improve the mechanical behaviors of concrete.

#### 2.1.3.1 Effect of the fiber parameters on RC

The mechanical properties of SFRC are mainly dependent upon fiber parameters, fiber content, matrix strength, and fiber-matrix interaction. In applying steel fiber into reinforced concrete, the mechanical properties of RC are affected in different ways. This happens due to the dosage of steel fiber, the shape of steel fiber, the length of steel fiber, and the tensile strength of steel fiber. Different researchers tried to investigate these parameters' effect on the behavior of SFRC.

##### 2.1.3.1.1 Effect of the steel fiber on Compressive strength

The addition of fibers had affected the high residual concrete strength after the appearance of the first crack and had increased the toughness [17].

The increase in the fiber volume content had increased the mechanical properties of the concrete. Also, predictive models have been presented for the mechanical properties of fiber-reinforced concrete using different fiber volume contents [1].

The addition of fiber into concrete slightly increases its compressive strength. This increment in the compressive strength may have resulted from the confining effect of added fibers to the concrete. The compressive strength of the concrete increased due to the arresting of the growth of cracks, depending on the bond strength of the steel fiber and the matrix. The high content of fiber reduces compressive strength due to the reduction of the concrete matrix and adversely affects the workability of the concrete [18].

The shape of steel fiber highly affects the compressive strength of concrete in addition to content. From straight, hooked end and deformed steel fibers hooked end steel fiber is the most which decrease the following ability of concrete. This affects the compaction operation which will decrease the compressive strength of SFRC [19].

The compressive strength and elastic modulus were slightly influenced by the fiber contents, whereas the strain capacity (strain at the peak) noticeably increased with the fiber content. The compressive strength slightly decreased with the addition of steel fibers for the case of normal concrete, whereas it slightly increased by including steel fibers for the cases of HSC and UHSC. The opposing results attributed to combined positive and negative effects by adding fibers, i.e., better crack inhibition, higher air content, fiber ball, etc. However, the amount of increase and decrease of compressive strength by steel fibers was insignificant [20].

The increment of steel fiber increases the compressive strength of RC. However, at the high volume fractions of steel fibers (Vf > 0.75%), smaller compressive strengths were observed in SFRCs, relative to the ordinary concrete, which was caused by the inhomogeneous dispersion of the fibers [11].

#### 2.1.3.1.2 Effect of the steel fiber on flexural strength

The dosage and aspect ratio of steel fiber greatly affects the flexural behavior of RC. When the content of steel fiber increases in RC, flexural strength of concrete rises due to residual stress development in SFRC.

**i) Effect of steel fiber content, type and length**

A summary of corresponding strength data shows that the flexural strength of SFRC is about 50 to 70 percent more than that of the un-reinforced concrete matrix in the normal third-point bending test. [21].

In an experimental study on the SFRC beam shows the flexural strength and corresponding deflection greatly increased with fiber content and compressive strength peak load. This great increase of the deflection at the peak was caused by superb fiber bridging at the crack surfaces, and this leads to a higher load-carrying capacity after first cracking [20].

It was observed that the deflection corresponding to the ultimate load increases with the increase in the fiber content. The increase in the fiber content from 0.5% to 1.5% has increased the flexural strength from 3% to 124% for the fiber with the smaller aspect ratio of 65, whereas for the higher aspect ratio of 80 to140% increase in the flexural strength have observed compared to the concrete without any fibers. For smaller lengths of the fiber and lesser content of the fiber, an almost negligible effect on the increase in flexural strength was observed. The deflection hardening behavior had observed in the concrete with a volume fraction of 1% of fiber for all lengths of the fibers. The initial part of the load-deflection curves for all water-to-cement ratios with different fiber contents is observed to be linear [18].

The increase in the length of fiber has increased the load and deflection behavior of concrete. The fibers with greater length have shown improved load and deflection behavior of the concrete irrespective of the fiber volume fraction [18]. The steel fiber type has a little effect on the pre-cracking stage, but significant influence on the post-cracking stage of load-deflection curves [23].

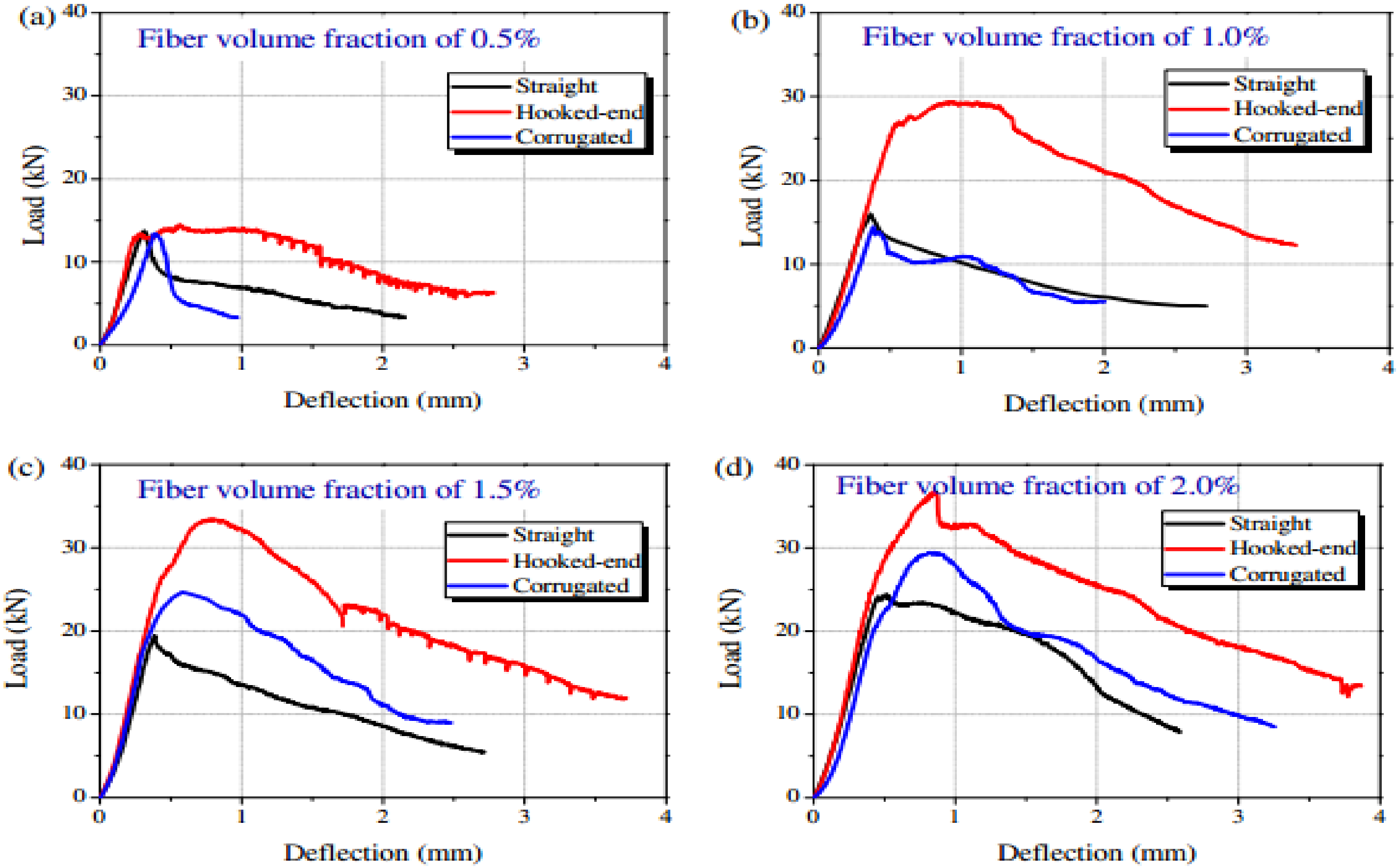



Figure 2.1: Typical diagram for effect of steel fiber type and steel fraction on the load-deflection curves for SFRC **[22]**

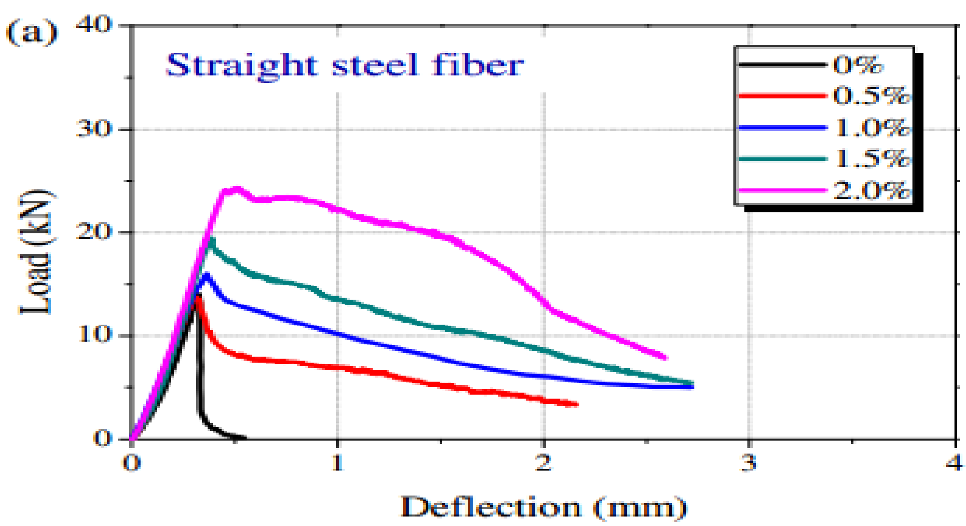



Figure 2.2: Typical diagram for effect of straight steel fiber volume fraction and aspect ratio on the load-deflection curves for SFRC. [22]

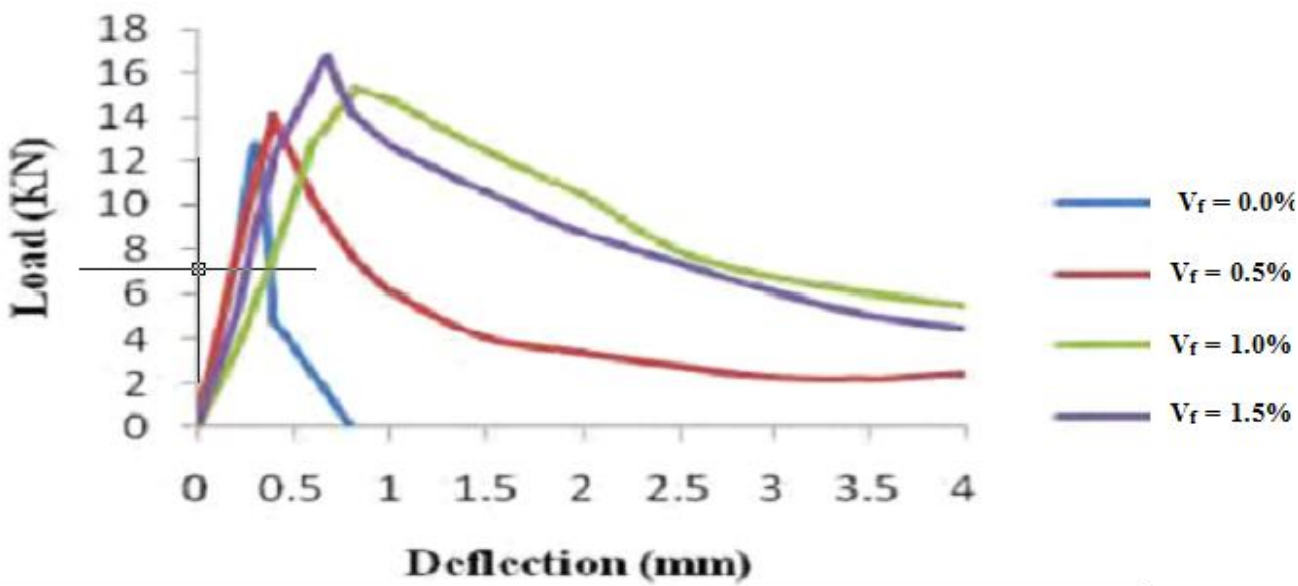



Figure 2.3: Graph shows effect of recovered steel fiber volume Vf on RC [21]

**ii) Effects of steel fiber orientation on tensile strength**

The orientation of fibers determines the tensile strength of the SFRC. If the orientation is parallel to the load direction the fiber increase the strength but if it is random orientation it has less effect on tensile strength. Unlike the compressive strength of the SFRC, more increases in the tensile strength of the concrete with the addition of fibers have been observed, with the value of 11% and 47% for 0.5% and 1.5% fiber contents, respectively, at 28 days. It has been observed that the tensile strengths increased linearly with an increase in the fiber content. The tensile strength of concrete with a lower water-to-cement ratio has shown a reduced increase in the tensile strength of about 31%, whereas the concrete with a higher water-to-cement ratio shows enhancement in the tensile strength of about 47% in the F15L60 mix, which is due to arresting of the cracks. The tensile strength of the concrete has increased linearly with an increase in the fiber content for all water-to-cement ratios. The enhancement in tensile strength was more pronounced in the concrete with lesser strength, owing to the decreased toughness of the matrix and the occurrence of crack arrest through fiber bridging. The benefit of the fiber for the enhancement in the tensile strength of concrete is dependent upon the crack arrest and the fiber transferring energy [18].

## 2.2 Numerical analysis of steel fiber reinforced concrete

Several kinds of literature show behavior of SFRC have studied experimentally and models were developed by different researchers for numerical analysis purpose/ design. Different scholars have studied the behavior of SFRC at the material and structural level; beam using nonlinear FEA, using software (eg. ANSYS, ABAQUS, DIANA, etc) and validating the results of software by laboratory experimental result data. Experimental investigations were performed by many researchers and tensile stress-strain relationship models have developed for numerical analysis. The aforementioned researchers from their experimental test result developed a stress-strain or stress-crack width relationship model for the design of SFRC structures for numerical analysis. And many researchers performed different investigations on the SFRC beam to confirm those proposed analytical models.

For recovered steel fiber reinforced concrete stress-strain relationship model was also proposed by [23]. And these proposed models were investigated experimentally for their effectiveness [23]. From these models proposed by different investigators, the stress-strain relationship proposed by Lok and Xiao 1999 is a sufficient model due to different reasons mentioned in [23].

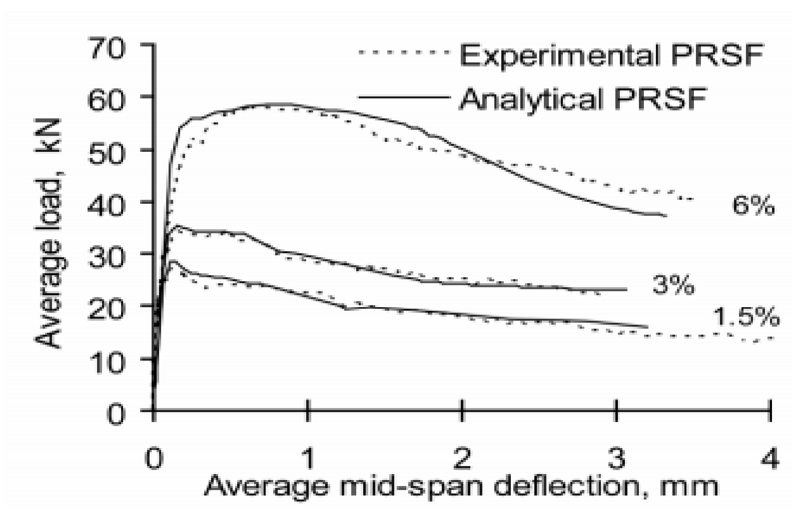



Figure 2.4: Typical diagram for recovered steel fiber reinforced concrete prisim (PRSF) [24].

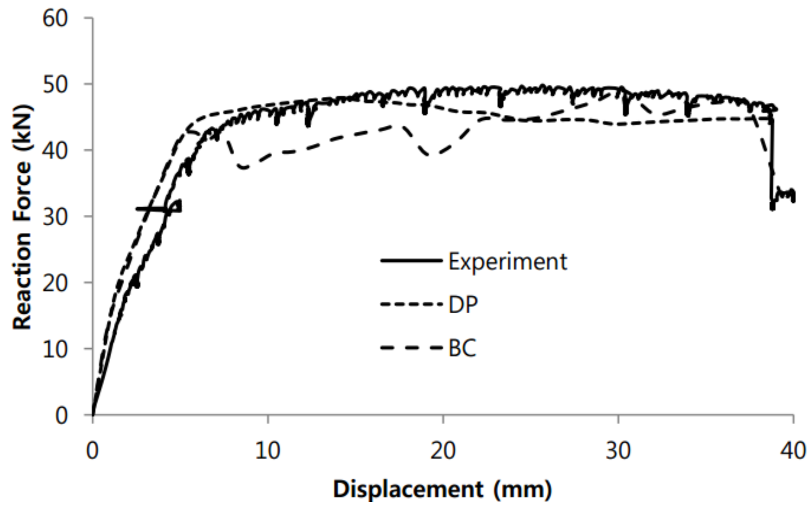



Figure 2.5: Load-deflection curve obtained experimentally and numerically by testing the specimens under static loading monotonically applied to failure with fibre content of Vf = 1% (DP = Damage plasticity model, BC = Brittle Cracking model) [11].

# CHAPTER THREE

# RESEARCH METHODOLOGY

## 3.1 Research Design

This study has used a numerical analysis method by the so-called nonlinear finite element analysis (NLFEA). There are several nonlinear finite element analysis software which simplifies the researcher's effort. From this software ABAQUS is well-known NLFEA commercial software. For this study the behavior of the SFRC beam a numerical model was simulated in Finite Element Analysis software called ABAQUS.

The numerical model realistically describes the fully brittle tensile behavior of plain concrete as well as the contribution of steel fibers to the post-cracking response. To have fresh and hardened behavior of concrete, laboratory tests have been performed for each batch of concrete (slump test, split test and compressive strength).

After comprehensively organizing a literature review of different previous published researches, designate the comparative study of RSFC beam with different parameters. Validation for the finite element modeling is conducted on pre-qualified and practical tests for Beam under axial load. After that specific study parameters introduced for RSFC beam to investigate the influence of those parameter on the response of beam in flexure.

This research has followed the following engineering research methodology's design procedures for FEA.

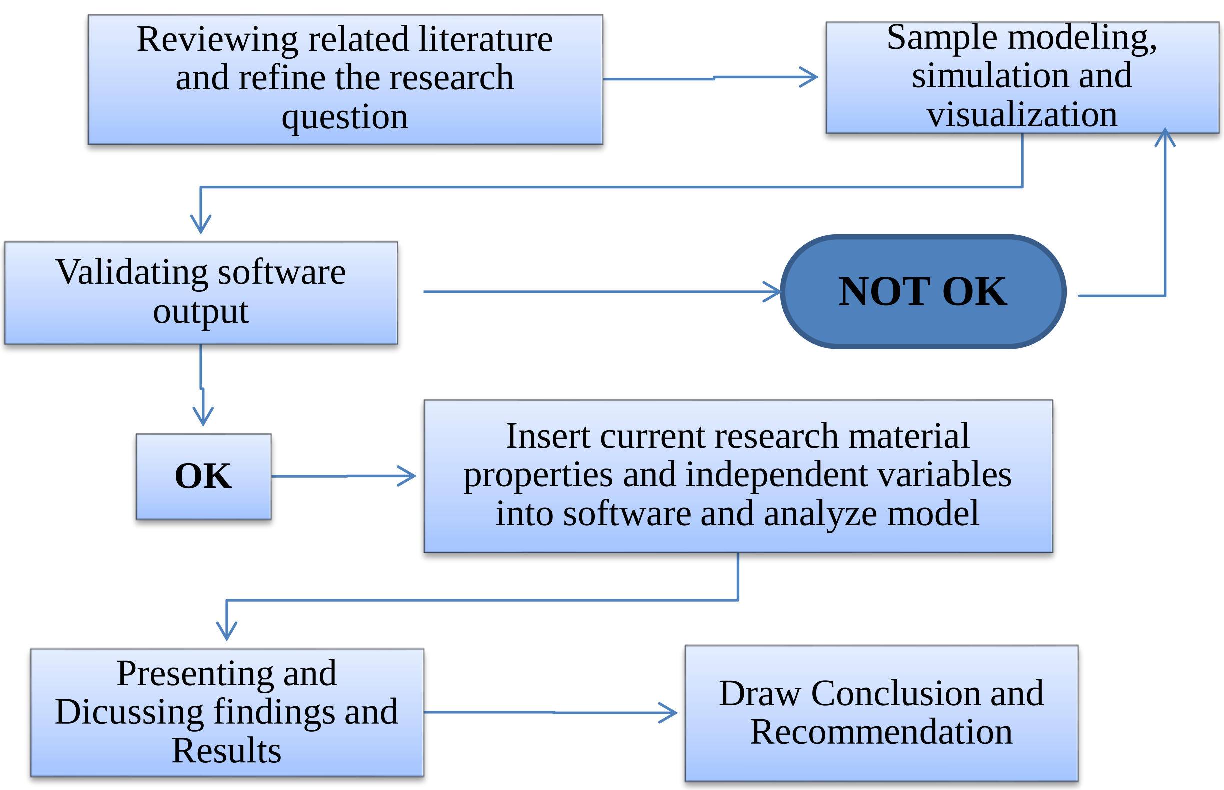



Figure 3.1: Flow chart of numerical analysis of SFRC beam (in ABAQUS)

### 3.2 Model Samples, Load Arrangement and Dimensions of current investigation

The researcher has investigated the behavior of RSFC using three grades of concrete by adding three different amounts of RSF. For each grade of concrete and steel fiber content, there are three control and nine samples of RSFC beams under investigation. Control samples have zero recovered steel fiber. There were nine samples of recovered steel fibered concrete (RSFC) beams for flexural analysis, for three different content of fiber (RSF). These samples were simulated by incorporating 1.0 %, 1.5 % and 2.0 % of RSF into the samples for each grade of concrete. These samples have a unique designation in the simulation and analysis process. These designations were indicated in detail in the table below. For instance, C-20-1.0 indicates that an RSF of 1.0% by volume of concrete was incorporated into a concrete mix design which will give nominal compressive strength of 20 Mpa to produce an RSFC beam sample. The length and diameter of RSF were taken as a constant value of 60mm and 0.89mm respectively which gives a constant aspect ratio of 67 for all beam samples.

**Table 3.1: shows RSFRC specimen's designation and fraction of steel fiber for compressive test.**

| Concrete Grade | Mix Designation | Specimens No | Steel fraction Vf, (%) |
|---|---|---|---|
| C-20 | Control 1 | C20001 | 0.0 |
| | | C20002 | 0.0 |
| | | C20003 | 0.0 |
| | C-20-1.0 | C20101 | 1.0 |
| | | C20102 | 1.0 |
| | | C20103 | 1.0 |
| | C-20-1.5 | C20151 | 1.5 |
| | | C20152 | 1.5 |
| | | C20153 | 1.5 |
| | C-20-2.0 | C20201 | 2.0 |
| | | C20202 | 2.0 |
| | | C20203 | 2.0 |

| Concrete Grade | Mix Designation | Specimens No | Steel fraction Vf, (%) |
|---|---|---|---|
| C-25 | Control 2 | C25001 | 0.0 |
| | | C25002 | 0.0 |
| | | C25003 | 0.0 |
| | C-25-1.0 | C25101 | 1.0 |
| | | C25102 | 1.0 |
| | | C25103 | 1.0 |
| | C-25-1.5 | C25151 | 1.5 |
| | | C25152 | 1.5 |
| | | C25153 | 1.5 |
| | C-25-2.0 | C25201 | 2.0 |
| | | C25202 | 2.0 |
| | | C25203 | 2.0 |

| Concrete Grade | Mix Designation | Specimens No | Steel fraction Vf, (%) |
|---|---|---|---|
| C-30 | Control 3 | C30001 | 0.0 |
| | | C30002 | 0.0 |
| | | C30003 | 0.0 |
| | C-30-1.0 | C30101 | 1.0 |
| | | C30102 | 1.0 |
| | | C30103 | 1.0 |
| | C-30-1.5 | C30151 | 1.5 |
| | | C30152 | 1.5 |
| | | C30153 | 1.5 |
| | C-30-2.0 | C30201 | 2.0 |
| | | C30202 | 2.0 |
| | | C30203 | 2.0 |

Table 3.2: shows beam specimen's designation and fraction of steel fiber for analysis.

| Concrete Grade | Mix Designation | Specimens No | Steel fraction Vf, (%) |
|---|---|---|---|
| C-20 | Control 1 | C-20-0.0 | 0.0 |
| | C-20-1.0 | C-20-1.0 | 1.0 |
| | C-20-1.5 | C-20-1.5 | 1.5 |
| | C-20-2.0 | C-20-2.0 | 2.0 |
| C-25 | Control 2 | C-25-0.0 | 0.0 |
| | C-25-1.0 | C-25-1.0 | 1.0 |
| | C-25-1.5 | C-25-1.5 | 1.5 |
| | C-25-2.0 | C-30-2.0 | 2.0 |
| C-30 | Control 3 | C-30-0.0 | 0.0 |
| | C-25-1.0 | C-30-1.0 | 1.0 |
| | C-25-1.5 | C-30-1.5 | 1.5 |
| | C-25-2.0 | C-30-2.0 | 2.0 |

A simply supported fibered reinforced concrete beam was analyzed as part of the present research study under static loading. Samples under this investigation have 1.70 m length, 0.18 m depth and 0.10 m width. All samples' support conditions are simply supported at both ends. Initially, concrete without fibers beams was analyzed and then fibers were added at a volume fraction of 1.0%, 1.5% and 2.0%, and analysis was continued for each fiber fraction added to the beam. The shape and geometry of the beam specimens were shown in Fig. 3.2.

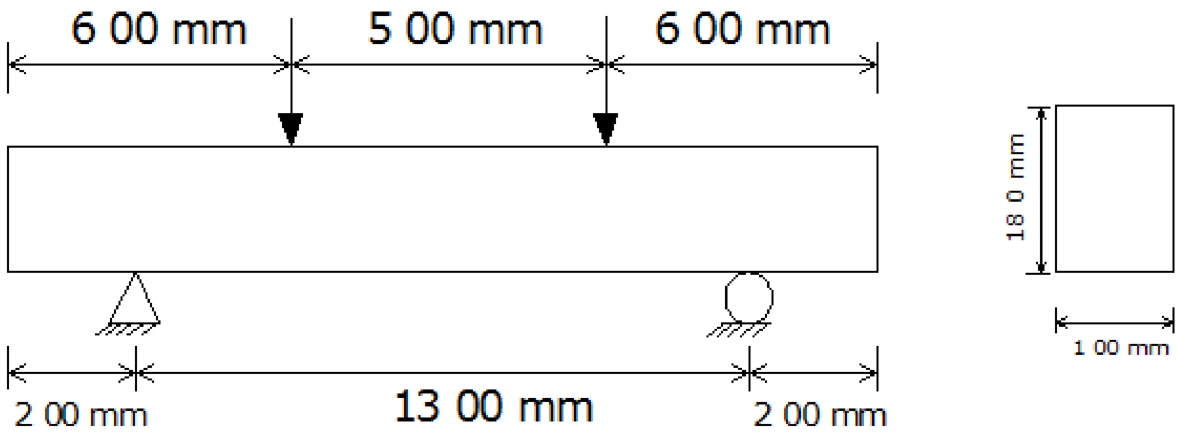



Figure 3.2: Dimensions and arrangement of current RSFRC beam for analysis

### 3.3 Data Processing and Analysis

**a) Finite Element analysis**

Finite element solvers can either use linear or non-linear analysis. Initially, the use of FE required the designer to define the location of every node for each element by hand and, then the data were entered as code that could be understood by a computer program written to solve the stiffness matrix. The Finite Element Analysis (FEA) of fibered reinforced concrete beam specimens was performed in a nonlinear static analysis format. In ABAQUS every complete finite-element analysis consists of three separate stages:

- *Pre-processing* or *modeling*: This stage involves creating an input file that contains an engineer's design for a finite-element analyzer (also called "solver"). Pre-processing involves creating a geometric representation of the structure, assigning properties, and then output the information as formatted data file
- *Processing* or *finite element analysis*: This stage produces an output visual file.
- *Post-processing* or generating a report, image, animation, etc. from the output file: This stage is a visual rendering stage.

Modeling and simulation of different types of samples of RSFC beam started and continued until all samples have finished.

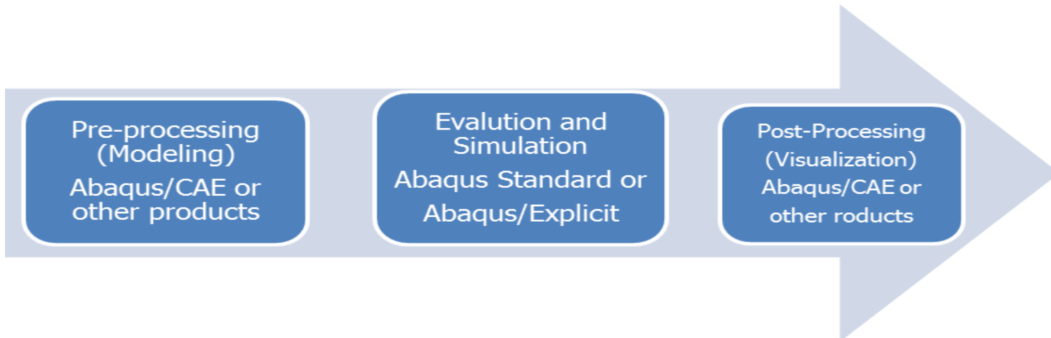



Figure 3.3: ABAQUS software products used in Finite Element Analysis and their order of use

**b) ABAQUS constitutive model**

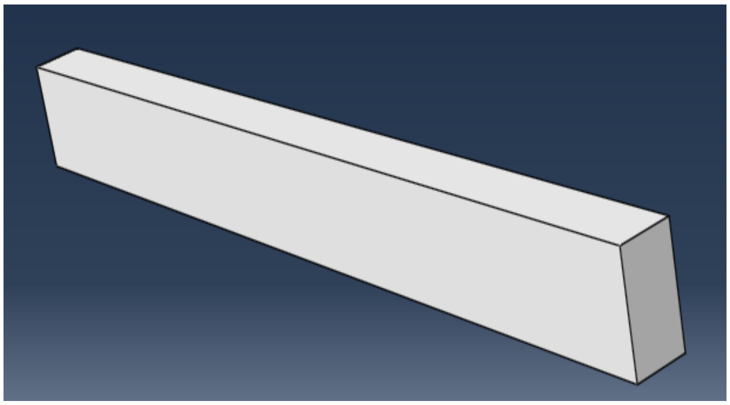
There are three main constitutive models have designed in ABAQUS (2016) software for NLFEA analysis of plain concrete namely smeared cracking model, Brittle cracking concrete model and more complex model called Damaged Plasticity concrete model. The first model needs material property definition under both tension and compression condition. But the second requires only tensile behavior of SFRC [11, 23]. For this study Damaged Plasticity concrete models were used [23], Suitable material relations describing compression and tension were taken for SFC and incorporated into ABAQUS software. This means constitutive relations would be incorporated into ABAQUS software to allow for the effects of fibers.

Incorporation of steel fibers at small dosages to the concrete mix results in a softening post cracking response, whilst the provision of higher fiber contents leads to a hardening behavior as the fibers undertake the tensile forces which are acting normal to the plane of crack and will cause the increase in residual tensile strength and in the latter hardening response case, failure eventually occurs to pull-out of the fibers and development of finer and more distributed multiple cracks as opposed to the single crack associated with softening behavior.

### 3.4 Finite Element modeling of simply supported four point load Beam

This section describes the finite element model that was developed in the study. It begins with examining first the simplification of the geometry of the physical specimen, followed by a description of the mesh elements used to discretize the geometry, an overview of boundary conditions imposed on the mesh, and a description of the various material models that define the behavior of the model. A complete 3D finite element model was developed in this modeling.

A total of two parts (Concrete and Plate for uniform load distribution) were used to represent simply supported RSC beam in the finite element model. The FEM of the RSFC beam was carried out by modeling the concrete part and plate part.



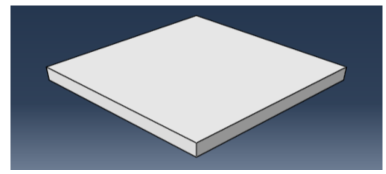


Figure 3.4: Parts used in during modeling (Concrete and steel Plate)

### 3.4.1 Element type and selection

The ABAQUS standard modules consist of a comprehensive element library that provides different types of elements depending on different situations. For reference, it is usual to use a ‘beam’ element; this will provide results for flexure, shear, and displacement directly. Beam and truss elements are generally triangular or quadrilateral with a node at each corner. However, elements have been developed that include an additional node on each side, this gives triangle elements with six nodes and quadrilateral elements with eight nodes. Since the only places where the forces are accurately calculated are at the nodes (they are interpolated at other positions), the accuracy of the model is directly related to the number of nodes.

To reduce computational time 3D 8-noded hexahedral (brick) elements having three degrees of freedom in each node (translations in X, Y, and Z directions) are used for modeling concrete elements with reduced integration (C3D8R) to prevent the shear locking effect. For modeling reinforcements 2-noded truss elements (T3D2) having 3 degrees of freedom in each node was used. The embedded method with a perfect bond between reinforcement and surrounding concrete is adopted to properly simulate the reinforcement-concrete bonding interaction.

### 3.4.2 Material modeling

Different researchers performed experimentally and numerically and several models were proposed by different other researchers and concluded that the model proposed by Lok and Xiao (1999) is more enough and suitable than others. Hence this model was used to define the compressive and post cracking tensile behavior of SFC [23].

### a) Compression properties of concrete

Modulus of elasticity of concrete were calculated as Ec = $9.5*(f_{ck}+8)^{1/3}$ where fck is the compressive strength of concrete in Mpa and calculated as 28.11, 29.68 and 31. (EBCS1995) . For SFC having steel content of 0.5% to 2% Lok and Xiao et al suggested the value of ultimate compressive strain, εcu of 0.0038 as mentioned in [25].

According to Lok and Xiao (1999), the compressive stress-strain relationship is described as;

$$\sigma = f'_c[(2\varepsilon/\varepsilon_{co}) - (\varepsilon/\varepsilon_{co})^2] \quad for\ \varepsilon \le \varepsilon_{co}$$

$$\sigma = f'_c[1-0.15*(\varepsilon - \varepsilon_{co} / \varepsilon_{cu} - \varepsilon_{co})] \quad for\ \varepsilon_{co} < \varepsilon < \varepsilon_{cu}$$

$$\varepsilon_{co} = f'_c / E_{co}$$

Where, $f'_c$ is cylindrical compressive strength of concrete

$E_{co}$ is modulus of elasticity of concrete

$\varepsilon_{co}$ **is corresponding** strain at maximum stress

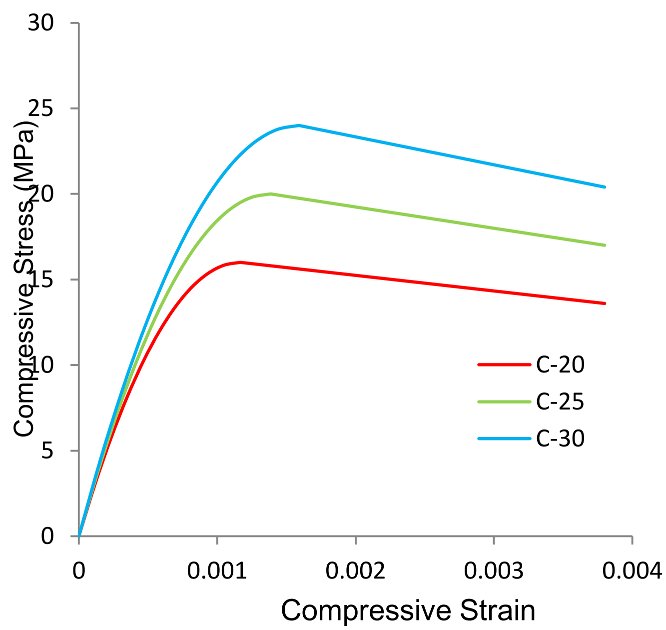



Figure 3.5: compressive stress strain relation for different grade of concrete adopted from Lok and Xiao 1999 for this study.

**b)Tension properties of concrete**

Lok and Xiao 1999 proposed the following tensile stress-strain relations for steel reinforced concrete and used to calculate tension stress and strain values that used for analysis:

$$\sigma_t = f_t[(2\varepsilon/\varepsilon_{t1}) - (\varepsilon/\varepsilon_{to})^2] \qquad for \quad 0 \le \varepsilon \le \varepsilon_{co}$$

$$\sigma_t = f_t[(1-(1/f_{tu})*(\varepsilon-\varepsilon_{to}/\varepsilon_{t1}-\varepsilon_{to})] \qquad for \quad \varepsilon_{to} \le \varepsilon \le \varepsilon_{t1}$$

$$\sigma_t = f_{tu} \qquad for \quad \varepsilon_{t1} \le \varepsilon \le \varepsilon_{tu}$$

Where $f_t$ is the ultimate tensile strength of SFRC, $\varepsilon_{to}$ is the corresponding ultimate strain and $f_{tu,}$ is the residual strength from the strain $\varepsilon_{t1.}$

*And these values are defined by Lok and Pei (1999) as:*

$$f_{tu} = \eta * v_f * \tau_d * L/d$$

$$\varepsilon_{t1} = \tau_d * L/d * 1/E_s$$

*where* $\eta$ *is fiber orientation factor in a three dimensional (3D) case, Lok and Xiao (1999) used the value of* $\eta$ *as 0.405 for beams and 0.50 for slabs to demonstrate a situation between 3D and 2D random orientations. In addition,* $V_f$ *is defined as the fiber volume fraction* $\tau_d$ *is the bond stress interaction between concrete and steel fibers 0.405 for straight fiber Oh et al (1998),* **L/d** *is aspect ratio of the steel fiber and* $E_s$ *is the elastic modulus of steel fiber 200 GPa is taken.*

Detail calculation results of stress and strain for Compression and Tensile behavior which are used for ABAQUS are summarized in the form of table under Appendix E.

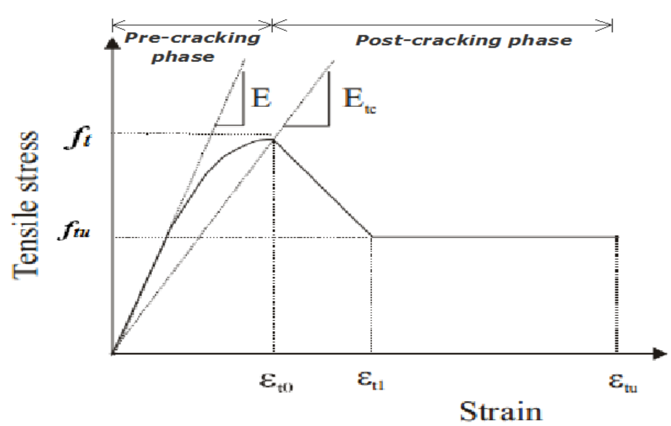



Figure 3.6: SFC model in uniaxial tension proposed by Lok and Xiao (1999)

### 3.4.3 Recovered steel fiber properties

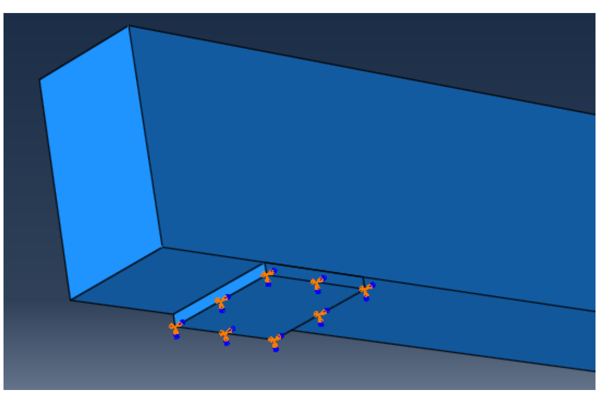
Property of recovered steel fiber used was summarized in Table 3.3

**Table 3.3: Material properties characterizing SFC for present study**

| RSF type | RSFRC type | Length, L (mm) | Diameter, d (mm) | Aspect ratio (L/d) | Fiber Volume ($V_f$) (%) | Compressive strength (from test) (MPa) | Tensile strength (from test) (MPa) |
|---|---|---|---|---|---|---|---|
| - | Control 1 | - | - | - | 0.0 | 21.45 | 2.40 |
| Straight | C-20-1.0 | 60 | 0.89 | 67 | 1.0 | 22.07 | 3.87 |
| Straight | C-20-1.5 | 60 | 0.89 | 67 | 1.5 | 22.35 | 4.62 |
| Straight | C-20-2.0 | 60 | 0.89 | 67 | 2.0 | 23.60 | 5.31 |
| - | Control 2 | - | - | - | 0.0 | 27.02 | 2.62 |
| Straight | C-25-1.0 | 60 | 0.89 | 67 | 1.0 | 27.65 | 4.20 |
| Straight | C-25-1.5 | 60 | 0.89 | 67 | 1.5 | 28.27 | 5.32 |
| Straight | C-25-2.0 | 60 | 0.89 | 67 | 2.0 | 29.44 | 6.30 |
| - | Control 3 | - | - | - | 0.0 | 34.63 | 3.17 |
| Straight | C-30-1.0 | 60 | 0.89 | 67 | 1.0 | 35.87 | 5.08 |
| Straight | C-30-1.5 | 60 | 0.89 | 67 | 1.5 | 36.22 | 6.71 |
| Straight | C-30-2.0 | 60 | 0.89 | 67 | 2.0 | 37.40 | 7.42 |

## 3.5 Boundary Conditions and Loading

In ABAQUS boundary conditions can impact both the results and stability of the analysis. The boundary condition was applied at rigid body constraint reference point with all degree of freedom fixed and the vertical translations at the support were fixed. Having these boundary condition an axial load on the top of beam at two points was exerted through displacement control loading. Uniformity of vertical displacement through the section was ensured and the loading rate could be controlled precisely.



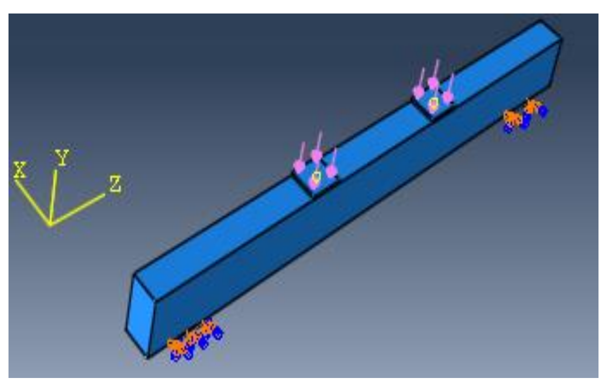



Figure 3.7 Boundary Conditions and Loading

**3.6 Meshing**

In ABAQUS meshing can be done individually on parts and then assembled or vice-versa. In this analysis, parts were individually meshed and then assembled for further process. Meshes are composed of tri-dimensional continuum solid elements with 8 nodes called C3D8R, 8 nodes linear brick elements with reduced integration were used for both materials. Meshing blocks size affects time to compute and output result accuracy. The coarser mesh size takes less computation time and gives less accurate result and vice versa. For this study the mesh size for concrete was taken as 30mm.

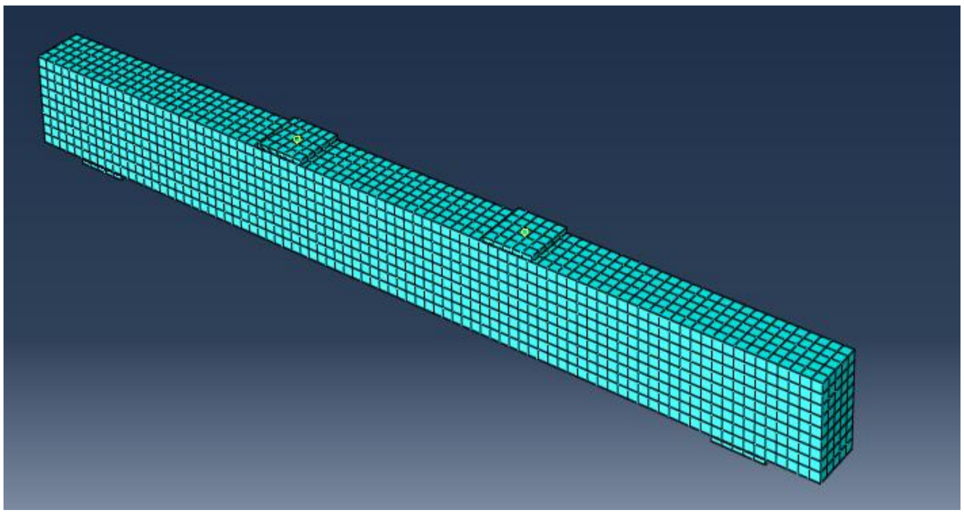


Figure 3.8 concrete meshing

**3.7 Validation of model for current investigation**

The numerical model was calibrated beside existing experimental data to confirm the trustworthiness of the FE prediction. This study has used the methods performed and followed by [11, 23], and however, before performing the present study, validation of the software was done using different trials simulation and modeling until the output was close to the experimental result. After validation, the dimensions and properties for the current study were inserted into software and then using these outputs study the mechanisms underlying the behavior of Concrete and SFC beam specimens when subjected to static loading and the effects of RSF on reinforced concrete structural responses was analyzed.

The finite element models of simply supported SFC beams were developed in this study was verified against tests detailed in [26]**.** In this experimental work [26] two simply supported SFC beams specimens with round steel fiber volume of 1% and 2% designated S0.5V1 and S0.5V2 were tested by respectively. These investigations were performed with a four-point bending test system of SRC beam with 1.7 m length, 18cm depth and 10cm width. As well as it has two longitudinal reinforcing bars at the bottom and top with a diameter of 16mm and 10mm respectively and a traverse reinforcing bar with a diameter of 6mm was applied 80mm center to center. The parameters used by the researcher were shown in table 3.5 (A), (B) and (C). Dimension and experimental setups as shown in figure 3.6 and the experimental result in terms of the Load-deflection curve is as shown in figure 3.7

**Table3.5: Parameters used for experimental work** by [26].

| Fiber type | Length, L (mm) | Diameter, d (mm) | Aspect ratio (L/d) | Fiber Volume, $v_f$ (%) | Compressive strength (MPa) | Split Tensile strength (MPa) |
|---|---|---|---|---|---|---|
| Round Straight | 42 | 0.7 | 60 | 1 | 38.7 | 4 |
| Round Straight | 42 | 0.7 | 60 | 2 | 42.4 | 5.1 |

(A) Compressive strength of concrete and tensile strength of fiber.

| S/N | Yield strength: Mpa | Tensile Strength: Mpa | Modulus of elasticity: $x10^5$ Mpa |
|---|---|---|---|
| Longitudinal steel | 420 | 545 | 2 |
| Stirrup | 359 | 534 | 2 |
| Steel fiber | 1303 | 1784 | 2 |

(B) Mechanical property of longitudinal transverse reinforcement bars and steel fiber,

| | Cement | Water | Sand | Aggregate |
|---|---|---|---|---|
| Content | 450 | 171 | 707 | 1060 |

(C) Proportion of concrete mix (kg/m$^3$)

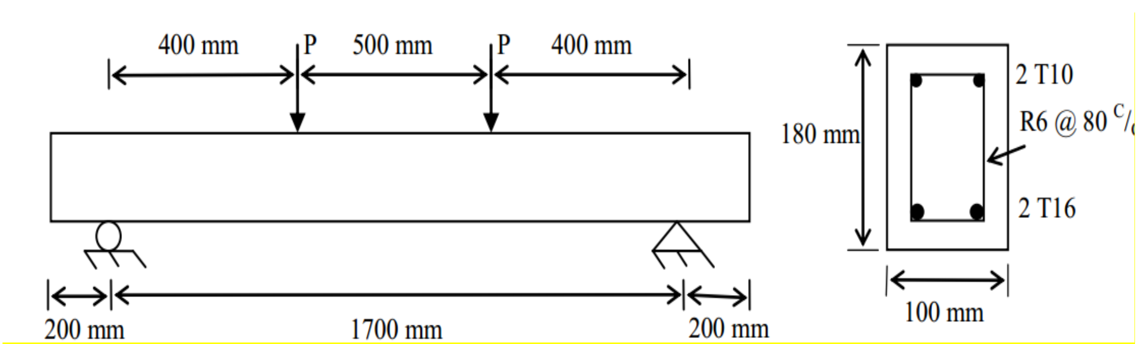
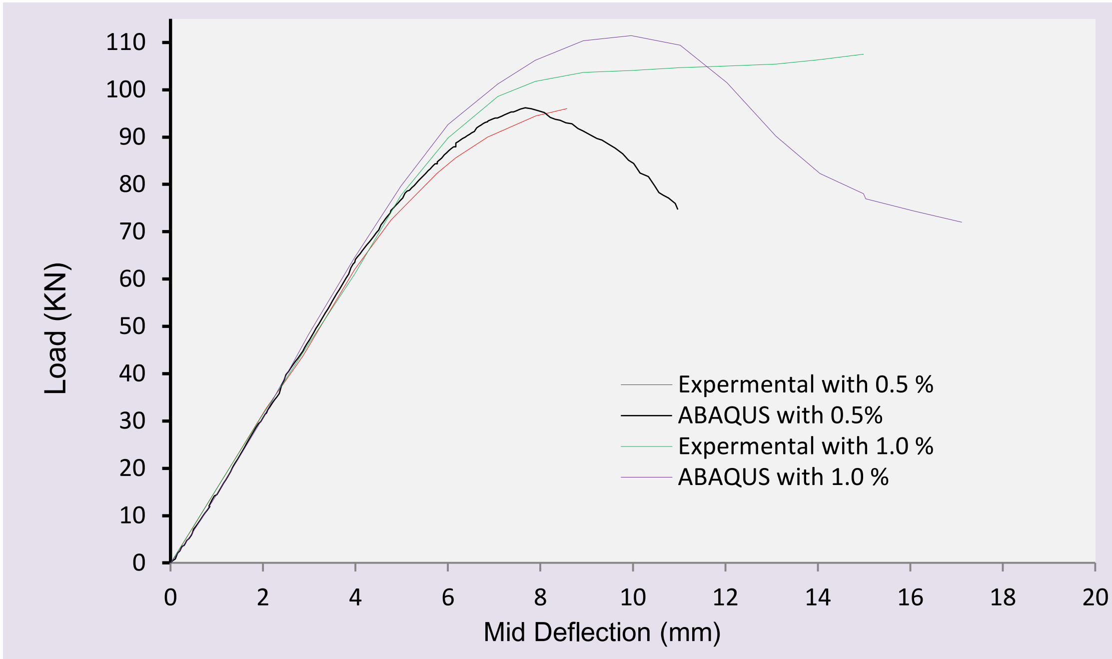



Figure 3.11: Dimension and loading condition of [26] for SFC beam experimental investigation

**a)**




**b)**

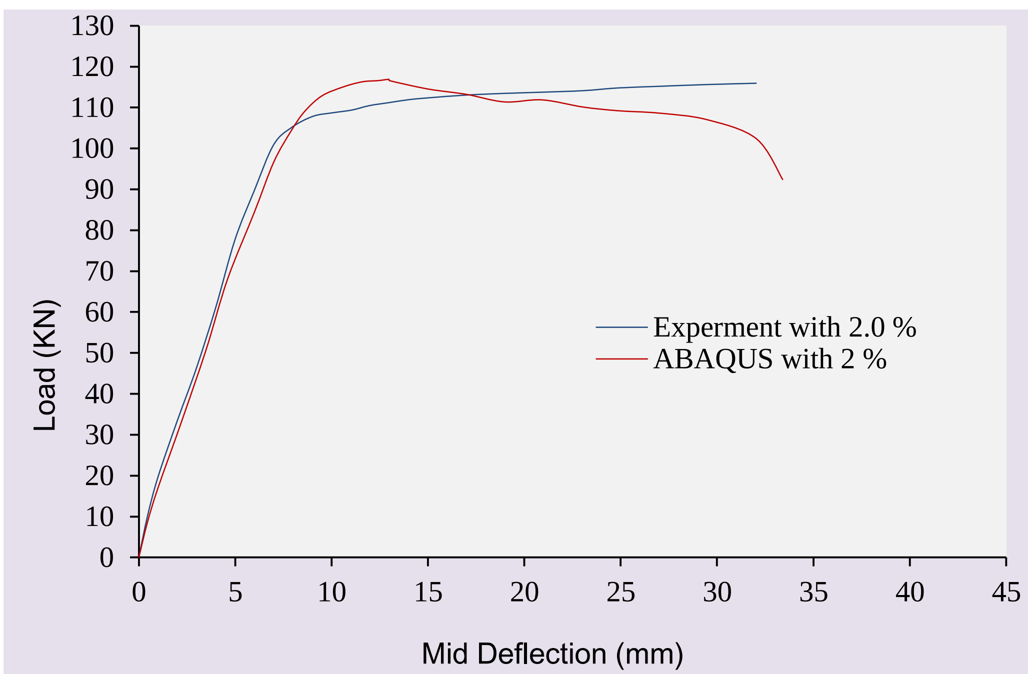



Figure 3.12: Validation graph using [26] experimental research with 50% stirrups of SFC beam with C35 concrete (a) with 0.5% and 1.0% fiber volume and (b) 2.0% fiber volume.

Having the above parameters and dimensions the same beam was modeled and analyzed to validate the FEA result. The comparison of experimental (previous study) result and numerical (for current study validation) result (load-deflection behavior) and failure behavior of the SFC beam is illustrated in Figures 3.12 (a) and (b).

The difference between experimental and analytical results for all percentage dosage of steel fiber summarized as follows:

- The difference between peak load carrying capacity of experimental beam and FEA, ABAQUS beam with 1.0 % steel fiber was 0.2 %.
- The difference between peak load carrying capacity of experimental beam and FEA, ABAQUS beam with 1.5 % steel fiber was 3.7 %.
- The difference between peak load carrying capacity of experimental beam and FEA, ABAQUS beam with 2.0 % steel fiber was 0.83 %.

Also it is observed that from the load versus mid deflection curve, failure pattern of concrete from the ABAQUS analysis result is matched well with the failure pattern of concrete with the experimental study result.

It was perceived that the peak axial capacity and peak axial deformation of these beams was nearly closer to the experimental values. So, the FEA model can predict the experimental behavior of the SFRC simply supported beam with good accuracy.

## 3.8 Experimental program

### 3.8.1 Materials

#### 3.8.1.1 Cement

In all mixes the locally manufactured Muger OPC cement produced in accordance with Ethiopian Standard Authority which has compressive strength 47.2R was used.

#### 3.8.1.2 Aggregates

For this research, a sample with a weight of 2.69 kg from 15 kg and a weight of 3.80 kg from 10 kg were taken for crashed coarse aggregate and for fine aggregate respectively for sieve analysis.

**a) Fine aggregate**

For this research work, the fine aggregate source was chewaka located 50 km west of Bedele city and 195 km from Jimma city as reported by the suppliers. The silt content of the original sample was found at 8%.

**b) Course aggregate**

The coarse aggregate used for the test was crushed basaltic stone with a maximum size of 19 mm. the source of this material was Aggaro town crusher located at the gate of town from Bedele direction located 48 km west of Jimma. The aggregate was initially sieved using a sieve size of 37mm. After sieve analysis, the sample was washed and dried, and kept in the laboratory. Sieve analysis results and other characteristics of the aggregates were presented in table 3.6 and Appendix A

**Table 3.6: Sieve analysis and physical properties of Aggregates**

| **A. Sieve analysis** | | |
|---|---|---|
| Sieve Number | Percentage passing | |
| | Fine Aggregate | Coarse Aggregate |
| 37.5mm | | 100.00 |
| 19mm | | 95.95 |
| 12.5mm | | 72.74 |
| 9.5mm | 99.78 | 34.53 |
| 4.75mm | 97.36 | 4.26 |
| 2.36mm | 91.25 | |
| 1.18mm | 73.11 | |
| 600 µm | 49.98 | |
| 300µm | 13.07 | |
| 150µm | 1.90 | |
| Fineness Modulus | **3.74** | **2.93** |

**B. Physical properties**

| | | |
|---|---|---|
| Silt Content (%) Not Washed<br>Washed | 8<br>1.12 | -<br>- |
| Moisture Content (%) | 1.53 | 3.82 |
| Absorption Capacity (%) | 1.56 | 0.34 |
| Bulk Specific Gravity | 2.6 | 2.7 |
| Bulk Specific Gravity (SSD Condition) | 2.85 | 2.72 |
| Apparent Specific Gravity | 2.94 | 2.83 |
| Crushing Value (%) | - | 17.83 |
| Los Angeles Abrasion (%) | - | 14.9 |

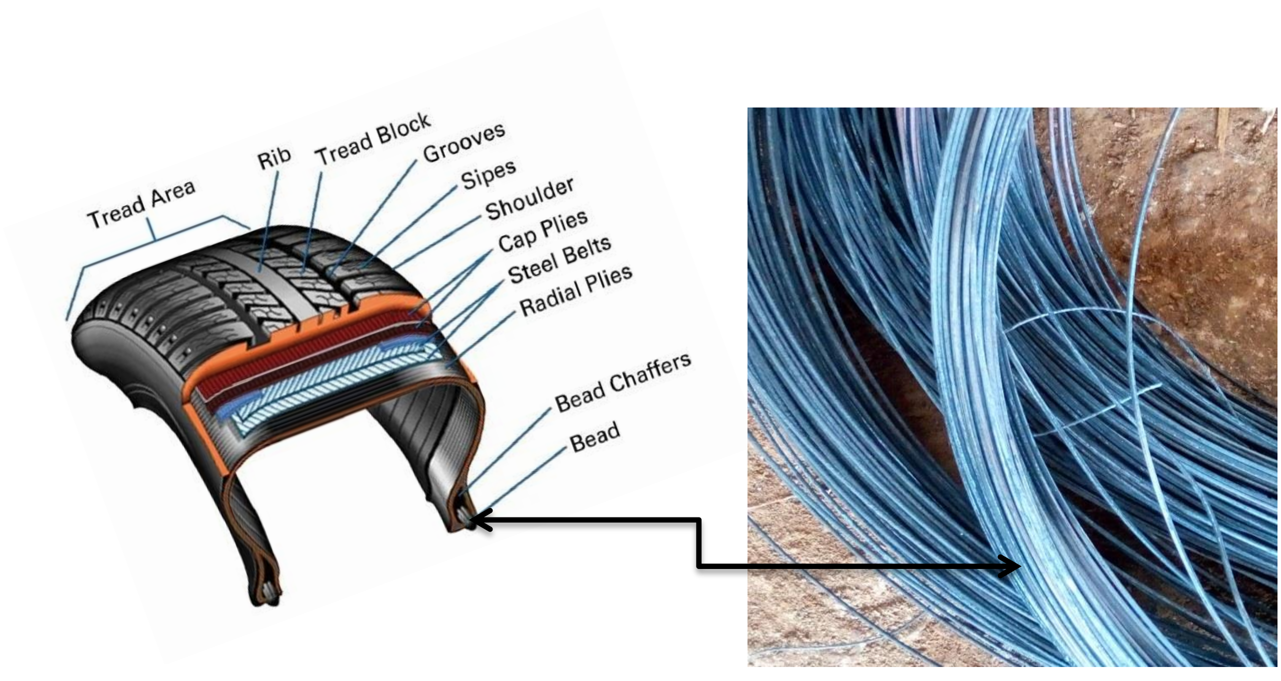
### 3.8.1.3 Water

Potable clean flowing river water was used for the concrete mixes.

### 3.8.1.4 Steel fibers

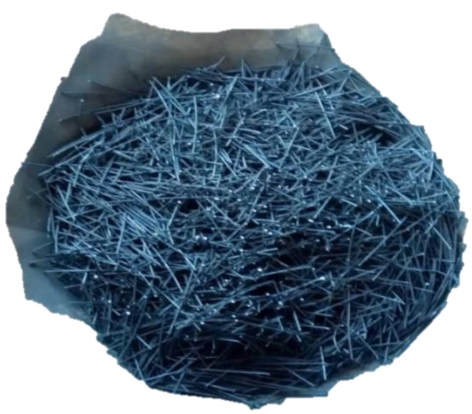
Since the diameter and tensile strength of steel fibers in a tire vary from one factory product to another, the tires used for steel fibers are all from the same source (heavy duty vehicle LING LONG Tire). The steel fiber used in this research was obtained by burning waste tires (pyrolysis process). The tires were burnt at a relatively low temperature to reduce the damage of steel fibers. The carbon black and rubber were removed from the surface of the bead wire/steel fibers as shown in figure 3.9 (A), (B) and (C).

Three types of steel fiber have been recovered from tires which are two steel cords twisted together to form two different core strands and the third one is bead wire. Among these, the latter with a diameter of 0.89 mm were used for this research. The fibers recovered from tires with low temperature were prepared by cutting into a uniform length of 60 mm with an aspect ratio of 67 as shown in Figure 3.9 (C)




(**A)**

**B )**



**C)**

Figure 3.13: Preparation of recovered Steel fiber A) Recovered Bead wire from tire, B) Marking and cutting of recovered bead wire and C) Bead wire ready for mix.

**Steel fibers Property**

Mechanical properties of steel fibers were analyzed by tensile tests on 10 randomly chosen samples. The test was performed on the recovered steel fiber and compared with virgin steel to examine the effect of burning on the tensile strength of the fiber. The tensile test was carried out by a Test metric machine in Matador Addis Tire Laboratory. The test report was presented in Table 3.8. Average tensile strength of 817.44 MPa was found for the RSF which was less than the minimum value specified by the manufacturer for VSF by 56.98 %. Elongation and breaking force results were also reduced by the manufacturer's requirement by 51.24% and 3.33%. The reduction of this value resulted from the burning process of the used tire to recover bead wire. However, this experimental test result meets [27] specification which is the average tensile strength shall not be less than 345 MPa and the individual sample test result shall not be less than 310 MPa.

**Table 3.7: Manufacturer's Specification of tensile strength, breaking load and elongation at break of recovered bead wire.**

| S/N | UNIT | Minimum Value |
|---|---|---|
| Tensile Strength | Mpa | 1900 |
| Nominal Breaking Force | N | 1182 |
| Elongation at Break | % | 6-9 |

**Table 3.8 Tensile strength, breaking load and elongation at break of RSF.**

| Sample | Tensile Strength (Mpa) | Breaking Load (N) | Elongation at Break (%) |
|---|---|---|---|
| 1 | 1215.2 | 621.7 | 4.4 |
| 2 | 485.6 | 707.6 | 5.6 |
| 3 | 423.8 | 444.1 | 5.3 |
| 4 | 197.7 | 672.1 | 4.2 |
| 5 | 728.7 | 418.6 | 6.2 |
| 6 | 1106.3 | 652.8 | 7.9 |
| 7 | 1236 | 774.9 | 6.9 |
| 8 | 832.9 | 424.6 | 5.2 |
| 9 | 982.9 | 574.9 | 6.1 |
| 10 | 965.3 | 472.9 | 5.9 |
| Average | 817.4 | 576.4 | 5.8 |
| Minimum | 197.7 | 418.6 | 4.2 |

### 3.8.2 Mix proportions

For mix design, the ACI mix design method was adopted [27]. Three different grades of concrete were designed to give a slump value of 20-100 mm and a 28-day compressive strength of 20, 25 and 30 MPa with a water-cement ratio of 0.60, 0.52 and 0.45 respectively. There are six control mix samples (plain concrete) for each grade of concrete and six mix samples for each grade of concrete with three fiber volume fractions of 1.0 %, 1.5 % and 2.0 % incorporating 60 mm fiber length were produced for studying fresh and compressive strength of concrete. Altogether a total of 72 samples were tested to study the effect of fiber volume over the mechanical properties of SFRC in the hardened state (for both 7$^{th}$ and 28$^{th}$ day of compressive strength). For split test totally 36 specimens were used. The mix design data sheets for all mixes were attached in Appendix B. The Proportions of mix series used for this study were presented along with the fiber contents and lengths in Table 4.9. The designation of mix design is in such a way that the letter and the number next to the letter and the number after minus sign describe the mix series and volume proportion of the fiber respectively. For instance, a concrete mix designated by **C20-1.5** was considered as concrete with characteristic strength of 20 MPa and 1.5% of fiber volume incorporation.

**Table 3.9: Concrete Mix proportion Summary**

| Mix Design per 1m$^3$ | **Cement kg** | **Water kg** | **Fine aggregate kg** | **Coarse aggregate kg** | **Fiber kg** |
|---|---|---|---|---|---|
| MIX A | | | | | |
| C20-0.0 | 280 | 165.13 | 750 | 1100 | 0 |
| C20-1.0 | 280 | 165.13 | 750 | 1100 | 78.6 |
| C20-1.5 | 280 | 165.13 | 750 | 1100 | 117.9 |
| C20-2.0 | 280 | 165.13 | 750 | 1100 | 157.2 |
| MIX B | | | | | |
| C25-0.0 | 320 | 164.45 | 710 | 1100 | 0 |
| C25-1.0 | 320 | 164.45 | 710 | 1100 | 78.6 |
| C25-1.5 | 320 | 164.45 | 710 | 1100 | 117.9 |
| C25-2.0 | 320 | 164.45 | 710 | 1100 | 157.2 |
| MIX C | | | | | |
| C30-0.0 | 370 | 163.67 | 660 | 1100 | 0 |
| C30-1.0 | 370 | 163.67 | 660 | 1100 | 78.6 |
| C30-1.5 | 370 | 163.67 | 660 | 1100 | 117.9 |
| C30-2.0 | 370 | 163.67 | 660 | 1100 | 157.2 |

### 3.8.3 Specimens preparation for laboratory test

For adjustment certain amount of water obtained from the mix, the design was added to the measured aggregates according to mix proportion and left aggregates for a while to make it Saturated Surface Dry condition (SSD). All materials were mixed in a dry condition for about one and half a minute. And then to avoid the balling effect recovered steel fibers were added carefully during the dry mix. Then addition followed one-third of the total mixing water volume in three cycles for the one-minute interval for each. Mixing was ceased after four minutes for all mixes. For each mix design, forty eight 150 mm cubes specimens for determination of $7^{th}$ and $28^{th}$-day compressive strength and twenty four 150x300 mm cylinders of specimens for determination of split tensile strength were cast. The casted specimens were left to cure for 24 hours. After 24 hrs, the specimens were carefully removed from the mold and placed in a curing room for 7 and 28 days for compressive and split strength tests.

### 3.8.4 Testing

. The slump test results of fresh fibered reinforced concrete vary from almost zero to a small number of centimeters. Compressive strength tests for hardened concrete also were carried out in accordance with the ASTM 39 specification. Before performing the test dimensions and weight of each specimen were taken accurately. The load to the specimen was applied at a constant rate of 0.0.301 MPa/s until the specimen failed and the compressive strength was read to the nearest two digits after a decimal immediately during crushing of samples. An average of the test results of three specimens belonging to each mix was accepted as the compressive strength of that mix for the respective day. And also Split tests were performed according to determine the tensile strength of each control and fiber reinforced concrete mixes.  The test results for all mixes were shown in appendix D.

Figure 3.14: Compressive strength test set up and crushed specimen

## 3.9 Study Variables

### 3.9.1 Independent variables

a) Content of steel fiber
b) Concrete grade

### 3.9.2 Dependent variables

**a.** Compressive strength of SFC
**b.** Workability of SFC
**c.** Tensile Strength of SFRC
**d.** Load-displacement SFRC

## 3.10 Sources of Data

For this study, different data sources were used. From these sources, different websites, books, research articles, and journals of different researchers on the related titles were used. However, the data sources mainly were taken from different journals of related titles. And different previous experimental and numerical investigations were reviewed.

# CHAPTER FOUR
# RESULT AND DISCUSSION

In this study, experimental and finite element analysis was used to investigate the effect of steel fiber recovered from used tire on mechanical behavior of concrete. Using these two research methods workability, compressive strength of concrete, flexural strength of concrete and failure of steel fibered reinforced concrete were investigated. Slump test, Compressive strength test and split test was used to investigate the behavior of fresh and hard RSFC in laboratory. The tensile strength test result was used for stress and strain calculation which further used for tensile property of RSFC for ABAQUS analysis. While the load deflection characteristics and cracking and failure behavior were analyzed using ABAQUS software. The experimental and FEA result obtained from these two methods was discussed in detail below.

## 4.1 Experimental Result

### 4.1.1 Slump Test

The slump test is the simplest test among other tests due to simplicity and its inexpensiveness, handled, transported, and placed, and consolidated with a less loss of homogeneity. In other words, it shows the workability of fresh concrete. Due to the involvement of a large number of parameters, it is difficult to predict the workability of SFC. Aggregate content and fiber geometry and volume fraction influence characteristics of SFC in its fresh state. The influence of the volume fraction of fiber on the properties of fresh concrete was investigated in this research work. To see the effect of volume fraction of fibers on workability, a slump test was performed on the fresh concrete for each mix and the results were presented in Table 4.1. It can be concluded from the result presence of the steel fibers strongly decreased the workability of the fresh concrete. All grade of concrete designed with low fiber content have high slump value relatively, whereas concrete with high fiber content have almost zero slump value. As the dosage of fiber content increased in the fresh concrete, aggregates and fibers are interlocked each other and protected the flow of paste of fresh concrete easily. So, the slump value goes smaller and smaller finally become zero as result. Finally when compared the slump values of concrete with fiber with different standards its workability falls under the low workability category.

**Table 4.1: Slump test result**

| Concrete Grade | Mix Design | Slump Value (mm) | Concrete Grade | Mix Design | Slump Value (mm) | Concrete Grade | Mix Design | Slump Value (mm) |
|---|---|---|---|---|---|---|---|---|
| 20 | Control 1 | 82 | 25 | Control 2 | 78 | 30 | Control 3 | 72 |
| | C-20-1.0 | 15 | | C-25-1.0 | 9 | | C-30-1.0 | 5 |
| | C-20-1.5 | 6 | | C-25-1.5 | 2 | | C-30-1.5 | 1 |
| | C-20-2.0 | 0 | | C-25-2.0 | 0 | | C-30-2.0 | 0 |

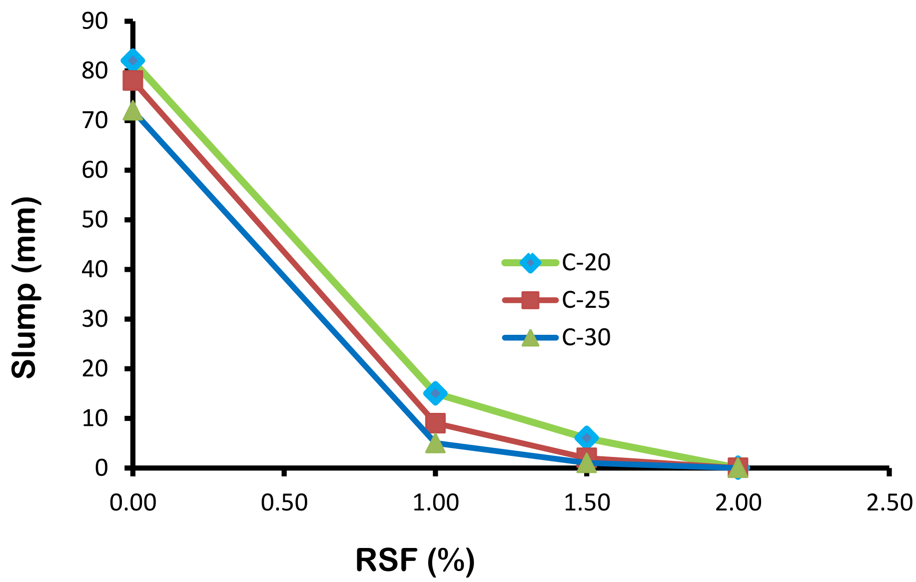


Figure 4.1: comparison of Fiber effect on workability of different grade of concrete.

### 4.1.2. Compressive strength

The compressive strength of the test cubic was measured for various fiber contents. The relative strength of the concrete in compression due to the addition of the recovered steel fibers is shown in Figure 4.2 and all raw data and results recorded during laboratory tests for 7$^{th}$ and 28$^{th}$ days of compressive strength were attached in Appendix C.

The mean compressive strength of the control 1 mix, in mix design A was primarily designed for characteristic strength of 20 MPa at 28 days. In this mix inclusion of recovered steel fibers has increased the mean compressive strength values varying from 0.63 MPa to 2.15 MPa with a maximum strength gain of 10 %. The lowest strength value in this Mix design was observed on specimen sample number two which have

1.5% of fiber (**C-20-1.5)**, while the highest strength was observed on specimen sample number three which have also 1.5% of fiber (**C-20-1.5).**

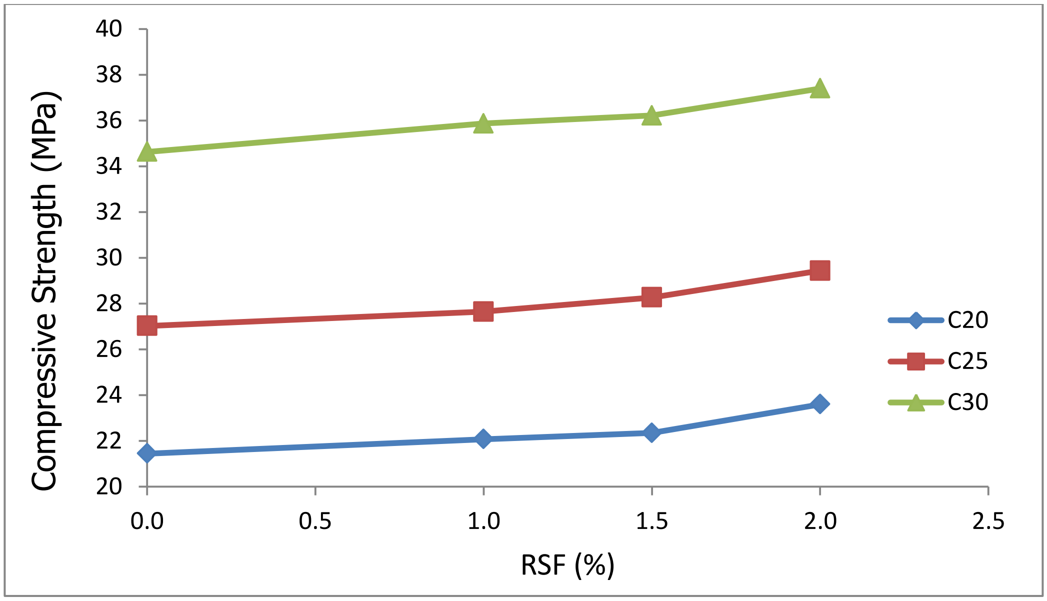



Figure 4.2: Fiber effect on Compressive strength of Reinforced concrete

The control 2 mix, in mix design B was primarily designed for the mean compressive strength of characteristic strength of 25 MPa at 28 days. In this mix design addition of recovered steel fibers has increased the mean compressive strength values varying from 0.63 MPa to 2.4 MPa with a maximum strength gain of 8.92 %. The lowest strength value in this Mix Series was observed in specimen sample number three with 1.0% fiber content (C-25-1.0), while the highest strength was recorded in specimen sample number three with have 2.0% fiber content (C-25-2.0). In Mix Series C the mean compressive strength of the control plain mix is 34.63 MPa which was designed for characteristics strength of 30 MPa. Mean Compressive strength values in this mix series increased up to 8.0 % following the addition of fiber. The highest compressive strength value was observed in mix C-30-2.0.

The addition of fibers in concrete is more advantageous in delaying the failure of the material and increasing the strain at the peak in the stress-strain curves for steel fiber reinforced concrete in compression rather than increasing the compressive strength. Sudden ejections of materials at collapse were observed during the experiment for the plain concrete specimens, while for the RSFC specimen a more ductile collapse was seen.

**Table 4.2: Mean compressive strength result of different mix designations**

| Mix | Mix Designation | Compressive strength (Mpa) | Relative Strength gain in (Mpa) | Relative Strength gain in % |
|---|---|---|---|---|
| MIX A | Control 1 | 21.45 | 0 | 0.0% |
| | C-20-1.0 | 22.07 | 0.63 | 2.9% |
| | C-20-1.5 | 22.35 | 0.90 | 4.2% |
| | C-20-2.0 | 23.60 | 2.15 | 10.0% |
| MIX B | Control 2 | 27.02 | 0 | 0.0% |
| | C-25-1.0 | 27.65 | 0.62 | 2.3% |
| | C-25-1.5 | 28.27 | 1.25 | 4.6% |
| | C-25-2.0 | 29.44 | 2.41 | 8.9% |
| MIX C | Control 3 | 34.63 | 0 | 0.0% |
| | C-30-1.0 | 35.87 | 1.23 | 3.6% |
| | C-30-1.5 | 36.22 | 1.59 | 4.6% |
| | C-30-2.0 | 37.40 | 2.77 | 8.0% |

Generally, as the inclusion of recovered steel fiber volume increased into concrete the compressive strength slightly increased. For all mixes, fiber volume fraction addition has increased the compressive strength. However, addition of fiber had no equal effect on compressive strength. Compressive strength of all classes of RSFC increased following the addition of 1% and 2% fiber with different percentages. But addition of 1.5% of fiber increased the compressive strength of all classes of RSFC nearly with constant percent (~ 4.5%).

### 4.1.3 Splitting tensile strength

The development of splitting tensile strength of SFC at various percentage fractions is shown in Figure 4.3. The strength of SFC was improved with increasing the volume fraction of RSF. The split tensile strength of SFC mixes of 28$^{th}$ days with 1.0 %, 1.5 %, and 2.0 % inclusion of fibers was obtained 60.88%, 92.37%, and 121.01% respectively higher than that of plain concrete for mix design A. For Mix Design B inclusion of fiber steel of 1.0 %, 1.5 %, and 2.0 % raised the 28$^{th}$ day's tensile strength of concrete by 60.07% 111.54%

and 134.04% respectively when compared to plain concrete. And inclusion of fiber steel of 1.0 %, 1.5 %, and 2.0 % raised the 28th day's tensile strength of concrete by 35.9 %, 31.4 %, and 24.6 % respectively when compared to plain concrete for Mix series C which is concrete grade 30. In all three mixes, it was clearly observed that dosage of a small quantity of steel fiber can greatly improve the tensile strength of the concrete due to the fiber bridging potential of tensile cracks. From the three ration of RSF 2% have showed greatest improvement of tensile strength for all classes of Concrete.

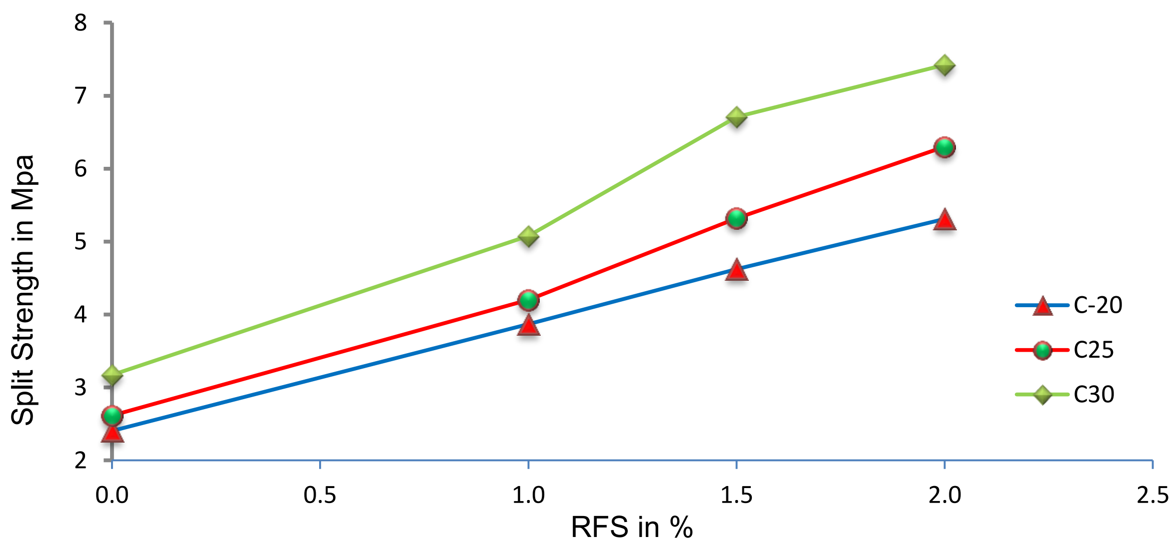



Figure 4.3: Fiber effect on tensile strength of Reinforced concrete

**Table 4.3: Effect of RSF dosage on Compressive and Tensile strength of reinforced concrete**

| Concrete Grade | Mix Designation | Fiber % | Aspect Ratio | Compressive strength, f'c (Mpa) | Tensile strength, $f'_t$ (Mpa) |
|---|---|---|---|---|---|
| C20 | Control 1 | 0.0 | 67 | 21.45 | 2.40 |
| | C-20-1.0 | 1.0 | 67 | 22.07 | 3.87 |
| | C-20-1.5 | 1.5 | 67 | 22.35 | 4.62 |
| | C-20-2.0 | 2.0 | 67 | 23.60 | 5.31 |
| C25 | Control 2 | 0.0 | 67 | 27.02 | 2.62 |
| | C-25-1.0 | 1.0 | 67 | 27.65 | 4.20 |
| | C-25-1.5 | 1.5 | 67 | 28.27 | 5.32 |
| | C-25-2.0 | 2.0 | 67 | 29.44 | 6.30 |
| C30 | Control 3 | 0.0 | 67 | 34.63 | 3.17 |
| | C-30-1.0 | 1.0 | 67 | 35.87 | 5.08 |
| | C-30-1.5 | 1.5 | 67 | 36.22 | 6.71 |
| | C-30-2.0 | 2.0 | 67 | 37.40 | 7.42 |

## 4.2 Finite Element Analysis Out put

### 4.2.1 Cracking and Failure Behavior

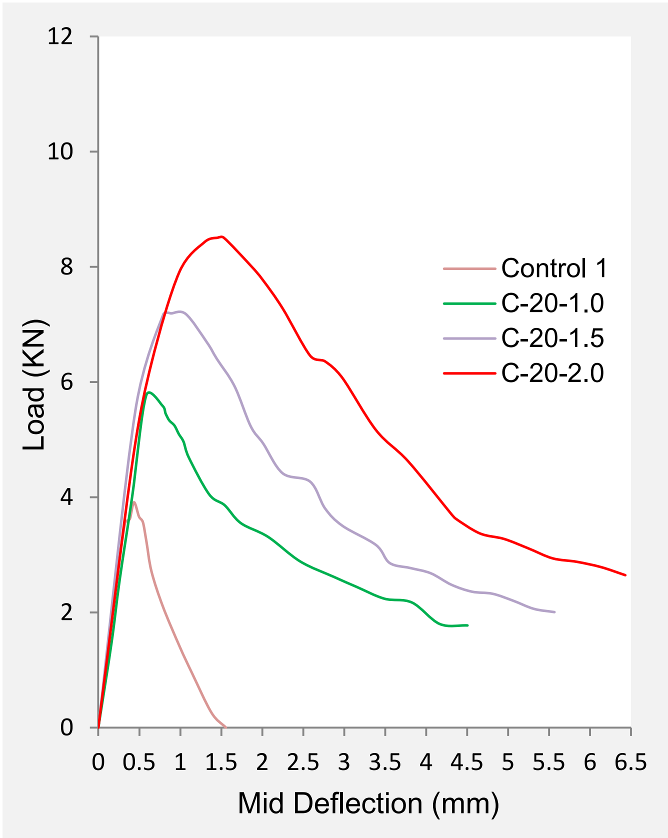
All analyzed beams without steel fiber exhibited less ductile behavior and failed in flexural-shear cracking, whereas fibrous beams failed under flexure. The flexural capacity of the RSFC beam is the contribution of both reinforcing bars and the residual tensile strength produced from fiber bridging cracks. Generally, beams with recovered steel fiber exhibited better cracking resistance and less failure behavior than those without fiber.

### 4.2.2 Load-deflection characteristics

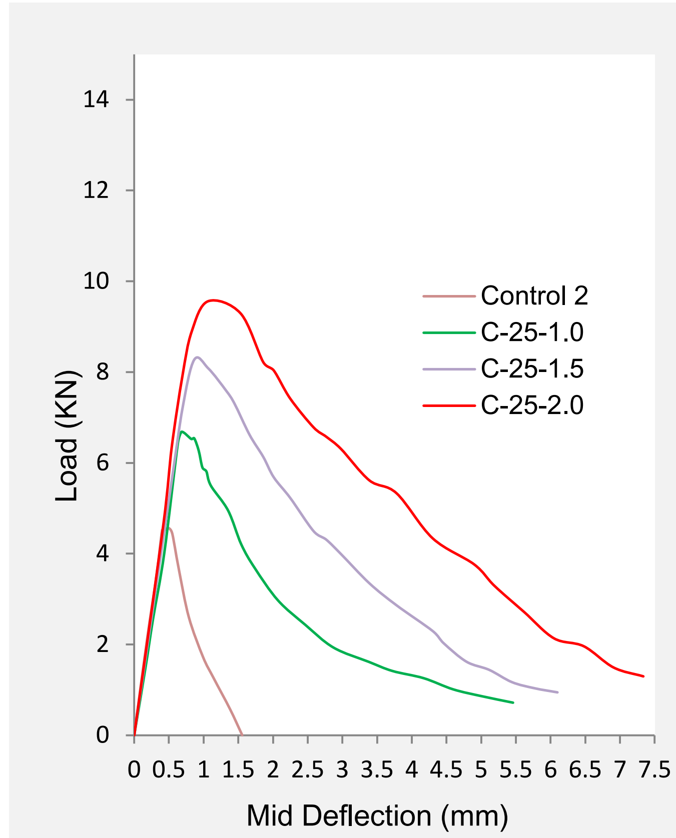
The significant different performance of concretes with and without steel fibers was observed in the load-deflection curves for this study. The energy was absorbed during flexural deflection of the beam when the load was induced. To quantify this energy absorption standardized methods so-called Load-deflection curves were used. This curve was drawn using data from the ABAQUS output of the static flexure analysis. Load-deflection curves for comparison are given for the three recovered steel fiber contents used in this investigation, 1.0 %, 1.5 %, and 2.0 % by volume for three different grades of concrete.

When RSF percentage increased in reinforced concrete improved its ductility. As the ductility of reinforced increased its load carrying capacity raised by resisting crack due to crack bridging action of fibers. As the flexural capacity of reinforced concrete increased it carried peak load until its failure by going through large deflection. Addition of 1%, 1.5% and 2% of recovered steel fiber on grade 20 RC beams increased the load carrying capacity by 47.6%, 83.4% and 121.4% respectively. For grade 25 RC beams dosage of 1%, 1.5% and 2% of recovered steel fiber increased the load carrying capacity by 46.5%, 81.3% and 109.5% respectively. Also for grade 30 RC concrete presence of 1%, 1.5% and 2% of recovered steel fiber increased the load carrying capacity of beam by 36.7%, 57.2% and 84.1%KN, respectively.

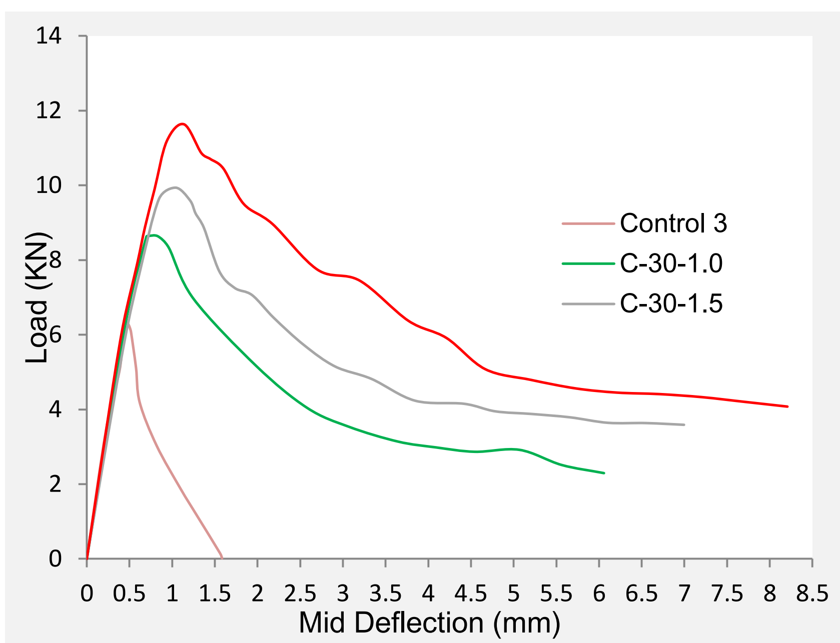
Generally, as the dosage of fiber volume increased the peak load carrying capacity of reinforced concrete beams were increased for all grades of concrete as indicated in Table 4.4. Effect of steel fiber in terms of load versus deflection response illustrated in the Figures 4.4 (a), (b), and (c) in detail in the form of graph.




(a)




(b)




(c)

Figure 4.4: Effect of fiber volume on Load-deflection curve of beam with, (a) Mix A, (b) Mix B and (c) Mix C

**Table 4.4: Effect of RSF dosage on peak Load carrying capacity of reinforced concrete**

| Concrete class | Fiber % | Max. Load, KN | Max. deflection | Increased peak load, KN | load. Icrement % |
|---|---|---|---|---|---|
| C20 | 0 | 3.91 | 1.56 | 0.00 | Reference |
| | 1 | 5.77 | 4.51 | 1.86 | 47.6% |
| | 1.5 | 7.19 | 5.57 | 3.28 | 83.8% |
| | 2 | 8.51 | 6.43 | 4.59 | 117.4% |
| C25 | 0 | 4.56 | 1.56 | 0.00 | Reference |
| | 1 | 6.68 | 5.46 | 2.12 | 46.5% |
| | 1.5 | 8.27 | 6.10 | 3.71 | 81.3% |
| | 2 | 9.56 | 7.34 | 5.00 | 109.5% |
| C30 | 0 | 6.32 | 1.58 | 0.00 | Reference |
| | 1 | 8.64 | 6.06 | 2.32 | 36.7% |
| | 1.5 | 9.94 | 7.00 | 3.62 | 57.2% |
| | 2 | 11.63 | 8.21 | 5.31 | 84.1% |

Due to bridging action of recovered steel fibers, the first cracking load was observed, which reflects the higher potential of steel fiber reinforced beams to resist the flexural stresses.

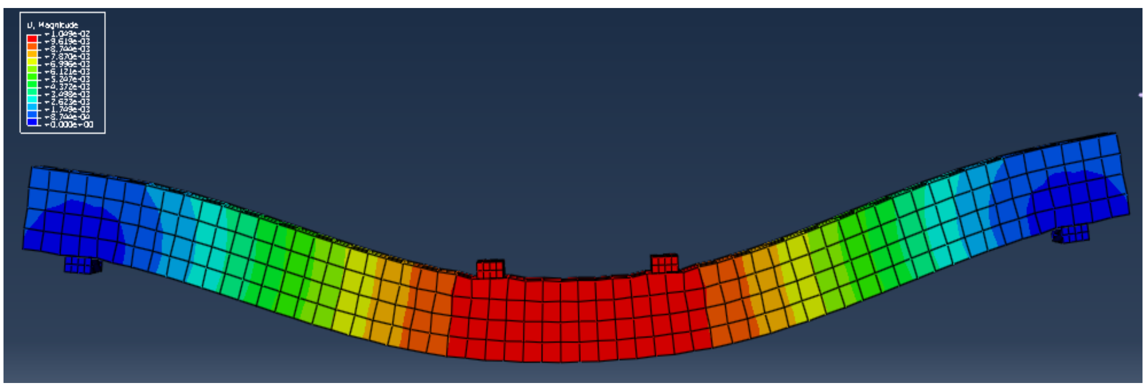
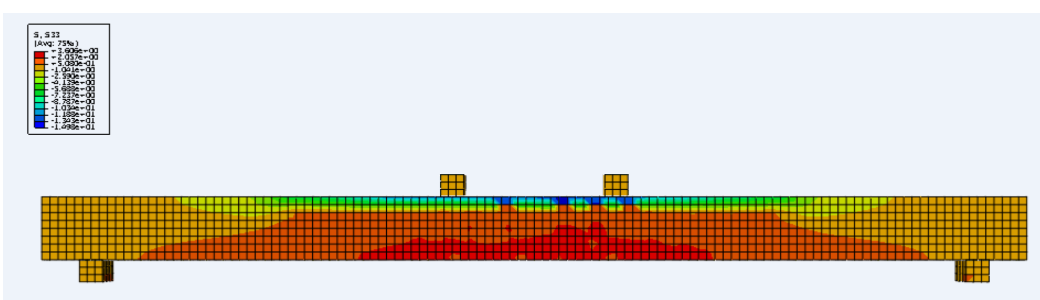


Figure 4.6: Deformed shapes sample resulted from abaqus analysis.



(b)

**Figure 4.7 Tension Damage of beam**

# CHAPTER FIVE
# CONCLUSIONS AND RECOMMENDATIONS

## Conclusions

This research presents result of experimental work performed for compressive strength and split strength to evaluate the fresh and hardened mechanical properties of concrete made with fibers extracted from used tires and Analytical analysis was done to evaluate the flexural behavior of hardened fibered concrete made with fibers extracted from used tires. In this research, the major test variable was the ratio of steel fibers in concrete. The fiber content varied from 0% to 2% by the volume of concrete.

From the experimental result, the workability of RSFC was decreased greatly until it reaches zero value which is not suitable for ordinary structures. Using fiber content of 1.5 % gave constant (~ 4.5%) increase of compressive strength for all classes of RSFC. Addition of 2% of RSF to concrete has increased the compressive strength but as the class of concrete increased the percentage increment of compressive strength was decreased (10%, 8.96 and 8% for mix design A, B and C respectively). The increment RSF ratio increased the tensile strength of RSFC significantly. This increment was varied from 60.07% to 140.79% which enables the RSFC to carry high axial load relatively.

A total of twelve beams were analyzed using ABAQUS software to investigate the effect of fiber reinforcement on the mechanical behavior of reinforced concrete beams in flexure. The analytical analysis (ABAQUS software) results obtained show that the use of fibers allows the achievement of better performances in flexure when compared to those of conventionally reinforced beams. The presence of fibers has increased the cracking limits of the beams when compared to a beam not fibered. The post cracking behavior of the designed SFRC was assessed by carrying out four-point notched beam analyses. Based on the load-displacement relationship, the values of the equivalent and residual flexural tensile strength parameters were obtained.

Based on the experimental test and analytical results on the mechanical behavior of the recovered steel fiber reinforced concrete beams the following conclusions were drawn:

a) The application of recycled steel fibers into construction industry can deliver low cost and environmentally approachable alternative to industrial steel fibers with enough crack detention competence and improved mechanical properties of reinforced concrete.
b) Uniaxial compressive tests indicated that the compressive strength of the material is less affected by the presence of fibers, however compressive failure manner of reinforced

specimens significantly changes form brittle to ductile. This occurrence is due to the higher deformability and energy absorption of SFRC during the cracking stage.

c) Tensile strength was increased along with the increment of steel fiber due to the high tensile strength and ability of steel fibers to bridge micro cracks and break the propagation of cracks until the composite ultimate stress of SFRC is sustained.
d) High dosage of steel fibers decreased workability of the fresh concrete.
e) From the analytical result obtained in finite element simulation high dosage of RSF ratio increased the peak load carrying capacity and the residual strength of RC beams after by bridging action of fiber. (i.e flexural strength and splitting strength of RC were increased significantly).
f) Due to steel fiber; the RSFRC become stiffer under flexural strength analysis which enhance the capability of SFRC to withstand higher load during first crack. This enables the beam to absorb high energy during deflection which results in high toughness.

The cracking and peak load capacities increased due to the addition of steel fibers. The peak load gain of the RC beams with fiber over those without fiber in peak loads was in the ranges of approximately 36.7 to 121.3 %. For all grades of concrete the dosage of RSF increased the deflection of respective beams when compared with no fiber RC beams.

In general, the flexural behavior, post cracking behavior and residual load carrying capacity of reinforced concrete beams fibered with recovered steel from used tires had a good capacity in resisting crack than reinforced concrete beams without steel fibers.

## Recommendations

Based on the investigation the points listed below are recommended for further study.

1. This investigation was made using steel fiber extracted from the used tire by burning it with controlling heat. However, this process of extracting was decreased the flexural strength of the bead wire which in turn decreased the fibers bridging action. Thus, using an extracting method that could not affect the property of this steel fiber, further investigation would be done on the effect of these steel fibers on the flexural behavior of reinforced concrete.
2. Further research work is still necessary to have a more in-depth understanding of the material properties and to evaluate possible practical applications.
3. This research was done on reinforced concrete at a material level. Further, investigation work is still necessary to have more knowledge on the effect of steel fiber inclusion on RC at the structural level.

**REFERENCES**

[1] J. Thomas, A. Ramaswamy, Mechanical properties of steel fiber reinforced concrete, J. Mater. Civ. Eng. 19 (5) (2007) 385–392.

[2] ACI 544.1R-96. (1996)Report on Fiber Reinforced Concrete. American Concrete Institute, Farmington Hills.

[3] ACI 544.4R-88. (1988) Design Considerations for Steel Fiber Reinforced Concrete. American Concrete Institute, Farm-ington Hills.

[4] ACI 544.3R-93. (1993)Guide for Specifying, Proportioning, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete. American Concrete Institute, Farmington Hills.

[5] Shetty M.S., Concrete Technology Theoryand Practice, Revised Edition, S. Chand and Company LTD., New Delhi, 2005.

[6] Altun F, Haktanir T, Ari K. Effects of steel fiber addition on mechanical properties of concrete and RC beams. Construction and Building Materials. 2007 Mar 1;21(3):654-61.

[7] Yoo DY, Moon DY. Effect of steel fibers on the flexural behavior of RC beams with very low reinforcement ratios. Construction and Building Materials. 2018 Nov 10;188:237-54.

[8] Ranjbaran F, Rezayfar O, Mirzababai R. Experimental investigation of steel fiber-reinforced concrete beams under cyclic loading. International Journal of Advanced Structural Engineering. 2018 Mar 1;10(1):49-60.

[9] Jin L, Zhang R, Dou G, Xu J, Du X. Experimental and numerical study of reinforced concrete beams with steel fibers subjected to impact loading. International Journal of Damage Mechanics. 2018 Jul;27(7):1058-83.

[10] Abbas A, Cotsovos DM, Behinaein P. Behaviour of steel-fibre-reinforced concrete beams under high-rate loading. Computers and Concrete, An International Journal. 2018 Sep 25;22(3):337-53.

[11] Karadelis JN, Zhang L. On the discrete numerical simulation of steel fiber reinforced concrete (SFRC). Journal of Civil Engineering Research. 2015;5(6):151-7.

[12] Soulioti DV, Barkoula NM, Paipetis A, Matikas TE. Effects of fibre geometry and volume fraction on the flexural behaviour of steel-fibre reinforced concrete. Strain. 2011 Jun;47:e535-41.

[13] MacDonald CN. Plastic and Steel Fiber-Reinforced Concrete Applications. Transportation Research Record. 1984; 1003:1.

[14] Zollo RF. Fiber-reinforced concrete: an overview after 30 years of development. Cement and concrete composites. 1997 Jan 1;19(2):107-22.

[15] Li FY, Cao CY, Cui YX, Wu PF. Experimental study of the basic mechanical properties of directionally distributed steel fibre-reinforced concrete. Advances in Materials Science and Engineering. 2018 Jan 1; 2018.

[16] Jianhua W, Jun L, Haiping Y. The study on steel fiber reinforced concrete under dynamic compression by damage mechanics method. Chem. Pharm. Bull. 2014;6:1759-67.

[17] Yee LL. *Mechanical properties of recycled steel fiber reinforced concrete* (Doctoral dissertation,Thesis]. Malaysia: Faculty of Civil Engineering, University Technology Malaysia).

[18] Abbass W, Khan MI, Mourad S. Evaluation of mechanical properties of steel fiber reinforced concrete with different strengths of concrete. Construction and building materials. 2018 April 20;168:556-69.

[19] Wu Z, Shi C, He W, Wu L. Effects of steel fiber content and shape on mechanical properties of ultra-high performance concrete. Construction and building materials. 2016 Jan 30; 103:8-14.

[20] Yoo DY, Yoon YS, Banthia N. Flexural response of steel-fiber-reinforced concrete beams: Effects of strength, fiber content, and strain-rate. Cement and Concrete Composites. 2015 Nov 1; 64:84-92.

[21] Bedewi N. *Steel fiber reinforced concrete made with fibers extracted from used tyres* (Doctoral dissertation, Addis Ababa University).

[22] Li B, Xu L, Shi Y, Chi Y, Liu Q, Li C. Effects of fiber type, volume fraction and aspect ratio on the flexural and acoustic emission behaviors of steel fiber reinforced concrete. Construction and Building Materials. 2018 Aug 30; 181:474-86.

[23] Abbas A, Mohsin SS, Cotsovos D. Numerical modelling of fibre-reinforced concrete. InProceedings of the international conference on computing in civil and building engineering ICCCBE 2010 Jun (p. 473).

[24] Neocleous K, Tlemat H, Pilakoutas K. Design issues for concrete reinforced with steel fibers, including fibers recovered from used tires. Journal of materials in civil engineering. 2006 Oct;18(5):677-85.

[25] Mohsin SM. *Behaviour of fibre-reinforced concrete structures under seismic loading* (Doctoral dissertation, Imperial College London).

[26] Oh, B.H., Lim, D.H., Yoo, S.W. and Kim, E.S., 1998. Shear behaviour and shear analysis of reinforced concrete beams containing steel fibres. Magazine of Concrete Research, 50(4), 283–291.

[27] ASTM A820 /A0820-16, Standard Specification for Steel Fibers for Fiber- Reinforced Concrete, ASTM International, West Conshohocken, PA, 2016.

[28] Kwaśniewski L, Szmigiera E, Siennicki M. Finite element modeling of composite concrete-steel columns.Archives of Civil Engineering. 2011;57 (4):373-88.

# APPENDIX

**APPENDIX-A: SIEVE ANALYSIS RESULTS**

**APPENDIX -B: ACI MIX DESIGN DATA SHEET**

**APPENDIX -C: COMPRESSIVE STRENGTH TEST RESULTS**

**APPENDIX -D: FLEXURAL TENSILE STRENGTH TEST RESULTS**

**APPENDIX -E: COMPRESSIVE AND TENSILE BEHAVIORS USED FOR ABAQUS INPUT**

**APPENDIX -G: PHOTOS FROM SITE AND LABORATORY**

# APPENDIX A: SIEVE ANALYSIS RESULTS

Test: Sieve analysis of Fine Aggregate

Test method:

Sample Number: SA.FA

Tested By: Addisalem Kasu

Project: Master of Science Thesis

Source: Aggaro

Date:11/04/2013EC

**Table A1: Sieve Analysis Results for Fine Aggregate**

| Sieve Size | Weight retained (g) | Percentage Retained (%) | Cumulative Retained (%) | Cumulative Passing (%) | Lower Limit (%) | Upper Limit (%) |
|---|---|---|---|---|---|---|
| 9.5mm | 6 | 0.22 | 0.22 | 99.78 | 100.00 | |
| 4.75mm | 65 | 2.42 | 2.64 | 97.36 | 95.00 | 100.00 |
| 2.36mm | 164 | 6.11 | 8.75 | 91.25 | 80.00 | 100.00 |
| 1.18mm | 487 | 18.14 | 26.89 | 73.11 | 50.00 | 85.00 |
| 600μm | 621 | 23.13 | 50.02 | 49.98 | 25.00 | 60.00 |
| 300μm | 991 | 36.91 | 86.93 | 13.07 | 10.00 | 30.00 |
| 150μm | 300 | 11.17 | 98.10 | 1.90 | 2.00 | 10.00 |
| Pan | 51 | 1.90 | 100.00 | 0.00 | 0.00 | 0.00 |
| Total | 2685 | 100.00 | 373.56 | 426.44 | 362.00 | 385.00 |
| Finesse Modulus = | | 3.74 | | | | |

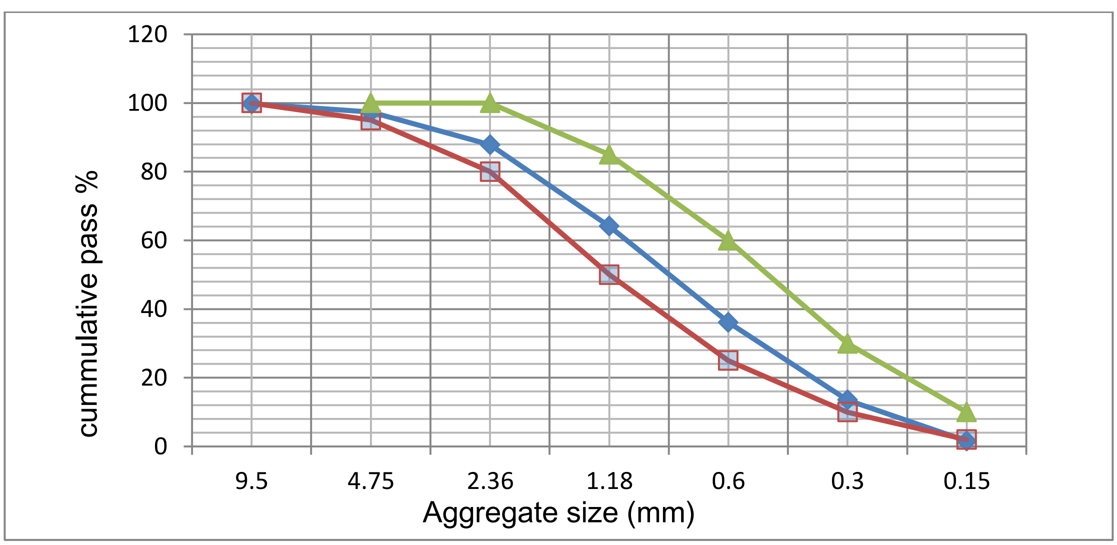



Figure A1: Gradation Curve for Fine Aggregate

Test: Sieve analysis of Coarse Aggregate
Test method: Dry Test using BS
Tested By: Addisalem Kasu
Project: Master of Science Thesis
Source: Aggar town
Date: 11/04/2013EC

**Table A2: Sieve Analysis Results for Coarse Aggregate**

| Sieve Size | Weight retained (g) | Percentage Retained (%) | Cumulative Retained (%) | Cumulative Passing (%) | Lower Limit (%) | Upper Limit (%) |
|---|---|---|---|---|---|---|
| 37.5mm | 0 | 0.00 | 0.00 | 100.00 | 100.00 | |
| 19mm | 154 | 4.05 | 4.05 | 95.95 | 90.00 | 100.00 |
| 12.5mm | 882 | 23.21 | 27.26 | 72.74 | 40.00 | 80.00 |
| 9.5mm | 1452 | 38.21 | 65.47 | 34.53 | 20.00 | 50.00 |
| 4.75mm | 1150 | 30.26 | 95.74 | 4.26 | 0.00 | 10.00 |
| Pan | 162 | 4.26 | 100.00 | 0.00 | 0.00 | 5.00 |
| | 3800 | 100.00 | 292.53 | 307.47 | 250.00 | 245.00 |
| Finesse Modulus = | | 2.93 | | | | |

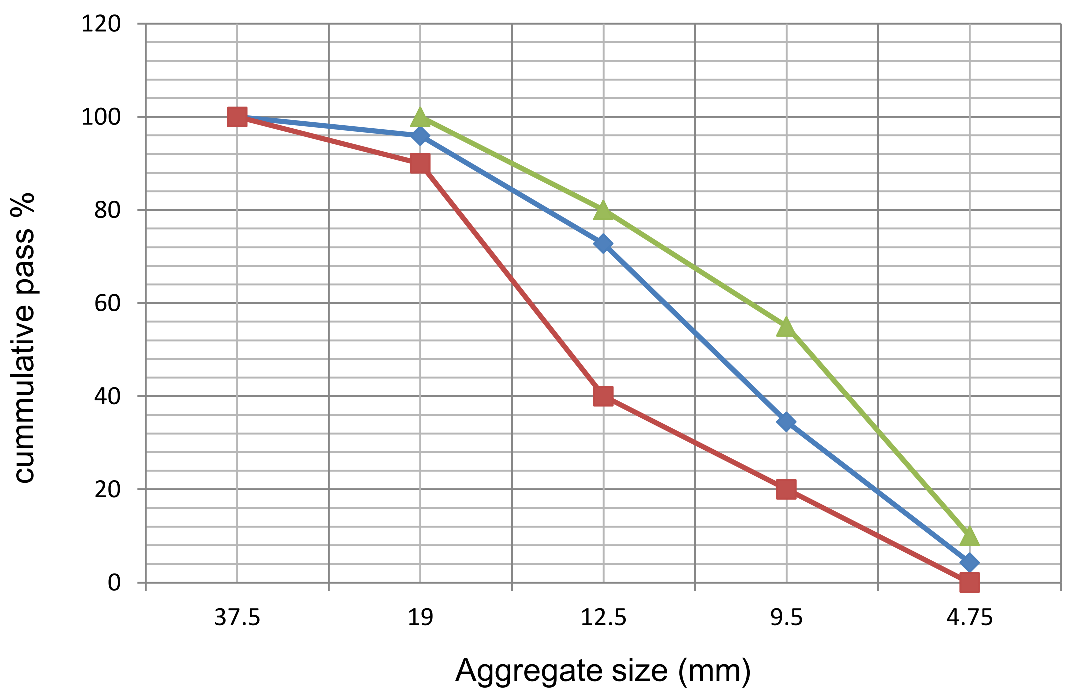



Figure A2: Gradation Curve for Coarse Aggregate

# APPENDIX B: ACI MIX DESIGN DATA SHEET

**Table B1: Mix design data sheet for Mix A (C-20)**

| **Material property** | | **Values** |
|---|---|---|
| 1 | Characteristic strength | 20 Mpa |
| 2 | Cement type | OPC |
| 3 | Coarse Aggregate type | Crushed |
| 4 | Fine Aggregate type | River |
| 5 | Unit weight of coarse aggregate | 1756 kg/m$^3$ |
| 6 | Unit weight of fine aggregate | 1340 kg/m$^3$ |
| 7 | Specific gravity of cement | 3.15 |
| 8 | Specific gravity of Coarse aggregate | 2.64 |
| 9 | Specific gravity of fine aggregate | 2.51 |
| 10 | Absorption capacity of Coarse aggregate | 0.34% |
| 11 | Absorption capacity of fine aggregate | 1.56% |
| 12 | Fines modulus of coarse aggregate | 2.93 |
| 13 | Fines modulus of fine aggregate | 4.08 |
| 14 | water/cement ratio | 0.60 |
| **Step** | | |
| **1** | **Recommended Slump** | 20 -100 mm (Table 1) |
| **2** | **Maximum Aggregate size** | 19 mm |
| **3** | **Mixing water content and air content** | |
| | 3.1 Mixing water content | 166 kg/m3 (Table 2) |
| | 3.2 Air content | 3.5% (Table 2 for mild and air entrained) |
| **4** | **Water cement ratio** | 0.60 (Table 3) |
| **5** | **Cement content** | 276.67 Kg/m$^3$ |
| **6** | **Coarse Aggregate Estimation** | |
| | 6.1 Maximum Aggregate size | 19mm |
| | 6.2 Fines modulus of coarse aggregate | 2.93 |
| | 6.3 Volume Dry-Rodded coarse aggregate per unit volume of concrete | 0.607 |
| | 6.4 Dry-rodded density | 1785 kg/m$^3$ |
| | 6.5 Coarse aggregate volume | 1083.495 kg/m$^3$ |
| **7** | **First estimate of fresh concrete volume** | 2275 kg/m$^3$ (Table 9) |
| **8** | **Fine Aggregate estimation** | 748 kg/m$^3$ |
| **9** | **Adjustment for moisture content** | |
| | 9.1 Extra water required for fine aggregate | 11.7 kg/m$^3$ |
| | 9.2 Extra water required for coarse aggregate | 3.68 kg/m$^3$ |
| | 9.3 Water content of coarse aggregate | 1.50% |
| | 9.4 Water on surface of coarse aggregate | 16.25 kg/m$^3$ |
| | 9.5 Surplus water on surface of coarse aggregate | 12.57 kg/m$^3$ |
| | 9.6 Corrected mix Proportion | |
| | 9.6.1 Cement | 276.67 kg/m$^3$ |
| | 9.6.2 Water | 165.13 kg/m$^3$ |
| | 9.6.3 Fine aggregate | 748 kg/m$^3$ |
| | 9.6.4 Coarse aggregate | 1099.75 kg/m$^3$ |

**Table B2: Mix design data sheet for Mix B (C-25)**

| **Material property** | | **Values** |
|---|---|---|
| 1 | Characteristic strength | 25 Mpa |
| 2 | Cement type | OPC |
| 3 | Coarse Aggregate type | Crushed |
| 4 | Fine Aggregate type | River |
| 5 | Unit weight of coarse aggregate | 1756 kg/$m^3$ |
| 6 | Unit weight of fine aggregate | 1340 kg/$m^3$ |
| 7 | Specific gravity of cement | 3.15 |
| 8 | Specific gravity of Coarse aggregate | 2.64 |
| 9 | Specific gravity of fine aggregate | 2.51 |
| 10 | Absorption capacity of Coarse aggregate | 0.34% |
| 11 | Absorption capacity of fine aggregate | 1.56% |
| 12 | Finess modulus of coarse aggregate | 2.93 |
| 13 | Finess modulus of fine aggregate | 4.08 |
| 14 | water/cement ratio | 0.52 |
| Step | | |
| **1** | **Recommended Slump** | 20 -100 mm (Table 1) |
| **2** | **Maximum Aggregate size** | 19 mm |
| **3** | **Mixing water content and air content** | |
| | 3.1 Mixing water content | 166 kg/$m^3$ (Table 2) |
| | 3.2 Air content | 3.5% (Table 2 for mild and air entrained) |
| **4** | **Water cement ratio** | 0.52 (Table 3) |
| **5** | **Cement content** | 319.23 Kg/$m^3$ |
| **6** | **Coarse Aggregate Estimation** | |
| | 6.1 Maximum Aggregate size | 19 mm |
| | 6.2 Fines modulus of coarse aggregate | 2.93 |
| | 6.3 Volume Dry-Rodded coarse aggregate per unit volume of concrete | 0.607 |
| | 6.4 Dry-rodded density | 1785 kg/$m^3$ |
| | 6.5 Coarse aggregate volume | 1083.495 kg/$m^3$ |
| **7** | **First estimate of fresh concrete volume** | 2275 kg/$m^3$ (Table 9) |
| **8** | **Fine Aggregate estimation** | 706.28 kg/$m^3$ |
| **9** | **Adjustment for moisture content** | |
| | 9.1 Extra water required for fine aggregate | 11.021 kg/$m^3$ |
| | 9.2 Extra water required for coarse aggregate | 3.68 kg/$m^3$ |
| | 9.3 Water content of coarse aggregate | 1.50% |
| | 9.4 Water on surface of coarse aggregate | 16.25 kg/$m^3$ |
| | 9.5 Surplus water on surface of coarse aggregate | 12.57 kg/$m^3$ |
| | 9.6 Corrected mix Proportion | |
| | 9.6.1 Cement | 319.23 kg/$m^3$ |
| | 9.6.2 Water | 164.45 kg/$m^3$ |
| | 9.6.3 Fine aggregate | 706.28 kg/$m^3$ |
| | 9.6.4 Coarse aggregate | 1099.75 kg/$m^3$ |

**Table B3: Mix design data sheet for Mix C (C-30)**

| **Material property** | | **Values** |
|---|---|---|
| 1 | Characteristic strength | 30 Mpa |
| 2 | Cement type | OPC |
| 3 | Coarse Aggregate type | Crushed |
| 4 | Fine Aggregate type | River |
| 5 | Unit weight of coarse aggregate | 1756 kg/$m^3$ |
| 6 | Unit weight of fine aggregate | 1340 kg/$m^3$ |
| 7 | Specific gravity of cement | 3.15 |
| 8 | Specific gravity of Coarse aggregate | 2.64 |
| 9 | Specific gravity of fine aggregate | 2.51 |
| 10 | Absorption capacity of Coarse aggregate | 0.34% |
| 11 | Absorption capacity of fine aggregate | 1.56% |
| 12 | Fines modulus of coarse aggregate | 2.93 |
| 13 | Fines modulus of fine aggregate | 4.08 |
| 14 | water/cement ratio | 0.45 |
| Step | | |
| **1** | **Recommended Slump** | 20 -100 mm (Table 1) |
| **2** | **Maximum Aggregate size** | 19 mm |
| **3** | **Mixing water content and air content** | |
| | 3.1 Mixing water content | 166 kg/$m^3$ (Table 2) |
| | 3.2 Air content | 3.5% (Table 2 for mild and air entrained) |
| **4** | **Water cement ratio** | 0.45 (Table 3) |
| **5** | **Cement content** | 368.90 Kg/$m^3$ |
| **6** | **Coarse Aggregate Estimation** | |
| | 6.1 Maximum Aggregate size | 19mm |
| | 6.2 Fines modulus of coarse aggregate | 2.93 |
| | 6.3 Volume Dry-Rodded coarse aggregate per unit volume of concrete | 0.607 |
| | 6.4 Dry-rodded density | 1785 kg/$m^3$ |
| | 6.5 Coarse aggregate volume | 1083.495 kg/$m^3$ |
| **7** | **First estimate of fresh concrete volume** | 2275 kg/$m^3$ (Table 9) |
| **8** | **Fine Aggregate estimation** | 656.61 kg/$m^3$ |
| **9** | **Adjustment for moisture content** | |
| | 9.1 Extra water required for fine aggregate | 10.24 kg/$m^3$ |
| | 9.2 Extra water required for coarse aggregate | 3.68 kg/$m^3$ |
| | 9.3 Water content of coarse aggregate | 1.50% |
| | 9.4 Water on surface of coarse aggregate | 16.25 kg/$m^3$ |
| | 9.5 Surplus water on surface of coarse aggregate | 12.57 kg/$m^3$ |
| | 9.6 Corrected mix Proportion | |
| | 9.6.1 Cement | 368.90 kg/$m^3$ |
| | 9.6.2 Water | 163.67 kg/$m^3$ |
| | 9.6.3 Fine aggregate | 656.61 kg/$m^3$ |
| | 9.6.4 Coarse aggregate | 1099.75 kg/$m^3$ |

# APPENDIX C: COMPRESSIVE STRENGTH TEST RESULTS

Table C1: 7th Day Compressive Strength Results for Mix design A (C20)

| Mix Designation | Specimens No | Dimension (mm) | | | Weight (g) | Volume ($cm^3$) | Unit weight ($g/cm^3$) | Load at failure (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| Control 1 | C20001 | 150.8 | 149.9 | 150.1 | 8448.30 | 3393.00 | 2.49 | 385.30 | 17.04 |
| | C20002 | 149.8 | 150.9 | 150.3 | 8443.30 | 3397.50 | 2.49 | 394.61 | 17.46 |
| | C20003 | 150.2 | 149.8 | 149.4 | 8452.30 | 3361.49 | 2.51 | 380.90 | 16.93 |
| | Average | | | | 8447.97 | 3384.00 | 2.50 | 386.94 | 17.14 |
| C-20-1.0 | C20101 | 149.6 | 150.0 | 149.5 | 8278.00 | 3354.78 | 2.47 | 398.40 | 17.75 |
| | C20102 | 150.0 | 149.8 | 150.0 | 8283.00 | 3370.72 | 2.46 | 406.25 | 18.08 |
| | C20103 | 149.8 | 150.1 | 149.9 | 8317.00 | 3370.50 | 2.47 | 403.10 | 17.93 |
| | Average | | | | 8291.67 | 3365.33 | 2.46 | 402.58 | 17.92 |
| C-20-1.5 | C20151 | 150.1 | 150.1 | 149.7 | 8476.00 | 3372.74 | 2.51 | 416.90 | 18.50 |
| | C20152 | 149.9 | 150.3 | 149.6 | 8483.00 | 3370.48 | 2.52 | 410.60 | 18.22 |
| | C20153 | 149.5 | 149.4 | 150.0 | 8451.90 | 3350.30 | 2.52 | 417.36 | 18.69 |
| | Average | | | | 8458.57 | 3364.51 | 2.52 | 414.95 | 18.47 |
| C-20-2.0 | C20201 | 150.0 | 150.8 | 149.8 | 8480.60 | 3388.70 | 2.50 | 427.90 | 18.92 |
| | C20202 | 149.9 | 149.8 | 150.1 | 8480.27 | 3370.50 | 2.52 | 429.80 | 19.14 |
| | C20203 | 149.7 | 150.2 | 149.9 | 8460.60 | 3370.49 | 2.51 | 432.50 | 19.24 |
| | Average | | | | 8463.90 | 3376.56 | 2.51 | 430.07 | 19.10 |

Table C2: 7th Day Compressive Strength Results for Mix design B (C25)

| Mix Designation | Specimens No | Dimension (mm) | | | Weight (g) | Volume ($cm^3$) | Unit weight ($g/cm^3$) | Load at failure (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| Control 2 | C25001 | 149.9 | 151.0 | 150.4 | 8396.32 | 3404.29 | 2.47 | 398.90 | 17.62 |
| | C25002 | 150.3 | 149.9 | 149.5 | 8282.89 | 3368.23 | 2.46 | 394.60 | 17.51 |
| | C25003 | 149.7 | 150.1 | 149.6 | 8450.18 | 3361.51 | 2.51 | 395.36 | 17.60 |
| | Average | | | | 8376.09 | 3378.01 | 2.48 | 396.29 | 17.58 |
| C-25-1.0 | C25101 | 150.1 | 149.9 | 150.1 | 8317.60 | 3377.47 | 2.46 | 463.99 | 20.62 |
| | C25102 | 150.9 | 150.0 | 150.2 | 8451.60 | 3399.10 | 2.49 | 407.89 | 18.02 |
| | C25103 | 149.9 | 151.0 | 150.4 | 8452.10 | 3403.61 | 2.48 | 409.59 | 18.10 |
| | Average | | | | 8459.90 | 3393.39 | 2.48 | 427.16 | 18.91 |
| C-25-1.5 | C25151 | 150.3 | 149.9 | 149.5 | 8479.75 | 3367.56 | 2.52 | 441.60 | 19.60 |
| | C25152 | 149.7 | 150.1 | 149.6 | 8479.42 | 3360.83 | 2.52 | 442.45 | 19.69 |
| | C25153 | 150.1 | 149.9 | 150.1 | 8444.35 | 3376.80 | 2.50 | 443.30 | 19.70 |
| | Average | | | | 8467.84 | 3368.40 | 2.51 | 442.45 | 19.67 |
| C-25-2.0 | C25201 | 149.7 | 149.6 | 150.2 | 8476.10 | 3363.75 | 2.52 | 456.49 | 20.38 |
| | C25202 | 150.2 | 151.0 | 150.0 | 8359.50 | 3402.26 | 2.46 | 459.80 | 20.27 |
| | C25203 | 150.1 | 150.0 | 150.3 | 8384.67 | 3384.00 | 2.48 | 450.09 | 19.99 |
| | Average | | | | 8454.93 | 3383.34 | 2.48 | 455.46 | 20.22 |

Table C3: 7th Day Compressive Strength Results for Mix design C (C30)

| Mix Designation | Specimens No | Dimension (mm) | | | Weight (g) | Volume ($cm^3$) | Unit weight ($g/cm^3$) | Load at failure (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| Control 3 | C30001 | 150.1 | 150.9 | 149.9 | 8452.30 | 3395.47 | 2.49 | 445.90 | 19.69 |
| | C30002 | 150.0 | 149.9 | 150.2 | 8458.97 | 3377.25 | 2.50 | 449.36 | 19.98 |
| | C30003 | 149.8 | 150.3 | 150.0 | 8448.30 | 3377.24 | 2.50 | 452.90 | 20.12 |
| | Average | | | | 8443.30 | 3383.32 | 2.50 | 449.39 | 19.93 |
| C-30-1.0 | C30101 | 150.9 | 150.0 | 150.2 | 8452.30 | 3399.10 | 2.49 | 460.80 | 20.36 |
| | C30102 | 149.9 | 151.0 | 150.4 | 8447.97 | 3403.61 | 2.48 | 461.60 | 20.40 |
| | C30103 | 150.3 | 149.9 | 149.5 | 8277.30 | 3367.56 | 2.46 | 472.61 | 20.98 |
| | Average | | | | 8282.30 | 3390.09 | 2.48 | 465.00 | 20.58 |
| C-30-1.5 | C30151 | 150.3 | 150.3 | 149.9 | 8483.30 | 3386.25 | 2.51 | 469.55 | 20.79 |
| | C30152 | 150.1 | 150.5 | 149.8 | 8480.30 | 3383.99 | 2.51 | 484.90 | 21.47 |
| | C30153 | 149.7 | 149.6 | 150.2 | 8479.97 | 3363.75 | 2.52 | 485.75 | 21.69 |
| | Average | | | | 8460.30 | 3378.00 | 2.51 | 480.07 | 21.31 |
| C-30-2.0 | C30201 | 149.8 | 150.2 | 149.7 | 8464.30 | 3367.57 | 2.51 | 493.90 | 21.95 |
| | C30202 | 150.2 | 150.0 | 150.2 | 8316.30 | 3383.56 | 2.46 | 508.40 | 22.57 |
| | C30203 | 150.0 | 150.3 | 150.1 | 8291.97 | 3383.33 | 2.45 | 497.30 | 22.06 |
| | Average | | | | 8476.30 | 3378.15 | 2.47 | 499.87 | 22.19 |

Table C4: 28th Day Compressive Strength Results for Mix design A. (C20)

| Mix Designation | Specimens No | Dimension (mm) | | | Weight (g) | Volume ($cm^3$) | Unit weight ($g/cm^3$) | Load at failure (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| Control 1 | C20001 | 150.2 | 149.9 | 149.7 | 8276.00 | 3370.49 | 2.46 | 513.92 | 22.83 |
| | C20002 | 149.8 | 150.0 | 149.9 | 8281.00 | 3368.48 | 2.46 | 486.20 | 21.64 |
| | C20003 | 150.8 | 149.5 | 150.0 | 8315.00 | 3381.92 | 2.46 | 448.20 | 19.88 |
| | Average | | | | 8290.67 | 3373.63 | 2.46 | 482.77 | 21.45 |
| C-20-1.0 | C20101 | 150.1 | 149.9 | 149.5 | 8475.00 | 3363.75 | 2.52 | 486.76 | 21.63 |
| | C20102 | 149.8 | 150.1 | 149.9 | 8482.00 | 3370.50 | 2.52 | 497.26 | 22.12 |
| | C20103 | 150.0 | 149.8 | 150.1 | 8479.00 | 3372.75 | 2.51 | 505.00 | 22.47 |
| | Average | | | | 8478.67 | 3369.00 | 2.52 | 496.34 | 22.07 |
| C-20-1.5 | C20151 | 150.1 | 150.0 | 149.8 | 8459.00 | 3372.75 | 2.51 | 490.84 | 21.80 |
| | C20152 | 149.9 | 149.6 | 150.0 | 8463.00 | 3363.76 | 2.52 | 505.24 | 22.53 |
| | C20153 | 149.5 | 149.7 | 149.6 | 8451.00 | 3348.07 | 2.52 | 508.35 | 22.71 |
| | Average | | | | 8457.67 | 3361.52 | 2.52 | 501.48 | 22.35 |
| C-20-2.0 | C20201 | 149.8 | 150.8 | 149.4 | 8447.00 | 3374.92 | 2.50 | 554.53 | 24.55 |
| | C20202 | 150.9 | 149.8 | 150.3 | 8442.00 | 3397.50 | 2.48 | 507.75 | 22.46 |
| | C20203 | 149.9 | 150.2 | 150.1 | 8451.00 | 3379.50 | 2.50 | 535.60 | 23.79 |
| | Average | | | | 8446.67 | 3383.98 | 2.50 | 532.63 | 23.60 |

Table C5: 28th Day Compressive Strength Results for Mix design B (C25)

| Mix Designation | Specimens Number | Dimension (mm) | | | Weight (g) | Volume ($cm^3$) | Unit weight ($g/cm^3$) | Load at failure (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| Control 2 | C25001 | 150.0 | 150.3 | 149.6 | 8450.40 | 3372.51 | 2.51 | 631.73 | 28.02 |
| | C25002 | 151.0 | 150.3 | 149.5 | 8450.90 | 3392.95 | 2.49 | 597.12 | 26.31 |
| | C25003 | 149.6 | 149.7 | 150.4 | 8458.70 | 3368.23 | 2.51 | 598.87 | 26.74 |
| | Average | | | | 8453.33 | 3377.89 | 2.50 | 609.24 | 27.02 |
| C-25-1.0 | C25101 | 149.9 | 150.1 | 150.1 | 8316.00 | 3377.25 | 2.46 | 617.19 | 27.43 |
| | C25102 | 150.1 | 150.1 | 149.6 | 8474.50 | 3370.04 | 2.51 | 637.70 | 28.31 |
| | C25103 | 149.9 | 149.7 | 149.5 | 8357.50 | 3354.56 | 2.49 | 610.43 | 27.20 |
| | Average | | | | 8382.67 | 3367.28 | 2.49 | 621.78 | 27.65 |
| C-25-1.5 | C25151 | 149.9 | 150.1 | 150.3 | 8394.32 | 3381.30 | 2.48 | 648.12 | 28.81 |
| | C25152 | 151.0 | 149.7 | 150.0 | 8282.00 | 3390.48 | 2.44 | 625.02 | 27.65 |
| | C25153 | 150.0 | 150.2 | 150.2 | 8449.29 | 3384.01 | 2.50 | 638.92 | 28.36 |
| | Average | | | | 8375.20 | 3385.26 | 2.47 | 637.35 | 28.27 |
| C-25-2.0 | C25201 | 151.0 | 149.9 | 150.4 | 8478.30 | 3404.06 | 2.49 | 661.83 | 29.24 |
| | C25202 | 149.9 | 150.3 | 150.2 | 8477.97 | 3383.55 | 2.51 | 661.03 | 29.34 |
| | C25203 | 150.1 | 149.7 | 150.1 | 8442.90 | 3372.74 | 2.50 | 667.95 | 29.73 |
| | Average | | | | 8466.39 | 3386.79 | 2.50 | 663.60 | 29.44 |

Table C6: 28th Day Compressive Strength Results for Mix design C (C30)

| Mix Designation | Specimens Number | Dimension (mm) | | | Weight (g) | Volume ($cm^3$) | Unit weight ($g/cm^3$) | Load at failure (KN) | Compressive strength (Mpa) |
|---|---|---|---|---|---|---|---|---|---|
| | | L | W | H | | | | | |
| Control 3 | C30001 | 150.1 | 149.9 | 149.5 | 8452.90 | 3363.08 | 2.51 | 795.30 | 35.35 |
| | C30002 | 150.2 | 151.0 | 150.4 | 8453.40 | 3410.65 | 2.48 | 762.10 | 33.60 |
| | C30003 | 149.7 | 150.0 | 150.2 | 8449.07 | 3372.07 | 2.51 | 784.60 | 34.95 |
| | Average | | | | 8451.79 | 3381.93 | 2.50 | 780.67 | 34.63 |
| C-30-1.0 | C30101 | 150.0 | 149.6 | 150.3 | 8449.40 | 3372.73 | 2.51 | 806.01 | 35.92 |
| | C30102 | 150.2 | 150.5 | 150.1 | 8444.40 | 3393.03 | 2.49 | 825.58 | 36.52 |
| | C30103 | 149.9 | 150.3 | 149.7 | 8293.67 | 3372.74 | 2.46 | 792.17 | 35.16 |
| | Average | | | | 8395.82 | 3379.50 | 2.48 | 807.92 | 35.87 |
| C-30-1.5 | C30151 | 150.3 | 149.7 | 149.8 | 8284.00 | 3370.26 | 2.46 | 825.39 | 36.69 |
| | C30152 | 149.9 | 150.1 | 150.0 | 8318.00 | 3374.77 | 2.46 | 810.39 | 36.02 |
| | C30153 | 150.9 | 150.3 | 150.1 | 8476.50 | 3404.31 | 2.49 | 815.49 | 35.96 |
| | Average | | | | 8359.50 | 3383.12 | 2.47 | 817.09 | 36.22 |
| C-30-2.0 | C30201 | 150.3 | 150.3 | 150.0 | 8480.50 | 3388.06 | 2.50 | 836.72 | 37.04 |
| | C30202 | 149.9 | 150.0 | 150.2 | 8480.17 | 3376.80 | 2.51 | 841.14 | 37.41 |
| | C30203 | 150.9 | 150.2 | 149.8 | 8460.90 | 3394.79 | 2.49 | 855.77 | 37.76 |
| | Average | | | | 8473.86 | 3386.55 | 2.50 | 844.54 | 37.40 |

# APPENDIX D: FLEXURAL TENSILE STRENGTH TEST RESULTS

Table D1: 28th Split test Results for Mix design A

| Mix Designation | Specimens No | Dimension (mm) | | Weight (g) | Volume ($cm^3$) | Unit weight ($g/cm^3$) | Load at failure (KN) | Tensile strength (Mpa) |
|---|---|---|---|---|---|---|---|---|
| | | Dia | H | | | | | |
| Control 1 | C200011 | 150.2 | 300.1 | 12648.89 | 5314.66 | 2.38 | 166.04 | 2.35 |
| | C200022 | 149.8 | 299.2 | 12912.82 | 5270.54 | 2.45 | 188.73 | 2.68 |
| | C200033 | 150.2 | 299.9 | 13171.57 | 5311.12 | 2.48 | 154.38 | 2.18 |
| | Average | | | 12911.09 | 5298.77 | 2.44 | 169.72 | 2.40 |
| C-20-1.0 | C201011 | 149.6 | 300.0 | 8475.00 | 5270.53 | 1.61 | 280.63 | 3.98 |
| | C201022 | 150.2 | 300.0 | 8482.00 | 5312.89 | 1.60 | 263.73 | 3.73 |
| | C201033 | 149.9 | 298.2 | 8479.00 | 5259.94 | 1.61 | 273.04 | 3.89 |
| | Average | | | 8478.67 | 5281.12 | 1.61 | 272.47 | 3.87 |
| C-20-1.5 | C201511 | 150.1 | 300.5 | 8459.00 | 5314.66 | 1.59 | 332.63 | 4.70 |
| | C201522 | 149.9 | 299.9 | 8463.00 | 5289.04 | 1.60 | 325.73 | 4.62 |
| | C201533 | 149.5 | 300.0 | 8451.00 | 5263.48 | 1.61 | 321.04 | 4.56 |
| | Average | | | 8457.67 | 5289.06 | 1.60 | 326.47 | 4.62 |
| C-20-2.0 | C202011 | 150.0 | 300.4 | 8447.00 | 5305.64 | 1.59 | 378.63 | 5.35 |
| | C202022 | 149.9 | 300.0 | 8442.00 | 5291.69 | 1.60 | 367.73 | 5.21 |
| | C202033 | 149.7 | 300.0 | 8451.00 | 5276.70 | 1.60 | 379.04 | 5.38 |
| | Average | | | 8446.67 | 5291.34 | 1.60 | 375.13 | 5.31 |

Table D2: 28th Split test Results for Mix design B

| Mix Designation | Specimens No | Dimension (mm) | | Weight (g) | Volume ($cm^3$) | Unit weight ($g/cm^3$) | Load at failure (KN) | Tensile strength (Mpa) |
|---|---|---|---|---|---|---|---|---|
| | | L | H | | | | | |
| Control 1 | C250011 | 149.6 | 300.5 | 8276.00 | 5278.43 | 1.57 | 187.49 | 2.66 |
| | C250022 | 150.0 | 300.5 | 8281.00 | 5307.58 | 1.56 | 178.72 | 2.53 |
| | C250033 | 150.2 | 300.9 | 8315.00 | 5327.94 | 1.56 | 188.92 | 2.66 |
| | Average | | | 8290.67 | 5304.65 | 1.56 | 185.04 | 2.62 |
| C-25-1.0 | C251011 | 150.0 | 300.5 | 8475.00 | 5307.58 | 1.60 | 310.63 | 4.39 |
| | C251022 | 150.3 | 300.4 | 8482.00 | 5326.17 | 1.59 | 295.73 | 4.17 |
| | C251033 | 149.7 | 301.0 | 8479.00 | 5295.17 | 1.60 | 285.04 | 4.03 |
| | Average | | | 8478.67 | 5309.64 | 1.60 | 297.13 | 4.20 |
| C-25-1.5 | C251511 | 150.3 | 298.7 | 8459.00 | 5296.91 | 1.60 | 381.63 | 5.41 |
| | C251522 | 149.9 | 300.5 | 8463.00 | 5300.51 | 1.60 | 375.73 | 5.31 |
| | C251533 | 150.3 | 300.5 | 8451.00 | 5328.83 | 1.59 | 372.04 | 5.25 |
| | Average | | | 8457.67 | 5308.75 | 1.59 | 376.47 | 5.32 |
| C-25-2.0 | C252011 | 149.8 | 300.4 | 8447.00 | 5291.68 | 1.60 | 434.63 | 6.15 |
| | C252022 | 150.0 | 299.7 | 8442.00 | 5293.45 | 1.59 | 444.73 | 6.30 |
| | C252033 | 150.1 | 300.6 | 8451.00 | 5317.14 | 1.59 | 456.04 | 6.44 |
| | Average | | | 8446.67 | 5300.75 | 1.59 | 445.13 | 6.30 |

Table D3: 28th Split test Results for Mix design C

| Mix Designation | Specimens No | Dimension (mm) | | Weight (g) | Volume ($cm^3$) | Unit weight ($g/cm^3$) | Load at failure (KN) | Tensile strength (Mpa) |
|---|---|---|---|---|---|---|---|---|
| | | L | H | | | | | |
| Control 3 | C300011 | 149.6 | 300.5 | 8276.00 | 5278.43 | 1.57 | 213.32 | 3.02 |
| | C300022 | 150.0 | 300.5 | 8281.00 | 5307.58 | 1.56 | 234.05 | 3.31 |
| | C300033 | 150.2 | 300.9 | 8315.00 | 5327.94 | 1.56 | 226.01 | 3.19 |
| | Average | | | 8290.67 | 5304.65 | 1.56 | 224.46 | 3.17 |
| C-30-1.0 | C301011 | 150.0 | 300.5 | 8475.00 | 5307.58 | 1.60 | 362.63 | 5.12 |
| | C301022 | 150.3 | 300.4 | 8482.00 | 5326.17 | 1.59 | 348.73 | 4.92 |
| | C301033 | 149.7 | 301.0 | 8479.00 | 5295.17 | 1.60 | 367.04 | 5.19 |
| | Average | | | 8478.67 | 5309.64 | 1.60 | 359.47 | 5.08 |
| C-30-1.5 | C301511 | 150.3 | 298.7 | 8459.00 | 5296.91 | 1.60 | 465.63 | 6.61 |
| | C301522 | 149.9 | 300.5 | 8463.00 | 5300.51 | 1.60 | 467.73 | 6.61 |
| | C301533 | 150.3 | 300.5 | 8451.00 | 5328.83 | 1.59 | 490.04 | 6.91 |
| | Average | | | 8457.67 | 5308.75 | 1.59 | 474.47 | 6.71 |
| C-30-2.0 | C302011 | 149.8 | 300.4 | 8447.00 | 5291.68 | 1.60 | 518.63 | 7.34 |
| | C302022 | 150.0 | 299.7 | 8442.00 | 5293.45 | 1.59 | 520.73 | 7.38 |
| | C302033 | 150.1 | 300.6 | 8451.00 | 5317.14 | 1.59 | 535.04 | 7.55 |
| | Average | | | 8446.67 | 5300.75 | 1.59 | 524.80 | 7.42 |

# APPENDIX E: COMPRESSIVE AND TENSILE BEHAVIORS USED FOR ABAQUS INPUT

**Table: E1 Compressive behavior for C-20, C-25 and C-30 concrete**

| C-20 | | | | | |
|---|---|---|---|---|---|
| ε | σ | Damage parameter | elastic strain | inelastic strain | plastic strain |
| 0 | 0.00 | 0.00 | 0.000000 | 0.000000 | 0.00000 |
| 0.000119 | 3.04 | 0.00 | 0.000132 | 0.000000 | 0.00000 |
| 0.000237 | 5.76 | 0.00 | 0.000251 | 0.000000 | 0.00000 |
| 0.000356 | 8.16 | 0.00 | 0.000356 | 0.000000 | 0.00000 |
| 0.000474 | 10.24 | 0.00 | 0.000446 | 0.000028 | 0.00003 |
| 0.000593 | 12.00 | 0.00 | 0.000523 | 0.000070 | 0.00007 |
| 0.000711 | 13.44 | 0.00 | 0.000586 | 0.000125 | 0.00013 |
| 0.00083 | 14.56 | 0.00 | 0.000634 | 0.000195 | 0.00020 |
| 0.000948 | 15.36 | 0.00 | 0.000669 | 0.000279 | 0.00028 |
| 0.001067 | 15.84 | 0.00 | 0.000690 | 0.000376 | 0.00038 |
| 0.001185 | 16.00 | 0.00 | 0.000697 | 0.000488 | 0.00049 |
| 0.001447 | 15.76 | 0.02 | 0.000687 | 0.000760 | 0.00075 |
| 0.001708 | 15.52 | 0.03 | 0.000676 | 0.001032 | 0.00101 |
| 0.00197 | 15.28 | 0.04 | 0.000666 | 0.001304 | 0.00127 |
| 0.002231 | 15.04 | 0.06 | 0.000655 | 0.001576 | 0.00153 |
| 0.002493 | 14.80 | 0.08 | 0.000645 | 0.001848 | 0.00180 |
| 0.002754 | 14.56 | 0.09 | 0.000634 | 0.002120 | 0.00206 |
| 0.003016 | 14.32 | 0.11 | 0.000624 | 0.002392 | 0.00232 |
| 0.003277 | 14.08 | 0.12 | 0.000614 | 0.002664 | 0.00258 |
| 0.003539 | 13.84 | 0.14 | 0.000603 | 0.002935 | 0.00284 |
| 0.0038 | 13.6 | 0.15 | 0.000593 | 0.003207 | 0.00310 |

| C-25 | | | | | |
|---|---|---|---|---|---|
| ε | σ | Damage parameter | elastic strain | inelastic strain | plastic strain |
| 0.0000 | 0.00 | 0.00 | 0.00000 | 0.00 | 0.00000 |
| 0.000138 | 3.80 | 0.00 | 0.00015 | 0.00 | 0.00000 |
| 0.000276 | 7.20 | 0.00 | 0.00029 | 0.00 | 0.00000 |
| 0.000414 | 10.20 | 0.00 | 0.00041 | 0.00000 | 0.00000 |
| 0.000552 | 12.80 | 0.00 | 0.00052 | 0.00003 | 0.00003 |
| 0.0007 | 15.00 | 0.00 | 0.00061 | 0.00008 | 0.00008 |
| 0.000828 | 16.80 | 0.00 | 0.00068 | 0.00015 | 0.00015 |
| 0.000966 | 18.20 | 0.00 | 0.00074 | 0.00023 | 0.00023 |
| 0.001103 | 19.20 | 0.00 | 0.00078 | 0.00032 | 0.00032 |
| 0.001241 | 19.80 | 0.00 | 0.00080 | 0.00044 | 0.00044 |
| 0.001379 | 20.00 | 0.00 | 0.00081 | 0.00057 | 0.00057 |
| 0.0016 | 19.70 | 0.02 | 0.00080 | 0.00082 | 0.00081 |
| 0.001863 | 19.40 | 0.03 | 0.00079 | 0.00108 | 0.00105 |
| 0.002106 | 19.10 | 0.05 | 0.00077 | 0.00133 | 0.00129 |
| 0.002348 | 18.80 | 0.06 | 0.00076 | 0.00158 | 0.00154 |
| 0.00259 | 18.50 | 0.08 | 0.00075 | 0.00184 | 0.00178 |
| 0.002832 | 18.2 | 0.09 | 0.00074 | 0.00209 | 0.00202 |
| 0.003074 | 17.9 | 0.11 | 0.00073 | 0.00235 | 0.00226 |
| 0.003316 | 17.6 | 0.12 | 0.00071 | 0.00260 | 0.00250 |
| 0.003558 | 17.3 | 0.14 | 0.00070 | 0.00286 | 0.00275 |
| 0.0038 | 17 | 0.15 | 0.00069 | 0.00311 | 0.00299 |

| C-30 | | | | | |
|---|---|---|---|---|---|
| ε | σ | Damage parameter | elastic strain | inelastic strain | plastic strain |
| 0.0000 | 0.00 | 0 | 0.00000 | 0 | 0 |
| 0.00015 | 4.56 | 0 | 0.00017 | 0 | 0 |
| 0.0003 | 8.64 | 0 | 0.00032 | 0 | 0 |
| 0.00045 | 12.24 | 0 | 0.00045 | 0.00000 | 0.00000 |
| 0.0006 | 15.36 | 0 | 0.00056 | 0.00004 | 0.00004 |
| 0.0008 | 18.00 | 0 | 0.00066 | 0.00009 | 0.00009 |
| 0.0009 | 20.16 | 0 | 0.00074 | 0.00016 | 0.00016 |
| 0.00105 | 21.84 | 0 | 0.00080 | 0.00025 | 0.00025 |
| 0.0012 | 23.04 | 0 | 0.00085 | 0.00035 | 0.00035 |
| 0.00135 | 23.76 | 0 | 0.00087 | 0.00048 | 0.00048 |
| 0.001500 | 24.00 | 0 | 0.00088 | 0.00062 | 0.00062 |
| 0.0017 | 23.64 | 0.015 | 0.00087 | 0.00086 | 0.00085 |
| 0.00196 | 23.28 | 0.030 | 0.00086 | 0.00110 | 0.00107 |
| 0.00219 | 22.92 | 0.045 | 0.00084 | 0.00135 | 0.00130 |
| 0.00242 | 22.56 | 0.060 | 0.00083 | 0.00159 | 0.00153 |
| 0.00265 | 22.2 | 0.075 | 0.00082 | 0.00183 | 0.00176 |
| 0.00288 | 21.84 | 0.090 | 0.00080 | 0.00208 | 0.00199 |
| 0.00311 | 21.48 | 0.105 | 0.00079 | 0.00232 | 0.00222 |
| 0.00334 | 21.12 | 0.120 | 0.00078 | 0.00256 | 0.00245 |
| 0.00357 | 20.76 | 0.135 | 0.00076 | 0.00281 | 0.00268 |
| 0.0038 | 20.4 | 0.150 | 0.00075 | 0.00305 | 0.00290 |

**Table: E2 Tensile behavior for C-20, C-25 and C-30 concrete**

| C-20 | | | | | |
|---|---|---|---|---|---|
| ε | σ | Damage parameter | Elastic strain | Cracking Strain | plastic strain |
| 0.000000 | 0.00 | 0.00 | 0.000000 | 0.000000 | 0.000000 |
| 0.000105 | 2.40 | 0.00 | 0.000105 | 0.000000 | 0.000000 |
| 0.000301 | 1.33 | 0.45 | 0.000058 | 0.000243 | 0.000196 |
| 0.000497 | 0.94 | 0.61 | 0.000041 | 0.000455 | 0.000392 |
| 0.000693 | 0.74 | 0.69 | 0.000032 | 0.000660 | 0.000588 |
| 0.000889 | 0.61 | 0.75 | 0.000027 | 0.000862 | 0.000784 |
| 0.001085 | 0.52 | 0.78 | 0.000023 | 0.001062 | 0.000980 |
| 0.001281 | 0.46 | 0.81 | 0.000020 | 0.001261 | 0.001176 |
| 0.001477 | 0.41 | 0.83 | 0.000018 | 0.001459 | 0.001372 |
| 0.001673 | 0.37 | 0.85 | 0.000016 | 0.001656 | 0.001568 |
| 0.001869 | 0.34 | 0.86 | 0.000015 | 0.001854 | 0.001764 |
| C-25 | | | | | |
| ε | σ | Damage parameter | Elastic strain | Cracking Strain | plastic strain |
| 0.000000 | 0.00 | 0.00 | 0.000000 | 0.000000 | 0.000000 |
| 0.000122 | 3.00 | 0.00 | 0.000122 | 0.000000 | 0.000000 |
| 0.000333 | 1.66 | 0.45 | 0.000068 | 0.000265 | 0.000211 |
| 0.000544 | 1.18 | 0.61 | 0.000048 | 0.000496 | 0.000422 |
| 0.000755 | 0.92 | 0.69 | 0.000037 | 0.000717 | 0.000633 |
| 0.000966 | 0.76 | 0.75 | 0.000031 | 0.000935 | 0.000844 |
| 0.001177 | 0.65 | 0.78 | 0.000027 | 0.001150 | 0.001055 |
| 0.001388 | 0.57 | 0.81 | 0.000023 | 0.001364 | 0.001266 |
| 0.001599 | 0.51 | 0.83 | 0.000021 | 0.001578 | 0.001477 |
| 0.001810 | 0.46 | 0.85 | 0.000019 | 0.001791 | 0.001688 |
| 0.002021 | 0.42 | 0.86 | 0.000017 | 0.002004 | 0.001899 |
| C-30 | | | | | |
| ε | σ | Damage parameter | Elastic strain | Cracking Strain | plastic strain |
| 0.000000 | 0.00 | 0.00 | 0.0000000 | 0.00000 | 0.000000 |
| 0.000132 | 3.60 | 0.00 | 0.0001324 | 0.00000 | 0.000000 |
| 0.000358 | 2.00 | 0.45 | 0.0000734 | 0.00028 | 0.000220 |
| 0.000584 | 1.41 | 0.61 | 0.0000520 | 0.00053 | 0.000444 |
| 0.000811 | 1.11 | 0.69 | 0.0000407 | 0.00077 | 0.000669 |
| 0.001037 | 0.92 | 0.75 | 0.0000337 | 0.00100 | 0.000894 |
| 0.001263 | 0.79 | 0.78 | 0.0000289 | 0.00123 | 0.001120 |
| 0.001489 | 0.69 | 0.81 | 0.0000253 | 0.00146 | 0.001345 |
| 0.001715 | 0.61 | 0.83 | 0.0000226 | 0.00169 | 0.001571 |
| 0.001941 | 0.56 | 0.85 | 0.0000204 | 0.00192 | 0.001797 |
| 0.002167 | 0.51 | 0.86 | 0.0000187 | 0.00215 | 0.002023 |

# APPENDIX F: ABAQUS ANALYSIS RESULT; LOAD VS MID DEFLECTION

| 0.0% Steel fiber | | | | | |
|---|---|---|---|---|---|
| Concrete Grade | | | | | |
| C-20 | | C-25 | | C-30 | |
| Deflection (mm) | Load (KN) | Deflection (mm) | Load (KN) | Deflection (mm) | Load (KN) |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.18 | 2.07 | 0.18 | 2.07 | 0.22 | 3.40 |
| 0.32 | 3.55 | 0.32 | 3.55 | 0.38 | 5.04 |
| 0.38 | 3.62 | 0.40 | 4.52 | 0.41 | 5.63 |
| 0.43 | 3.91 | 0.43 | 4.52 | 0.44 | 6.22 |
| 0.50 | 3.66 | 0.50 | 4.56 | 0.46 | 6.32 |
| 0.54 | 3.57 | 0.54 | 4.47 | 0.49 | 6.27 |
| 0.59 | 3.23 | 0.59 | 4.13 | 0.51 | 6.18 |
| 0.65 | 2.71 | 0.65 | 3.61 | 0.52 | 6.07 |
| 0.79 | 2.10 | 0.79 | 2.60 | 0.58 | 5.12 |
| 0.99 | 1.41 | 0.99 | 1.73 | 0.62 | 4.19 |
| 1.14 | 0.95 | 1.14 | 1.26 | 0.82 | 3.03 |
| 1.38 | 0.25 | 1.38 | 0.57 | 1.10 | 1.87 |
| 1.56 | 0.00 | 1.56 | 0.00 | 1.56 | 0.15 |

| 1% Steel fiber | | | | | |
|---|---|---|---|---|---|
| Concrete Grade | | | | | |
| C-20 | | C-25 | | C-30 | |
| Deflection (mm) | Load (KN) | Deflection (mm) | Load (KN) | Deflection (mm) | Load (KN) |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.16 | 1.48 | 0.16 | 1.48 | 0.24 | 3.35 |
| 0.26 | 2.56 | 0.27 | 2.56 | 0.48 | 6.60 |
| 0.41 | 4.01 | 0.43 | 4.01 | 0.70 | 8.62 |
| 0.59 | 5.77 | 0.63 | 6.44 | 0.72 | 8.64 |
| 0.78 | 5.59 | 0.68 | 6.68 | 0.83 | 8.63 |
| 0.82 | 5.45 | 0.82 | 6.53 | 0.96 | 8.33 |
| 0.87 | 5.33 | 0.87 | 6.54 | 1.25 | 6.97 |
| 0.93 | 5.24 | 0.93 | 6.27 | 1.99 | 5.16 |
| 0.98 | 5.10 | 0.98 | 5.90 | 2.58 | 4.04 |
| 1.04 | 4.96 | 1.04 | 5.81 | 3.07 | 3.53 |
| 1.10 | 4.69 | 1.10 | 5.50 | 3.64 | 3.14 |
| 1.35 | 4.05 | 1.35 | 4.95 | 4.09 | 2.98 |
| 1.54 | 3.86 | 1.54 | 4.21 | 4.54 | 2.87 |
| 1.74 | 3.55 | 1.74 | 3.68 | 5.07 | 2.92 |
| 2.07 | 3.31 | 2.07 | 2.97 | 5.56 | 2.51 |
| 2.46 | 2.89 | 2.46 | 2.44 | 6.06 | 2.29 |
| 2.87 | 2.62 | 2.87 | 1.93 | | |
| 3.15 | 2.44 | 3.38 | 1.62 | | |
| 3.49 | 2.24 | 3.72 | 1.42 | | |
| 3.83 | 2.17 | 4.17 | 1.26 | | |
| 4.17 | 1.80 | 4.60 | 1.01 | | |
| 4.51 | 1.77 | 5.46 | 0.72 | | |

| 1.5% Steel fiber | | | | | |
|---|---|---|---|---|---|
| Concrete Grade | | | | | |
| C-20 | | C-25 | | C-30 | |
| Deflection (mm) | Load (KN) | Deflection (mm) | Load (KN) | Deflection (mm) | Load (KN) |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.45 | 5.51 | 0.53 | 5.51 | 0.21 | 2.82 |
| 0.79 | 7.17 | 0.69 | 7.17 | 0.45 | 5.87 |
| 0.89 | 7.19 | 0.86 | 8.27 | 0.61 | 7.62 |
| 1.07 | 7.18 | 1.07 | 8.08 | 0.84 | 9.63 |
| 1.33 | 6.69 | 1.33 | 7.59 | 1.04 | 9.94 |
| 1.45 | 6.40 | 1.45 | 7.30 | 1.21 | 9.60 |
| 1.66 | 5.93 | 1.66 | 6.62 | 1.27 | 9.24 |
| 1.86 | 5.23 | 1.86 | 6.13 | 1.37 | 8.86 |
| 2.01 | 4.93 | 2.01 | 5.68 | 1.55 | 7.70 |
| 2.25 | 4.42 | 2.25 | 5.23 | 1.73 | 7.25 |
| 2.58 | 4.27 | 2.58 | 4.50 | 1.94 | 7.06 |
| 2.77 | 3.81 | 2.77 | 4.31 | 2.19 | 6.45 |
| 2.98 | 3.50 | 2.98 | 3.99 | 2.54 | 5.72 |
| 3.39 | 3.17 | 3.39 | 3.35 | 2.91 | 5.15 |
| 3.55 | 2.86 | 3.78 | 2.86 | 3.33 | 4.82 |
| 3.81 | 2.77 | 4.30 | 2.30 | 3.85 | 4.23 |
| 4.06 | 2.68 | 4.46 | 2.03 | 4.42 | 4.15 |
| 4.31 | 2.48 | 4.79 | 1.62 | 4.78 | 3.95 |
| 4.56 | 2.36 | 5.12 | 1.44 | 5.21 | 3.88 |
| 4.81 | 2.32 | 5.44 | 1.17 | 5.66 | 3.79 |
| 5.06 | 2.20 | 5.77 | 1.04 | 6.10 | 3.64 |
| 5.57 | 2.01 | 6.10 | 0.95 | 7.00 | 3.59 |

| 2 % Steel fiber | | | | | |
|---|---|---|---|---|---|
| Concrete Grade | | | | | |
| C-20 | | C-25 | | C-30 | |
| Deflection (mm) | Load (KN) | Deflection (mm) | Load (KN) | Deflection (mm) | Load (KN) |
| 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 0.42 | 4.68 | 0.42 | 4.68 | 0.31 | 4.68 |
| 0.65 | 6.34 | 0.54 | 6.34 | 0.43 | 6.34 |
| 0.99 | 7.91 | 0.69 | 7.91 | 0.59 | 7.91 |
| 1.30 | 8.43 | 0.83 | 8.88 | 0.68 | 8.88 |
| 1.46 | 8.51 | 1.06 | 9.56 | 0.79 | 9.90 |
| 1.53 | 8.50 | 1.53 | 9.29 | 0.94 | 11.18 |
| 1.86 | 8.02 | 1.86 | 8.22 | 1.14 | 11.63 |
| 2.01 | 7.76 | 2.01 | 8.03 | 1.34 | 10.87 |
| 2.25 | 7.28 | 2.25 | 7.41 | 1.45 | 10.70 |
| 2.58 | 6.46 | 2.58 | 6.78 | 1.60 | 10.45 |
| 2.77 | 6.36 | 2.77 | 6.58 | 1.84 | 9.50 |
| 2.98 | 6.07 | 2.98 | 6.31 | 2.17 | 8.97 |
| 3.39 | 5.16 | 3.39 | 5.61 | 2.70 | 7.74 |
| 3.78 | 4.62 | 3.78 | 5.33 | 3.20 | 7.45 |
| 4.30 | 3.72 | 4.30 | 4.34 | 3.77 | 6.37 |
| 4.36 | 3.63 | 4.90 | 3.76 | 4.21 | 5.91 |
| 4.66 | 3.37 | 5.19 | 3.29 | 4.67 | 5.08 |
| 4.95 | 3.28 | 5.62 | 2.71 | 5.20 | 4.79 |
| 5.25 | 3.11 | 6.05 | 2.14 | 5.73 | 4.56 |
| 5.54 | 2.94 | 6.48 | 1.96 | 6.71 | 4.41 |
| 5.84 | 2.88 | 6.91 | 1.49 | 7.21 | 4.33 |
| 6.43 | 2.65 | 7.34 | 1.30 | 8.21 | 4.08 |

Table F: Load versus Deflection

# APPENDIX G: PHOTOS FROM SITE AND LABORATORY

Figure F1: Sieve analysis

Figure F2: RSF preparation

Figure F3: SFRC mixing

Figure 4: Slump test

Figure F5: Casting RSFC Specimens


Figure F6: Weighing Specimens

Figure F7: Putting Specimens on machine

Figure F8: Crushed Specimen