

**ADDIS ABABA UNIVERSITY**  
**ADDIS ABABA INSTITUTE OF TECHNOLOGY**  
**SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING**



**INVESTIGATION OF THE USE OF STEEL  
FIBERS EXTRACTED FROM USED TYRES  
FOR REINFORCED CONCRETE BEAMS  
UNDER CYCLIC LOADING**

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**A Thesis in Structural Engineering**

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A Thesis

Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science

The undersigned have examined the thesis entitled ‘**Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading**’ presented by **Lemlem Adefirs**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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## **UNDERTAKING**

I certify that research work titled “Investigation of the use of steel fiber extracted from used tyres for reinforced concrete beams under cyclic loading” is my own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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## **ABSTRACT**

Reinforced concrete (RC) beams under cyclic loading usually suffer from reduced aggregate interlock and eventually weakened concrete compression zone due to severe cracking and the brittle nature of compressive failure. On the other hand, the addition of steel fibers with conventional steel reinforcements can reduce and delay cracking and also increase shear capacity and the ductility of RC beams. In this thesis shear strength test of nine beams were conducted experimentally and analytically; seven beams with different steel fiber volume and shear spacing and two as control specimen. The variables were shear spacing, volume of steel fiber and type of loading. Steel fibers, which were extracted from used tyre, each with a length-to-diameter ratio equal to 63.158 were added to the steel fiber reinforced concrete (SFRC) beams. Accompanying, compression, and splitting tests were also carried out to evaluate the compressive and tensile splitting strength of the used fibrous concrete mixtures. Test results indicated that the control specimen demonstrated shear diagonal cracking failing in a brittle manner, whereas for the SFRC beams after the diagonal crack appeared, the steel fiber reduces and delay diagonal crack width. The SFRC beam with 1% steel fibers and its shear spacing increased by 50% exhibited an improved cyclic response, achieving a pronounced shear behavior with significant strength.

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## List of Symbols

$AR_f$	Aspect ratio of steel fiber
$b$	Width of the beam
$d$	Effective depth
$df$	diameter of steel fiber
$E_{cm}$	young's modulus of concrete
$E_s$	young's modulus of steel
$F$	applied force on specimen
$f_{ck}$	compressive strength of concrete
$f_{ctk}$	tensile strength of concrete
$f_u$	ultimate tensile stress;
$F_y$	material yield stress
$l$	effective length
$l_f$	length of steel fiber
$S$	Shear spacing
$w/c$	Water to Cement ratio
$\rho_w$	Percentage of reinforcement based on web width ( $A_s/bwd$ )

## LIST OF ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Standard Testing Method
EC2	Euro code 2
FE	Finite Element
FEM	Finite Element Method
FRC	Fiber Reinforced Concrete
FRP	Fiber Reinforced Polymer
HSC	High Strength Concrete
kN	Kilo Newton
LVDT	Linear Variable Displacement Transducer
MPa	Mega Pascal
NLFEA	Non Linear Finite Element Analysis
OPC	Ordinary Portland Cement
RC	Reinforced Concrete
RSF	Recovered Steel Fiber
RSFRC	Recycled Steel Fiber Reinforced Concrete
SFRC	Steel Fiber Reinforced Concrete
SP	Super Plasticizers
SSD	Saturated Surface Dry Condition
VF	Volume of Steel fiber

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# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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## CHAPTER 1 INTRODUCTION

### 1.1 Background

A reinforced concrete member is a composite material that achieves its strength from the compressive action of concrete in compression, and the reinforcing steel in tension. When this flexure element is under-reinforced, large deformations originated from the yielding of the steel bars in tension will occur prior to failure.

Since the addition of fibers to a concrete mix enhances the concrete ductility, and confinement increases the concrete compression strength, numerous studies on both systems, researched individually, were conducted. However, the study and analysis on the contribution of these two mechanisms simultaneously applied to one flexure element, has not been explored. Also, the majority of studies on concrete confinement are limited to compression members. These members are either confined by wrapping or jacketing the entire member, or by the use of stirrups in the direction of the lateral strains.

The evaluation of the ultimate bearing capacity of framed structures under actions due to severe earthquake, as suggested by Codes, requires a nonlinear analysis, for which the complete constitutive laws of the materials are required for both monotonic and cyclic response. To ensure adequate dissipative capacity of the structural system and high ductility values, particular attention should be paid to the design of longitudinal and transverse steel reinforcements, especially when high strength concrete (HSC) members are used, avoiding brittle failure due to shear in the beams or in the joint regions. In fact, although high strength concrete offers, with respect to normal strength concrete, several advantages like more strength and durability, it is characterized by high brittleness in the post-peak response. To reduce the brittleness effect and to ensure adequate local ductility of the members a larger amount of transversal reinforcement is required with respect to normal strength concrete, especially in members subjected to axial load and bending moment when high values of compressive strain are involved. The studies (Bentur and Mindess, 1990) have shown that the use of discontinuous short fibers, randomly distributed in the matrices in adequate percentages and shapes, and

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coupled with traditional steel transverse reinforcement (spirals, stirrups, etc.), allows: i) to obtain high values of curvature ductility ii) to avoid brittle shear failure in the beams ensuring the making of flexural mechanism iii) to increase the shear strength also in the core of the beam-column joints in which high values of stress are concentrated. In this way it is possible to reduce, for these critical regions, the amount of transverse reinforcement required, generally difficult to place in cast.

Fiber-reinforced concrete, with the supplement of steel fibers is commonly applied to make industrial floors as well as road and airport runways. Fiber-reinforced concrete is also used to make machine foundations and other elements exposed to dynamic loads. In addition, concrete with the supplement of fibers is used as the short discrete technology, for example as casing of the underground structures or at renovation-repair activities. At the same time, it should be noted that fiber-reinforced concrete is used more and more often as the material for structural elements. An example may be the latest structural solution, the steel-fiber composite floor (Fig. 1-1) or RC elements absorbing energy of destruction in the case of structures exposed to seismic action. An interesting example of fiber-reinforced concrete application in water construction is the surface slab of the dam in Longshua (China), located in the area of seismic impacts. This structure is located in alternately wet and dry environment, and it is periodically influenced by large difference in temperatures (during the day and at night). Some of the dam panels were made of traditionally reinforced concrete and some of the dam panels made of concrete with the supplement of steel fibers. The longest panel with fibers has 75 meters and it does not show clear cracks even after the recent earthquake.

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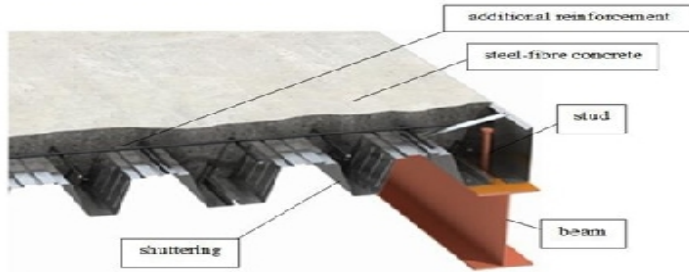


Figure. 1-1 Steel-fiber composite floor in Longshua (China)

Another example of steel fibers application in the structural elements is a thin shell structure covered buildings located in the European Oceanographic Park in Valencia. Structures are a combination of traditionally reinforced concrete and fiber-reinforced concrete (Figure. 1-2).



Figure. 1-2: SFRC shells in the European oceanographic park in Valencia

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## 1.2 Statement of the problem

Concrete is a brittle material and has less tensile and flexural strength. Concrete fails mostly due to the tensile stresses produced in it due to its self-weight or after the application of superimposed loads, in this regard heavy conventional reinforcement in the form of steel bars of different grades is provided at the tensile stressed zones of the concrete structural members which further increase the self-weight of the structure. Hence, these weak parameters such as tensile and flexural strength and also brittle nature of concrete can be improved by substituting the steel fibers to the concrete mix with definite proportion. These steel fibers serve the function of interlocking and transferring loads. This composite fibrous concrete mix can be used in conventional RC structures.

## 1.3 Objective of the research

### General Objective

-To investigate the possibility use of steel fibers, extracted from used tyres for reinforced concrete beams under cyclic loading.

### Specific Objective

- To investigate the adequacy of the shear strength of SFRC beams.
- To investigate the influence of steel fibers of different volume fractions with varying of shear spacing on the shear strength capacity.
- To simulate the experimental investigation result through nonlinear finite element modeling software.

## 1.4 Methodology

In this entire research four stages are carried out to find the respective solution for the objective of the research. In the first stage, a review of essential literature on steel fiber reinforced beam and the bead wire, which are extracted from used tyre. The second phase of the study includes the experimental investigation. Nine beams were casted in different

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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category; normal RC beams and SFRC beams. In normal beam category two beams and for steel fiber reinforced beam seven beams, which have different volume of steel fiber and varying shear spacing, were casted. On this experimental investigation; test specimens, materials used, specimen fabrication, specimen preparation and testing setup are properly done. The third phase of the study consist analytical modeling. Vector 2 analysis software was used for this research. All fixed parameter used for finite element analysis were identical to experimental program. In the fourth phase of the study there are interpretation of the experiment and analytical results.

## **1.5. Structure of the research**

The thesis was structured into six chapters and each chapter contains a number of sections and further subsections. A general introduction is provided along with the research objective, statement of the problem and methodology in the first chapter. The second chapter provides a review of relevant literature on the steel fiber reinforced concrete beam. Basic theories in reinforced concrete beam and SFRC beam and their properties expose to cyclic loading and their failure mode are discussed. Recent studies with regard to steel fiber and shear spacing are also incorporated. And also the extraction of steel fiber from used tyre.

The experimental program of the research is elaborated in the third chapter. It describes beam specimens, materials, specimen fabrication, loading conditions and test setup of instrumentations.

In the forth chapter the nonlinear finite element software is elaborated. Here the boundary conditions, loading mechanism, modeling and different assumptions taken are discussed. Chapter 5 covers the result and discussion of experimental and finite element simulation outputs. Chapter 6 offers the conclusion of the study with recommendation for future works.

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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## CHAPTER 2 LITERATURE REVIEW

### 2.1 Back ground

Fibers as a structural element have a very promising prospect, especially in high earthquake zones. The positive aspects of fiber concrete were underlined by the research work conducted by Hadi [1] and Paultre et al. [2], concluding that the addition of steel-fibers to the fresh concrete mix in a certain amount, improved the bond between the mortar matrix and the aggregates, and enhancing the energy absorption and toughness behavior. The steel-fibers thus contributed to the concrete ductility performance of the concrete, through the improvement of its stress-strain relationship behavior. Further, the study carried out by [3], proved that steel-fiber concrete maintained good ductility performance, even when exposed to substantially high temperatures. The steel-fibers imbedded in concrete are also less susceptible to corrosion when compared to the reinforcing concrete bars used in reinforced concrete elements [4]. Additionally, the continuing research work of Antonius [5] on steel-fiber concrete showed that the presence of these fibers take a major role in the deformation pattern of the resulting concrete, so that the fracture process of the concrete material can be controlled through the use of steel-fiber.

It is clearly seen from the literature that the behavior of beam is affected by the properties of core concrete. Ductility is desirable in reinforced concrete frames under seismic loading. Ductility is generally achieved by providing closely spaced horizontal ties, but this causes difficulties in placing concrete in densely reinforced portions resulting in bad concreting. To avoid such closely spaced stirrups, confinement characteristics of core concrete has to be improved, which increases the ductility of the core concrete. In this respect, steel fiber reinforced concrete (SFRC) which posse's ductility, toughness and tensile strength more than the plain conventional concrete can be considered to replace the plain concrete.

The significance of steel fibers in reinforced concrete has been known to improve primarily the post-cracking tensile response and crack control characteristics [6]. The

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fundamental concept of SFRC is simple. Concrete is weak in tension and reinforcement steel bars are continuous at some specified locations only; hence, the tensile response of conventionally reinforced concrete is improved only in the direction of the reinforcement. Steel fibres, on the other hand, are randomly distributed and discontinuous. These characteristics allow cracks in any direction to be bridged by the fibres and permit improved stress transfer across all cracks, improving post-cracking shear and flexural resistance [7] Further, fiber bridging allows crack openings to be controlled, enabling the development of additional cracks. In turn, this reduces the crack width and crack spacing, increasing post-cracked ductility and energy absorption capacity [7, 8, 9, 10]. In tension, SFRC fails only after the fibers fracture or are pulled out from the matrix [11]. In compression, similar to the tensile response, the addition of steel fibers primarily improves the post-peak ductility and toughness [12].

## **2.2 Steel fiber property**

### **2.2.1 Steel fiber volume**

One of the key variables influencing the behavior of SFRC is the fiber volume fraction. Many tension-critical tests, such as the uniaxial direct tension test, flexural test and direct shear test, have shown that increases in fiber volume fraction will lead to improved toughness, ductility and strength [6,13]. As the fiber content increases, more fibers are likely to intersect cracks, improving the matrix's ability to bridge cracks and enhance post-cracked behavior. Research by Shah and Rangan [6] showed that toughness, defined as the area under the load-deflection diagram, is significantly improved with increases in fiber content; this results in a significant increase in ductility. Tensile strength, however, is only marginally improved. Doubling the fiber content from 0.5% to 1.0% increased the concrete uniaxial tensile toughness from 1.8 times to 2.7 times that of the plain concrete, but the concrete uniaxial tensile strength was only increased from 1.1 times to 1.3 times that of plain concrete. These improved behaviors were more pronounced in flexural tests.

A high fiber volume can cause strain-hardening behavior, a desirable response where the concrete's maximum tensile stress is higher than the first-cracking stress [14]. Although

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the exact fiber amount required for strain-hardening depends on other properties of the fiber, some studies have shown that 1.5% fiber volume may be sufficient to cause strain-hardening [15,16]

Despite the advantages associated with increases in the fiber content, limits should be placed on the maximum fiber volume fraction due to workability issues and fiber saturation. The usual amount of steel fibers ranges from 0.25% by volume, i.e., 20 kg/m<sup>3</sup>, to 2% by volume, i.e., 157 kg/m<sup>3</sup>. The low end of the range applies to lightly loaded ground slabs, some precast applications, and composite steel deck toppings. The upper end of the range is common for security applications (safes, vaults, etc) [17].

## 2.2.2 Steel fiber aspect ratio

The fiber aspect ratio, defined as the ratio of the fiber length ( $l_f$ ) to fiber diameter ( $d_f$ ) [ $AR_f=l_f/d_f$ ], has important influence over the effectiveness of fiber reinforcement. Under the same fiber volume, a higher aspect ratio will lead to higher fiber surface area which, in turn, creates an improved bond between the fibers and the matrix; this has the effect of creating a stiffer matrix and improving composite actions [8].

According to ACI Committee 544.3 R Report, fiber length varies from 12.7 to 63.5 mm. The most common fiber diameters are in the range of 0.45 to 1.0 mm.

## 2.2.3 Steel fiber types

The shape of the fiber is another important variable. Steel fibers may be straight, end-hooked, crimped; flattened-end, etc. (see Figure 2-1). Many studies have shown that at the onset of failure, steel fibers tend to be pulled out from the matrix instead of rupturing [15, 18]; as a result, the mechanical anchorage from deformed fibers is critical in the overall response of SFRC. Recent experimental investigations and constitutive model developments have been based upon straight fibers with end-hooks [16, 18, - 21].

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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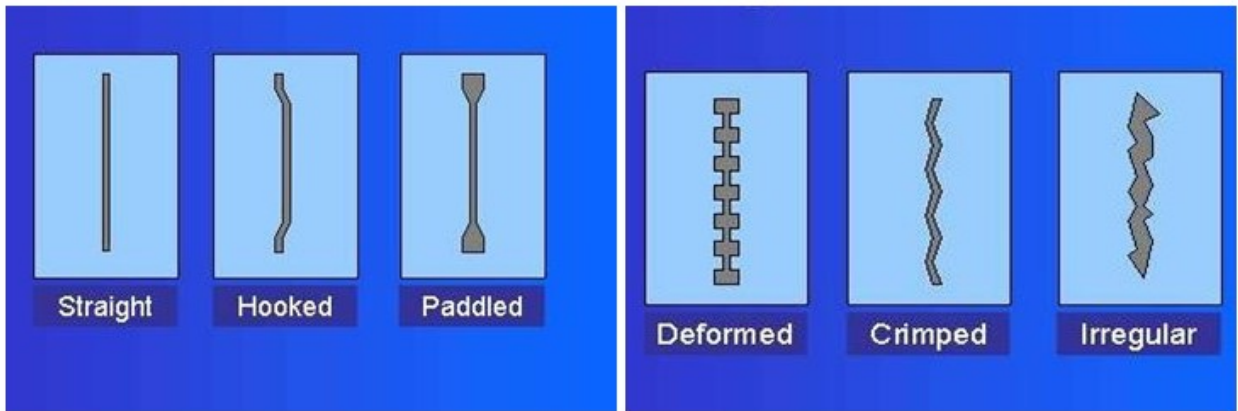


Figure 2-1 Different types of steel fibers

## 2.3 Compression and Tensile Behavior of SFRC

SFRC under compression exhibits increased strength only in mixtures with a high amount and adequate aspect ratio of fibers; whereas it exhibits a rather marginal contribution of the fibers on the compressive strength in most of the examined cases [22–27].

Nevertheless, significant improvement of the post-cracking stress–strain compressive behavior with noticeable toughness and a ductile response even in low volumetric proportions of fibers has been revealed. A significant increase in the SFRC compressive strength is achieved in mixtures with at least 3% volume fraction of steel fibers.

The flexural tensile behavior of SFRC has been studied by using three- or four-point bending tests of small-scaled notched prismatic specimens. The majority of the experimental studies pointed out the favorable influence of the added steel fibers on the post-cracking regime [28]. Further, fibrous concrete mixtures with a high percentage of fibers showed an enhanced overall performance and a re-hardening response after cracking [23]. Furthermore, long steel fibers proved more effective than the short ones to ameliorate the flexural response at large deflections in terms of strength, deformation capacity, toughness, and cracking behavior [29]. Similar concluding remarks concerning the splitting tensile strength of SFRC have also been derived from extensive data of splitting tests performed on cylinders and cubes. The favorable influence of steel fiber

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orientation on tensile strength increase has been highlighted through splitting and flexural tensile tests on magnetically driven concrete and mortar cube specimens [30].

The orientation distribution effect of the added steel fibers has also been examined in the post-cracking tensile behavior of SFRC through tests of specially fabricated specimens subjected to direct tension and by applied different casting methods of the fresh mixtures. It has been found that distribution and orientation of fibers greatly influence the overall performance of fibrous concrete.

Uniaxial tests of prismatic specimens under direct tension revealed that the addition of an adequate amount of short steel fibers mainly increase the tensile load capacity, whereas longer steel fibers enlarge the ultimate tensile deformation. However, SFRC with inadequate dosage of steel fibers demonstrated a negligible increase in the tensile strength and limited improvement in the post-cracking behavior [31]. Thus, a critical volume fraction of steel fibers has been proposed in order to design high-performance fibrous concrete mixtures that achieve strain hardening under direct tension with advanced ductility and energy absorption capacity, such as ultra-high performance SFRC.

Nevertheless, dispersion of long steel fibers with higher volumetric proportions was found to be problematic with regard to the fine workability properties of fibrous mixtures with short lengths or even microfilament steel fibers that were 13 mm long [32].

## **2.4 Shear behavior of SFRC beam under monotonic loading**

Unlike flexure failures, shear failures in reinforced concrete are much more brittle, can occur without warning and are more difficult to predict; hence, means for improving the shear response and ductility of reinforced concrete are highly desirable. As aforementioned, the addition of steel fibers can significantly enhance the matrix's tensile response and cracking characteristics. One of the primary structural benefits as a result of these improvements is in enhancing the matrix's shear strength and shear response.

Similar to the effects of transverse reinforcement, the addition of steel fibers allows a more uniform distribution of diagonal shear cracks and reduced crack widths; this, in turn, improves the concrete matrix's shear resistance mechanism, aggregate interlock.

This enhanced behavior is particularly important in large members, where the so-called

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“size effect” is predominant and the member becomes more dependent on aggregate interlock to resist shear.

In past decades, a significant amount of research into the shear behavior of SFRC under monotonic loading was conducted. The results of these studies led to the permitted structural use of SFRC in the ACI building code. ACI Committee 318 (2008) now permits SFRC beams to be exempt from minimum conventional shear reinforcement. There are studies related to SFRC under monotonic loading were based upon beam tests. Steel fibers can generally prevent localization of tensile cracking and produce multiple diagonal cracks [33-35]. As a result, after initial diagonal cracking, SFRC beams will have a higher stiffness and can decrease the beam deflection. Greater ductility can also be achieved with the addition of steel fibers [35]. Further, the presence of fibers generally increases the beam’s first diagonal cracking load and ultimate shear strength.

Numerous studies have shown that the effectiveness of steel fiber depends on the geometry of the beams. The shear strength enhancement varies for different types of beams under monotonic loading; with 0.8% fiber content, T-beams exhibited an 80% increase in shear strength while rectangular beams showed a 30% shear strength improvement. As well, the increase in the cracking load and the ultimate load was more pronounced for beams with smaller shear span-depth ratios .

Parra-Montesinos [33] compiled a database of 147 monotonically loaded SFRC beams without stirrups to evaluate the feasibility of using steel fibers as minimum shear reinforcement in lieu of stirrups. ACI suggests the value for concrete’s contribution to a beam’s shear strength to be  $0.17\sqrt{f'_c}$ (MPa) [37]. However, to be conservative, ACI requires the use of minimum shear reinforcement if the ultimate shear stress exceeds half of plain concrete’s contribution,  $0.085\sqrt{f'_c}$  (MPa). Parra-Montesinos’s [33] database showed that all SFRC beams with at least 0.75% fiber volume fraction exhibited a normalized shear stress at failure larger than  $0.3\sqrt{f'_c}$  (MPa); this value is significantly higher than plain concrete’s contribution. Hence, the data support the use of deformed steel fibers as an alternative to conventional shear reinforcement for shear demands up to  $0.17\sqrt{f'_c}$  (MPa).

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## 2.5 Shear behavior of SFRC beam under cyclic loading

Cyclic loading is one of the most challenging cases of loading, as each layer of the structural member is subjected to alternating tension and compression. Under these alternating stresses, the load-deflection envelope curve for shear-critical members will typically exhibit a lower maximum load capacity and a softer post-peak envelope relative to the monotonically loaded backbone curve [19,38]. Various mechanisms are involved in producing the lower ultimate load, such as the bond deterioration between the concrete and the steel reinforcement, the cyclic softening of materials, the time lag of the force redistribution in the compressive zone due to crack closure, etc. [38]. Progressive stiffness degradation upon reloading and unloading in inelastic deformation cycles and pinching of hysteretic loops is also characteristic features of shear-critical reinforced concrete elements [18]. Limited research has been done to investigate the shear behavior of SFRC under reversed cyclic loading; however, many of these studies conclude positive effects are attained from the addition of steel fibers in reinforced concrete. These effects include improved energy dissipation, shear strength, and crack control [16,18,19,38].

Daniel and Loukili [38] suggested that the use of steel fibers in flexural fibrous concrete beams with different longitudinal reinforcement ratios can be efficient to prevent an early development of macro-cracks during the pre-peak stage and enhances the energy absorption over both the elastic and inelastic stages. Tests by Campione and Mangiavillano [39] demonstrated that the addition of fibers increases the load-bearing capacity of the examined specimens, ensures more ductile behavior, and reduces degradation effects under cyclic deformations, especially in beams with increased concrete cover thickness.

Further, Harajli and Gharzeddine [40] investigated the influence of steel fibers on the bond performance of spliced steel bars in normal and high strength concrete. The experimental results showed that the existence of steel fibers delayed the formation and propagation of splitting cracks along the spliced region and increased the absorbed energy of the SFRC beams, resulting in a less brittle failure.

Parra-Montesinos[33] and Chompreda [39] investigated the experimental behavior of SFRC beams with and without steel transverse reinforcement. Results from the tests

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showed that the fibrous concrete specimens presented a pure strain-hardening behavior with advanced damage tolerance developing multiple flexural and diagonal cracks.

Chalioris [19] investigated the influence of steel fibers in shear-critical RC beams with and without steel transverse reinforcement under reversal loading. Steel fibrous beams demonstrated improved overall shear performance with increased shear strength, ameliorated pre-crack and post-crack behavior, and enhanced energy dissipation capabilities compared to the non-fibrous specimens.

## **2.6 Steel fibers extracted from used tyres**

### **2.6.1 Waste Management of used tyres**

It is estimated that, worldwide, more than one billion used tyres arise annually. The waste management of used tyres is of major concern for many environmental bodies and agencies worldwide. This is also true in Ethiopia, where environmental legislation is the driving force behind the waste management of used tyres. Reuse of tyres and material recovery has become the most environmentally viable ways for disposing used tyres.

Material recovery from used tyres is undertaken by utilizing either mechanical or thermal degradation processes. The former reduces tyres to steel fibers and granulated rubber and, the latter process breaks down the tyres into steel.

Recovered Steel Fiber (RSF) could be utilized as concrete reinforcement and recent research shows that the application of RSF in concrete leads to an increase in concrete strength, ductility, and toughness. The use of RSF in concrete is like any other type of steel fibers.

### **2.6.2 Recovery of steel fibers from used tyres**

Tyre shredding and the cryogenic process can be used to mechanically recover RSF from used tyres. In addition, steel fibers can be recovered by utilizing anaerobic thermal degradation, such as conventional pyrolysis and microwave-induced pyrolysis of tyres. The amount of extracted steel fibers depends mainly on the type of tyre. Tyres of light vehicles contain up to 15% steel, whereas truck tyres contain up to 25% steel [41].

#### ***2.6.2.1 Shredding Process***

The shredding process reduces tyres into rubber granules and steel fibers through a number of cutting and granulating stages. In the first stage of processing, a complete tyre

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is chopped or shredded until it is reduced to pieces ranging in size from about 50 to 150 mm. The rubber pieces, which still contain steel, are then fed into a second shredder that reduces them to smaller pieces (Fig. 2.2 ). At the end of this stage, magnets are used to separate the steel from the rubber. The rubber is then fed into a knife or hammer mill, where it is granulated to approximately 1 to 10 mm in size. The number of grinding cycles depends on the desired size of the rubber granules. During the granulating process, magnets are used to remove any remaining steel.

The steel extracted after the second stage of shredding and the final stage of grinding differs in quality. The former contains large pieces of rubber as well as much of the textile wire in long lengths. The cord is sometimes undamaged, but much of it is deteriorated into individual wires.

The latter is much finer, comprising mostly of thin individual steel wires, but still containing around 10% rubber and fluff.

Mechanical shredding is considered as a commercially mature and technologically reliable process. However, it can be quite costly, as the cutting blades require constant maintenance. The rate of deterioration of the blades is high because the tyre contains high strength steel and the steel in the bead is normally of a large diameter. It is noted that tyre shredding has increased over the years, as it is more economical to transport shredded tyres rather than whole tyres[42].

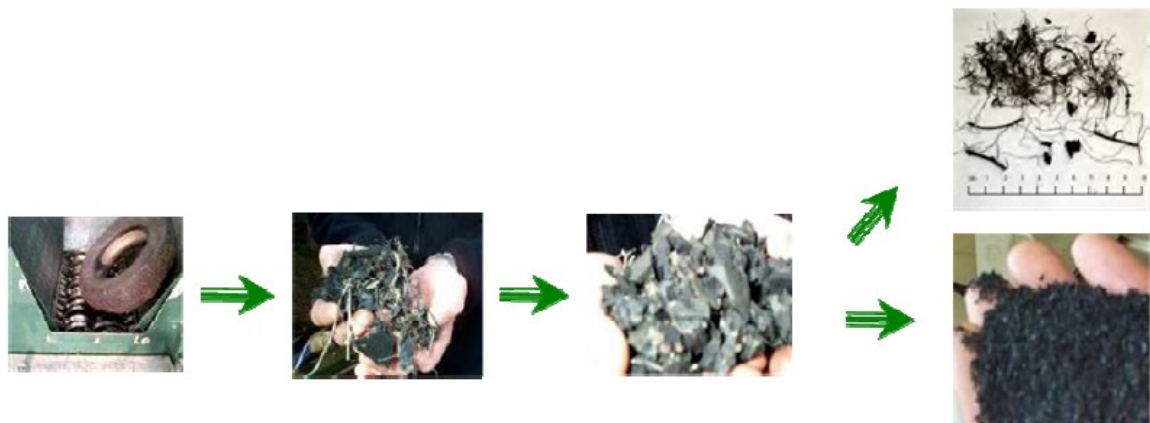


Figure 2-2 Shredding process

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## ***2.6.2.2 Cryogenic Process***

The cryogenic process [43,44] involves the cooling of tyres, and their subsequent brittle fracturing and reduction to rubber, steel, and textile. In a typical cryogenic process, the used tyres are initially shredded at ambient temperature, and then transferred to a deep-freezing tunnel system. Inside the first tunnel section, the fragmented tyres are pre-cooled by a counter-current of gaseous nitrogen at approximately  $-120^{\circ}\text{C}$ . The tyre pieces are then transferred into the main cooling tunnel, where they are cooled down below their embrittling temperature and, as a result, they become nearly brittle. At the next stage, the fragmented tyres are granulated through a series of mills, and are reduced to rubber, steel fibers, and textile. The steel and textile are separated, whereas the rubber granules are dried, passed through a steel extraction unit, and finally sieved.

The extracted steel is fairly clean, but it may lose its ductility, if it is cooled down below its embrittling temperature [45]. The cryogenic process is considered to be energy efficient because it requires less energy to separate the rubber from the steel rather than ambient-temperature processes [43]. However, the high cost of liquid nitrogen is the main drawback of this process.

## ***2.6.2.3 Pyrolysis Process***

Pyrolysis [46, 47] of tyres is the process where tyres are thermally decomposed, in the absence of oxygen, to their organic and inorganic components. The process generates gases (hydrogen, methane and other hydrocarbons), oil, and solid residuals of steel and char, which is a low grade carbon black. The balance between the end-products of the process can be altered by changing the imposed conditions, such as the heating temperature and duration. In a typical pyrolysis plant, used tyres are fed into a pyrolysis reactor, where they are heated to the desired temperature. The gases and the liquids are separated from the extracted vapors through a system of gas-liquid separators. At the end of the process, the steel is separated from the char and the char is ground.

The steel comes out of the process still containing some char on its surface. In most pyrolysis plants, the tyres are shredded before being fed to the reactor and, hence, the RSF are already damaged to a certain degree, as in the case of the shredding process.

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Since the pyrolysis process is contained, the release of combustion gases is minimized [46]. Pyrolysis is energy efficient because the derived gases and oil have high calorific value and can be used for the energy requirements of the process. It is noted that it can be difficult to market some of the pyrolysis end-products due to their low quality (especially the char), and consequently, many pyrolysis plants are not economically viable [48].

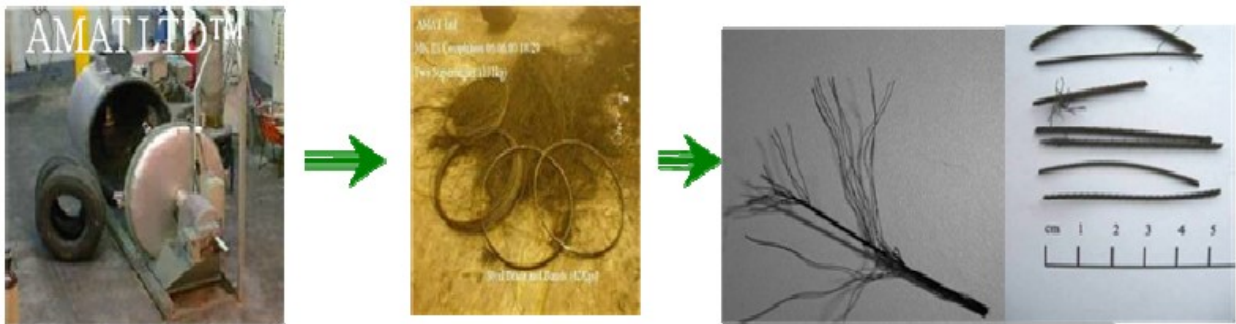


Figure 2-3 Pyrolysis Process

### 2.6.2.4 Microwave Induced Pyrolysis Process

The microwave-induced pyrolysis process [49], called “Advanced Molecular Agitation Technology”, optimizes microwave power at the molecular level to thermally decompose tyres to their constituents. According to the developers of this process [49], the microwaves excite the molecular bonds of the long-chain rubber hydrocarbons enough to break them into shorter hydrocarbons, which are released as volatile gases at a temperature around 350°C. The process operates at relatively low temperatures and hence, the derived steel cord and textile wire remain intact, while the rubber is converted to oil, gases, and char. Similarly to the conventional pyrolysis process, the gases can be used for the energy requirements of the process. The derived steel cord can be cut to any length.

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## CHAPTER 3 EXPERIMENTAL PROGRAM

The experimental program of this research were conducted the construction and testing of nine beams from these, two control beams and seven steel fiber reinforced concrete beams under monotonic and cyclic loading. All experiments were performed at the Construction Materials Laboratory of Addis Ababa Institute of Technology (AAiT). The main parameters of this research were volume of steel fiber, shear spacing and type of loading. Other parameters kept constant. Specific details of the specimens, their material property, test setup and instrumentation will be discussed in the following sections.

**Table 3-1 Fixed parameters**

Fixed parameters	Description
Crosssection	Rectangular
Width(b)	200mm
Depth(h)	300mm
Total Length(L)	1800mm
Concrete Grade	C-25/30
Shear span to effective depth ratio(a/d)of beam	2.92

### 3.1 Specimen summary

The primary goal of this study was to investigate the use of steel fiber for reinforced concrete beam under cyclic loading. A total of nine beams, two beams with no steel fiber and seven beams with different steel fiber volume and shear spacing were casted. All beams have 1.8 meter length, and rectangular cross section of 200mm width and 300 mm depth. The beams were given designations depending on their steel fiber volume, shear spacing and loading type. For instance, a beam with shear spacing increased by 50%, steel fiber volume 0.5% and monotonically loading were designated as S50VF0.5%M, where S stands for shear spacing; VF stands for volume of steel fiber and M stands for

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monotonic loading. A detailed summary of the nine beam specimens is given on table 3-2 and table 3-3.

**Table 3-2 Beam specimens**

Specimen no	Beam Designation	Description
1	CBM	Control Beam under monotonic loading
2	CBC	Control Beam under cyclic loading
3	S50VF0.5M	Shear spacing increase by 50% and Volume of steel fiber 0.5% under monotonic loading
4	S50VF0.5C	Shear spacing increase by 50% and Volume of steel fiber 0.5% under cyclic loading
5	S50VF1C	Shear spacing increase by 50% and Volume of steel fiber 1% under cyclic loading
6	S50VF1.5C	Shear spacing increase by 50% and Volume of steel fiber 1.5% under cyclic loading
7	S100VF0.5C	Shear spacing increase by 100% and Volume of steel fiber 0.5% under cyclic loading
8	S100VF1C	Shear spacing increase by 100% and Volume of steel fiber 1% under cyclic loading
9	S100VF1.5C	Shear spacing increase by 100% and Volume of steel fiber 1.5% under cyclic loading

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**Table 3-3 Details of beam specimens**

Specimen no	Beam Designation	Shear Reinforcement	Steel fiber Volume
1	CB1	φ8 c/c 190mm	0
2	CB2	φ8c/c 190mm	0
3	S50VF0.5	φ8 c/c 285mm	0.5%
4	S50VF0.5	φ8 c/c 285mm	0.5%
5	S50VF1	φ8 c/c 285mm	1%
6	S50VF1.5	φ8 c/c 285mm	1.5%
7	S100VF0.5	φ8 c/c 380mm	0.5%
8	S100VF1	φ8 c/c 380mm	1%
9	S100VF1.5	φ8 c/c 380mm	1.5%



Figure 3-1 Beam layout

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## 3.2 Material properties

### 3.2.1 Concrete

The concrete mix was specified according to ACI mix design to have a target cylindrical compressive strength of 25 MPa, a slump of 25 to 50 mm, with a nominal maximum aggregate size of 25 mm and was mixed in the Construction Materials Laboratory of AAiT. During the casting process, cube samples and cylinder samples (diameter 150 mm and height 300mm) were taken from each beam to determine the compressive strength and split tensile strength of the concrete respectively. Specimens were left to cure in the same environmental conditions as their respective beams.

Cubes were tested in compressive testing machines shown in Figure 3-1, while the concrete tensile strength was measured via split cylinder tests according to ASTM standard C496 – 96 as shown in Figure 3-2. All samples were tested on the same day of one point loading tests on beams.



Figure 3-2: Compressive Strength testing machine

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Figure 3-3: Split tensile strength test

Concrete strengths at test day are given in result section. The splitting tensile strength of concrete was computed from the applied compressive force,  $P$ , by using equation (3.1); where  $l$  and  $d$  are the length and diameter of the concrete cylinder samples. While the tensile strength of concrete computed as 90% of split tensile stress.

$$\sigma_t = \frac{2P}{\pi ld} \quad (3.1)$$

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**Table 3-4 Mix proportion**

Beam Designation	Cement Quantity (kg)	W/C Ratio	Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Admixture (ltr)	Steel fiber (kg)
CB1	312	0.61	179	770	1110	3.12	0
CB2	312	0.61	179	770	1110	3.12	0
S50VFO.5	312	0.61	179	770	1110	3.12	39
S50VF0.5	312	0.61	179	770	1110	3.12	39
S100VFO.5	312	0.61	179	770	1110	3.12	39
S50VF1	312	0.61	179	770	1110	3.12	78
S100VF1	312	0.61	179	770	1110	3.12	78
S50VF1.5	312	0.61	179	770	1110	3.12	117
S100VF1.5	312	0.61	179	770	1110	3.12	117

### **3.2.1.1 Cement**

The cement used in all mixes was locally manufactured Dangote OPC R42.5 Cement.

### **3.2.1.2 Aggregates**

The coarse aggregate used for preparation of specimen was crushed basaltic stone with maximum size of 25mm. The aggregates were bought from werabe area. The aggregates were initially washed and dried. Then sieve size analysis and physical tests were conducted. The sieve size analysis of aggregates presented on APPENDIX A.

**Table 3-5 Physical tests of aggregates**

Physical Test	Coarse aggregate	Fine aggregate
SSD Specific gravity	2.87	2.44
Apparent Specific gravity	2.95	2.59
Bulk Specific gravity	2.79	2.34
Water absorption (%)	2.84	4.17

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## 3.2.2. Reinforcing Steel

For preparation of specimen, diameter 20mm for bottom reinforcement, diameter 12mm for top reinforcement and diameter 8mm for shear reinforcement were used. The tensile strength tests of the reinforcements were done at the AAit construction laboratory.



Figure 3-4 Rebar test

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**Table 3.6 Rebar test result**

Specimen no	Diameter D(mm)	Yield load(kN)	Yield stress(MPa)	Failure load(kN)	Failure stress(MPa)	Elongation (%)	Mass/length(kg/m)	Length(m)
8-1	8	26.9	535.16	33.4	664.47	23.1	346.3	91
8-2	8	25.9	515.26	32.8	652.53	23.0	340.1	90
8-3	8	26.4	525.21	32.1	638.6	23.1	340.8	89.8
<b>Average</b>	<b>8</b>	<b>26.4</b>	<b>525.21</b>	<b>32.8</b>	<b>651.9</b>	<b>23.07</b>	<b>342.4</b>	<b>90.27</b>
12-1	12	56.9	503.1	67.7	599.12	22.2	770.9	90
12-2	12	58.7	519.5	72.4	640.71	22.0	752.1	90
12-3	12	59.7	528.32	72.1	638.1	22.1	769.9	90
<b>Average</b>	<b>12</b>	<b>58.43</b>	<b>516.97</b>	<b>70.73</b>	<b>625.98</b>	<b>22.1</b>	<b>764.3</b>	<b>90</b>
20-1	20	175.2	557.7	207.7	661.5	22.5	2303.3	96
20-2	20	174.4	555.41	215.3	685.7	22.7	2256.9	95
20-3	20	175.6	559.24	210	668.8	22.7	2276.3	96
<b>Average</b>	<b>20</b>	<b>175.07</b>	<b>557.45</b>	<b>211</b>	<b>672</b>	<b>22.63</b>	<b>2278.83</b>	<b>95.67</b>

### 3.2.3. Steel fiber

The steel fibers used for this study were the bead wire, which are extracted from used tyre, and cutting to the required length.

The bead wires were purchased from the same supplier, who primarily used the tyres for heating sheet metals to produce different house hold utensils. The bead wires were undamaged, since the tyres were burnt at a relatively low temperature. They were clean from rubber and contain carbon black on the surface. The fibers were prepared by cutting

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the bead wire into a length of 60mm. The diameters of steel fibers were 0.95mm and aspect ratio (l/d) of 63.16. It is in the recommended limit of ACI Committee 544.3 R Report, fiber length varies from 12.7 to 63.5 mm and the most common fiber diameters are in the range of 0.45 to 1.0 mm.

Mechanical properties of steel fibers were evaluated by tensile tests on 10 randomly chosen samples. The tensile test was carried out by Testometric machine (M350-5KN) in Horizon Addis Tyre factory Laboratory. The table reports the values of breaking load, tensile strength and elongation at break of steel fiber.

An average tensile strength of 1023.912 MPa was found. The obtained results are in good agreement with the tensile requirement specified in ASTM A820 stated as “*The average tensile strength shall not be less than 345 MPa and the tensile strength of any one of the ten test specimens shall not be less than 310 MPa.*”

**Table 3.7 Steel fiber test result**

Sample	Breaking load(N)	Diameter(mm)	Tensile strength(Mpa)	Strain at break
1	803.6	0.95	1133.712	5.235
2	800.1	0.95	1128.777	7.866
3	669.1	0.95	943.961	4.864
4	530.3	0.95	748.143	6.754
5	635.8	0.95	896.984	6.055
6	760	0.95	1072.205	6.551
7	789.3	0.95	1113.541	6.775
8	534.5	0.95	754.068	6.578
9	875	0.95	1234.443	6.811
10	860	0.95	1213.284	7.448
Average	725.77	0.95	1023.912	6.4937

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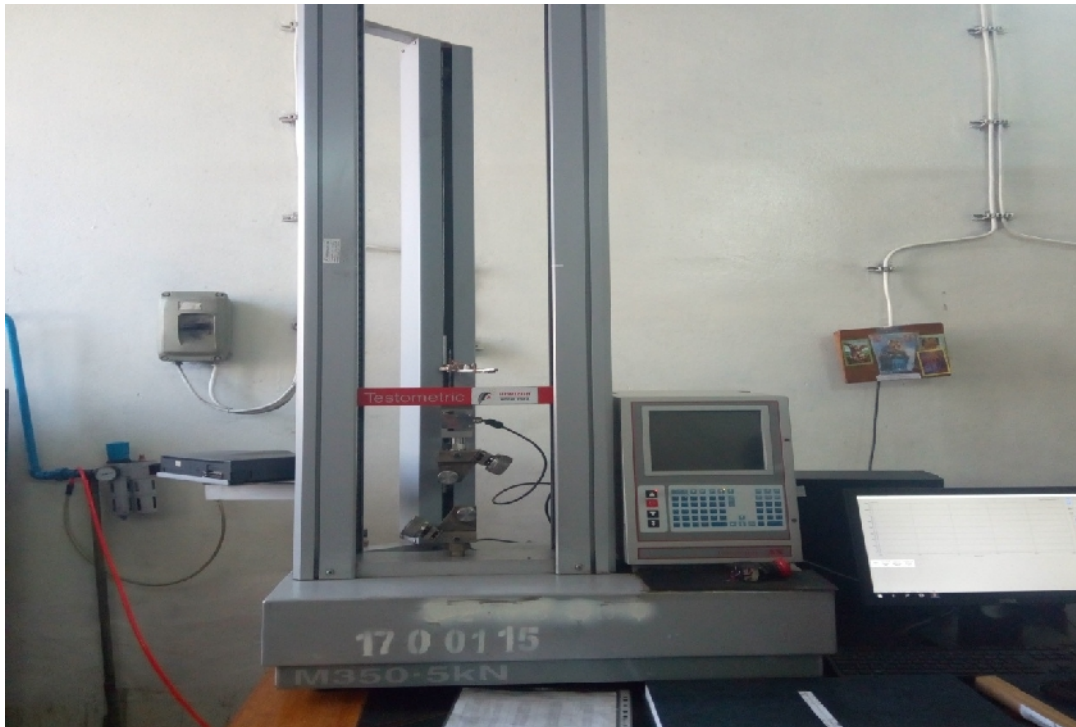


Figure 3-5 Testometric machine for steel fiber test



Figure 3-6 Cutting the bead wire to the required length

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## **3.2.4. Chemical admixture**

To obtain sufficient consistency in the steel fiber reinforced concrete mixes high performance Super plasticizing admixture with the commercial name SASplast SP 60 was used in all mixes. SASPlast SP60 is chloride free a naphthalene sulphonate based liquid super plasticizer for high performance concrete. It is supplied as a brown solution which instantly disperses in water.

Based on the product manual for high workability concrete the normal dosage range is from 0.50 to 2.50 liters/100 kg of cementitious material. In this research work 1% of admixture per cementitious material (i.e. 1.0 liter/100 kg) was used in all mixes.

## **3.2.5 Water**

Water is an important ingredient of concrete as it actively participates in the chemical reaction with cement. In this thesis potable water supplied by the municipality was used for all concrete mixes.

## **3.3 Test Specimen fabrication**

### **3.3.1 Rebar preparation**

The reinforcements were prepared as per the design proposed for this research. The reinforcement cage was also properly done based on the design.

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Figure 3-7 Reinforcement cage for CBM and CBC



Figure3-8 Reinforcement cage for 50% increase shear spacing



Figure 3-9 Reinforcement cage for 100% increase shear spacing

### 3.3.2 Formwork Preparation

The specimens had a rectangular cross-section with 200mm width, 300mm depth and a total development length of 1800mm. Extreme care was taken for the proper alignment of formworks and positions of reinforcement. Wood formwork was used. These Formworks were oiled and closed at the end prior to placement of the reinforcement cage. A concrete cover of 25mm spacer was prepared to tie and keep the cover on the longitudinal and shear reinforcement bars. The reinforcement cages were placed inside the formwork after maintaining a concrete cover of 25mm.

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Figure 3-10 Formwork



Figure 3-11 Installation of reinforcement cage into formwork

### 3.3.3 Casting of concrete

The amount of the materials were based on mix design, and checked first by different trial mixes. During the casting of the specimens, a mechanical mixer was used throughout the mixes. Consequently, the slumps for all the mixes were taken.

The specimens were cast outside the laboratory and high frequency electric vibrator was used to ensure good concrete compaction around steel reinforcement.

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Figure 3-12 Adding concrete ingredients into the mixer



Figure 3-13 Adding steel fibers into the concrete ingredients

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Figure 3-14 Mixing all ingredients using mixer



Figure 3-15 Mixed concrete



Figure 3-16 Slump test



Figure 3-17 Casting of the beam

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## 3.4 Test Setup

All beams were tested under one point loading supported by steel plates with a roller on both sides. A concentrated force was applied at mid span by a hydraulic jack of maximum capacity around 500 kN. Since the load was applied manually by using a hydraulic Jack; loading rate could not be kept constant. Though the loading rate varied randomly for each experiment, it was kept below 11.5 kN/s for all experiment tests. Therefore the effect of increase in loading rate was somehow controlled but not consistently regulated as with an automatic actuator. Although consistent loading rate would have been preferred for this research, due to limitation in laboratory equipment, it could not be so.



Figure 3-18 Test setup

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## 3.5 Instrumentation

Instruments mainly employed for data acquisition and load application. The load was applied by the hydraulic Jack (Figure 3-18) and its load was measured by a load cell (Figure 3-19). A Linear variable displacement transducer (LVDT)(Figure 3-21) is used to measure the mid-span displacement of the beam throughout the experiment. The LVDT is attached to a static horizontal rod fixed on the beam at support position. The load cell and LVDT were connected to data logger (Figure 3-20) and a comprehensive data: entailing load and displacement, is obtained using a USB from the data logger.



Figure 3-19 Hydraulic jack



Figure 3-20 Load cell

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading



Figure 3-21 Data logger



Figure 3-22 A Linear variable displacement transducer (LVDT)

## 3.6 Loading Pattern

Either monotonic or one-side cyclic loading was applied on all beams. One-side cyclic loading was applied basically by monotonically increasing the load to 90% of the section capacity of the beam and unloading instantly when this maximum load is reached.

Since load was applied manually by a hydraulic jack: when the aforementioned maximum cyclic load is reached, the beam is unloaded by unbolting the hydraulic jack.

Thus some inconsistencies are to be expected.



Figure 3-23 Manual loading

## Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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Figure 3-24 Unloading by unbolting the hydraulic jack

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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## CHAPTER 4 FEM ANALYSIS USING VECTOR 2

### 4.1 About the software

Nonlinear finite element model was conducted using Vector 2. VecTor2 is a nonlinear finite element analysis (NLFEA) program for the analysis of two-dimensional reinforced continuum structures subjected to quasi-static or dynamic load conditions. While primarily intended for reinforced concrete, a number of continuum material types (concrete, SFRC, steel, masonry, wood, others) and reinforcement types (mild steel, prestressing steel and FRP others) can be considered with the built-in material models.

VecTor2 uses a smeared, rotating-crack formulation for reinforced concrete based on the Modified Compression Field Theory and the Disturbed Stress Field Model. The program's solution algorithm is based on a secant stiffness formulation using a total-load iterative procedure, giving it numerically robust and stable performance with good convergence characteristics.

### 4.2 Specimens

A non linear finite element analysis was carried out for the specimens. Beams were categorized depending up on spacing of shear reinforcement and volume fraction of steel fiber. Based on these criteria's, analyses were conducted under monotonic loading. The nomenclature used for experimental beams shall be implemented for the respective specimens only adding A (i.e. Analytical) as prefix. Hence A-S50VF0.5%M is the equivalent specimen for S50VF0.5%M.

All the fixed parameters were similar to experimental program. Summary of all specimens studied under finite element analysis listed on table 4-2.

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

**Table 4-1 Fixed parameters for Vector 2 software**

Fixed parameters	Description
Crosssection	Rectangular
Width(b)	200mm
Depth(h)	300mm
Total Length(L)	1800mm
Effective length(l)	1500mm
Shear span to effective depth ratio(a/d)of beam	2.92

**Table 4-2 Beam specimens**

Specimen no	Beam Designation	Description
1	A-CBM	Control Beam under monotonic loading
2	A-S50VF0.5M	Shear spacing increase by 50% and Volume of steel fiber 0.5% under monotonic loading
3	A-S50VF1M	Shear spacing increase by 50% and Volume of steel fiber 1% under monotonic loading
4	A-S50VF1.5M	Shear spacing increase by 50% and Volume of steel fiber 1.5% under monotonic loading
5	A-S100VF0.5M	Shear spacing increase by 100% and Volume of steel fiber 0.5% under monotonic loading
6	A-S100VF1M	Shear spacing increase by 100% and Volume of steel fiber 1% under monotonic loading
7	A-S100VF1.5M	Shear spacing increase by 100% and Volume of steel fiber 1.5% under monotonic loading

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

## 4.3 Materials

### 4.3.1 Concrete

Since the analytical model was expected to confirm to the experimental test results, the concrete compressive strength obtained from compression test on 150 mm cube samples experimentally used as input for the analytical model. The cylindrical strength, modulus of elasticity and tensile strength of concrete were all computed according to Eurocode specification. The cylindrical strength was determined by multiplying the cubic strength with a 0.8 coefficient. The shear reinforcement was computed by equation 4.1

$$\rho = \frac{A_{sw}}{s \cdot b} \quad (4.1)$$

where  $A_{sw}$  = Area of shear reinforcement

$s$  = spacing

$b$  = width of the beam

**Table 4-3 Property of concrete**

Specimen	Cylindrical Compressive strength(Mpa)	Split Tensile Strength(Mpa)	Shear reinforcement ratio(%), $\rho$	Steel fiber volume(%)
A-CBM	29.984	2.575	0.264	0
A-S50VF0.5%M	30.792	3.58	0.18	0.5
A-S50VF1%M	34.24	4.421	0.18	1
A-S50VF1.5%M	28.852	4.299	0.18	1.5
A-S100VF0.5%M	30.348	3.57	0.132	0.5
A-S100VF1%M	33.989	4.4	0.132	1
A-S100VF1.5%M	28.725	4.21	0.132	1.5

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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## 4.3.2 Steel

The tensile strength of each diameters of reinforcement bars were experimentally obtained from tensile test was directly used as input for the analytical model. The conventional reinforcement (stirrups) was considered as smeared reinforcement as well by using the ductile steel reinforcement reference type and the longitudinal reinforcements as truss element.

**Table 4-4 Property of reinforcement**

Diameter(mm)	Average Yield stress(MPa)	Average Ultimate stress(MPa)
8	525.21	651.9
12	516.97	625.98
20	557.45	672

## 4.3.3 Steel fiber

The fiber reinforcement was modeled as smeared reinforcement by selecting straight steel fiber as the reference type. The tensile strength of steel fiber was tested in Horizon Addis tyre factory laboratory and an average tensile strength of 1023.912 MPa was obtained.

The steel fibers had length of 60mm and 0.95mm diameter.

## 4.4 Modeling

For this research, the beams were modeled with a cross - section of 200mm by 300mm and a development length of the beam is 1800mm and the effective length of 1500mm by taking a shear span to effective depth ratio as 2.92, the length of shear span become 750mm. All the beams were provided with a bottom longitudinal reinforcement of 3diameter 20mm and top longitudinal reinforcement of 2 diameter 12mm deformed bars. The fiber reinforcement was modeled as smeared reinforcement by selecting straight steel fibre as the reference type. The stirrup was modeled as smeared reinforcement as well by using the ductile steel reinforcement reference type. And the longitudinal reinforcement modeled as truss element by selecting ductile reinforcement.

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

## CHAPTER 5 RESULT AND DISSCUSSION

### 5.1 Results

#### 5.1.1 Test results

All beams fail in shear with their maximum load. Shear failure was observed in all specimens with no evidence of anchorage failure.

Specimen CBM and S50VF0.5%M were first tested monotonically to get their section capacity. And by taking their 90% section capacity one side cycling loading were tested. The monotonically loaded experimental results of specimen CBM and S50VF0.5%M were similar to finite element analysis results of A-CBM and A-S50VF0.5%M. However, for the other five types of beam their section capacity would be taken from Vector 2 4.2 results. Table 5-1 displays a numerical overview of the entire experimental program and its results.

Table 5-1 Summary of experimental results

Specimen	Cylindrical compressive strength( $f_c$ )(Mpa)	Split Tensile strength( $f_t$ )(Mpa)	Tensile strength $f_{ctk}$ (EC2)(Mpa)	Maximum load(kN)	Number of cycle
CBM	29.984	2.575	2.3177	347.14	Monotonic
CBC	30.176	2.588	2.329	312.3	20
S50VF0.5%M	30.792	3.58	3.222	340.14	Monotonic
S50VF0.5%C	31.632	3.598	3.238	306.126	21
S50VF1%C	34.24	4.421	3.98	320.36	60
S50VF1.5%C	28.852	4.299	3.87	312.83	49
S100VF0.5%C	30.348	3.568	3.211	293.55	15
S100VF1%C	33.989	4.428	3.986	305.3	40
S100F1.5%C	28.725	4.31	3.878	302.121	33

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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## 5.1.1.1 CBM

CBM is a control beam, without steel fiber was the first beam tested under monotonic loading. During loading of CBM initial surface cracks appeared near the bottom of the beam. Then the diagonal cracks were dispersed. The first shear crack was observed near left support of beam. A major diagonal crack started growing wider and the beam fail at 347.14 kN. Specimen CBM exhibited brittle shear failure.



Figure 5-1 CBM after failure

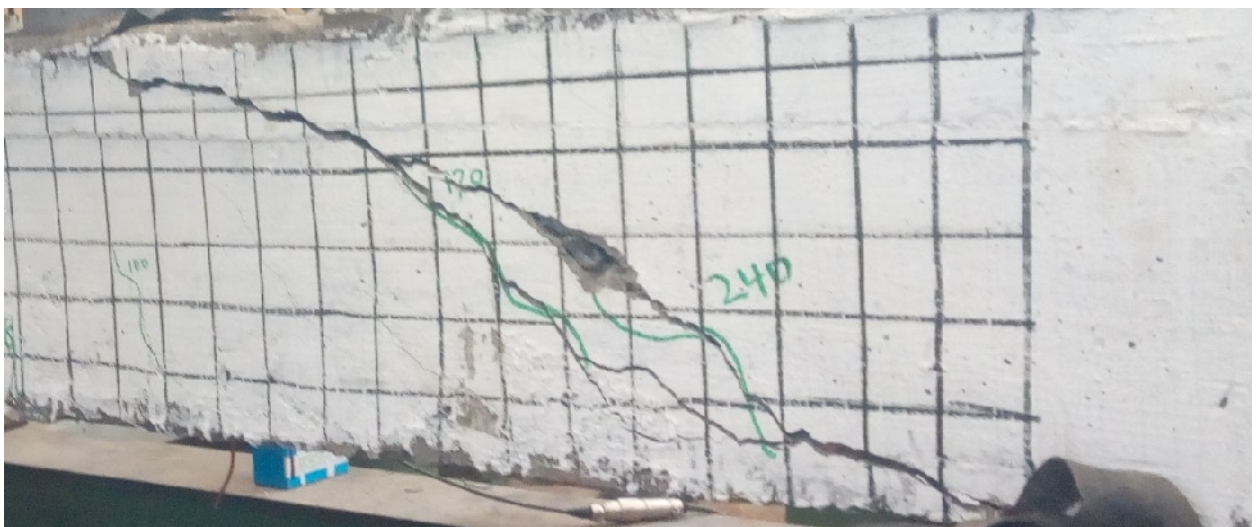


Figure 5-2 CBM after failure (close up view)

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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## 5.1.1.2 CBC

Specimen CBC is a control beam, without steel fiber tested under one side cyclic loading. This beam is similar to CBM in size, percentage of reinforcement (both longitudinal and transverse) and concrete strength. The compressive strength of the concrete in beam CBC was nearly equivalent to CBM.

Specimen CBC was monotonically loaded up to 90% of the maximum capacity of CBM and it exhibited a slightly stiffer response in the first cycle of loading than CBM. The first initial cracks occurred near the bottom of beam. The diagonal shear cracks widen at right side of the beam.

Stiffness degradation and crack development was intensified with every cycle until the beam had a shear failure on the twentieth cycle. Starting from the ninth cycle, the initial stiffness of the beam was highly reduced. At failure, concrete crushing at point of load application and at the support was accompanied by spalling of concrete as shown on Figure 5-3&5-4



Figure 5-3 CBC after failure

## Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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Figure 5.4 CBC after failure (close up view)

### ***5.1.1.3 S50VF0.5%M***

S50VF0.5%M is a steel fiber reinforced concrete beam, with 0.5% steel fiber and the shear spacing increased by 50% were tested under monotonic loading. During loading of this beam first initial vertical cracks were formed at the bottom of the beam. After initial cracks are formed the diagonal shear cracks extended to right side of the beam. Finally at the load of 340.14 kN the beam fails gradually and the steel fiber pulled out and bridging the concrete.

The specimen S50VF0.5%M exhibits diagonal shear failure. The section capacity of S50VF0.5M were less than CBM. But after the initial cracks are formed the cracking width of S50VF0.5%M were not increased rapidly as CBM until it reaches ultimate capacity.

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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Figure 5-5 S50VF0.5%M after failure



Figure 5-6 S50VF0.5%M after failure(close up view)

## **5.1.1.4 S50VF0.5%C**

S50VF0.5%C is a steel fiber reinforced concrete beam, with 0.5% steel fiber and the shear spacing increased by 50% were tested under one side cyclic loading. This beam is analogous to S50VF0.5%M in size, percentage of reinforcement (both longitudinal and transverse) , volume fraction of steel fiber and concrete strength. The cylindrical compressive strength of S50VF0.5%C is slightly the same as S50VF0.5%M. This beam was stiffer than CBM & CBC.

## Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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Specimen S50VF0.5%C was loaded monotonically until 90% of section capacity of S50VF0.5%M. During the first cycle initial cracks are formed at the bottom of the beam and diagonal shear cracks were appeared. At 21<sup>th</sup> cycle shear failure occurred and the steel fibers were pulled out.



Figure 5-7 S50VF0.5%C after failure

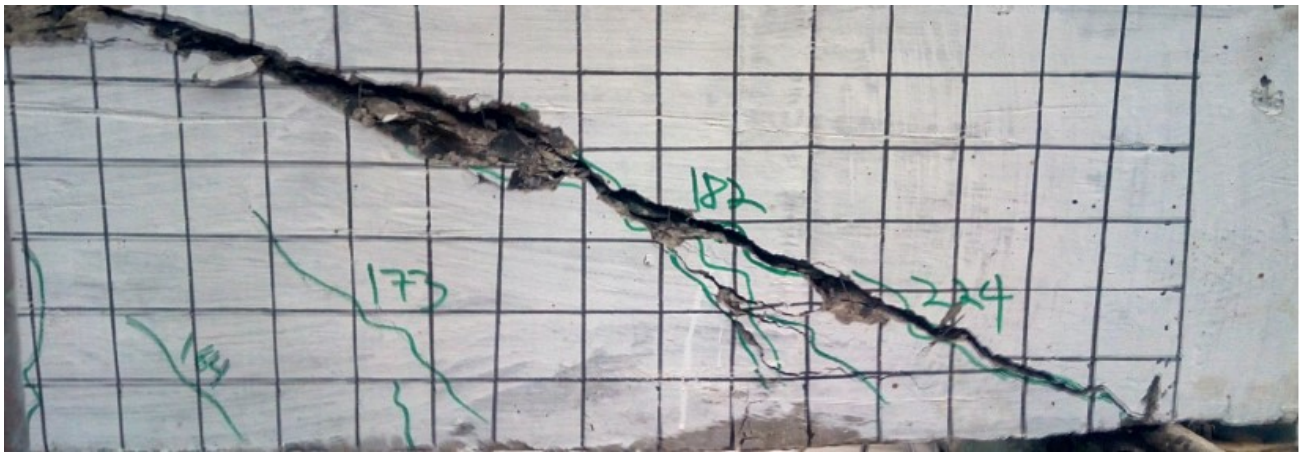


Figure 5-8 S50VF0.5%C after failure (close up view)

### **5.1.1.5 S50VF1%C**

S50VF1%C is a steel fiber reinforced concrete beam, with 1% steel fiber and the shear spacing increased by 50% was tested under one side cyclic loading. Its section capacity was taken from vector 2 finite element analysis.

The maximum load for S50VF1% was 355.953kN and by taking 90% of its section capacity one side cycling loading was perform. This beam result indicated higher

## Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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stiffness and section capacity than all beams. The initial cracks were formed near at the bottom of beam then diagonal shear cracks appered. After initial cracks formed the crack width of the beam not widen for many cycles of loading. At 60<sup>th</sup> cycle shear failure were occurred gradually and steel fibers pulled out and it form bridging between concrete.

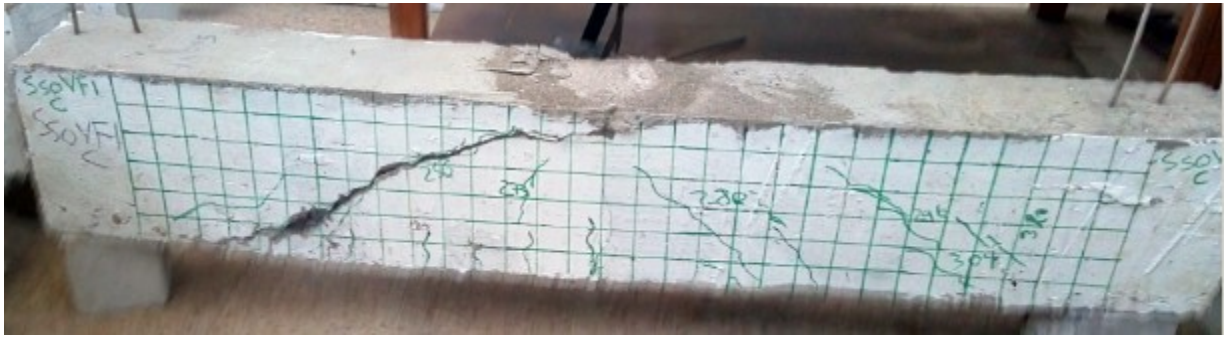


Figure 5-9 S50VF1%C after failure

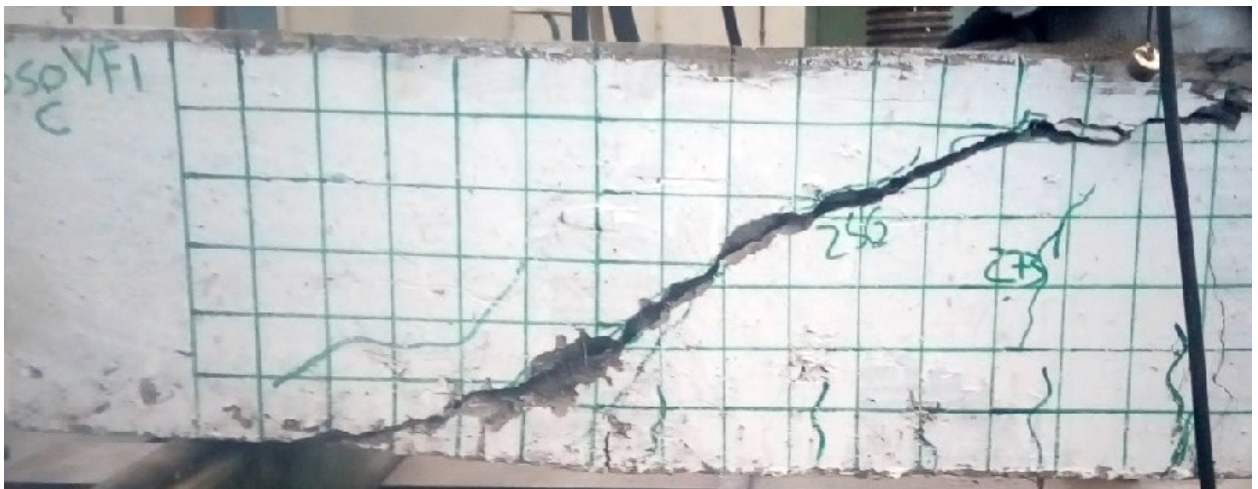


Figure 5-10 S50VF1%C after failure(close up view)

## Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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Fig 5-11 S50VF1%C after failure (close up view)

### **5.1.1.6 S50VF1.5%C**

S50VF1.5%C is a steel fiber reinforced concrete beam, with 1.5% steel fiber and the shear spacing increased by 50% was tested under one side cyclic loading. Its section capacity was taken from vector 2 finite element analysis which is 347.588kN. The section capacity of S50VF1.5% was slightly higher than CBM .

Specimen S50VF1.5%C was monotonically loaded up to 90% of its maximum capacity which is 312.83kN. The initial cracks occurred in the first cycle .The diagonal cracks were appeared at both side of the beam. This beam had higher stiffness than CBC.The Post initial cracking behavior of the beam exhibited lower cracking width .The beam occurred failure at the 49<sup>th</sup> cycle of loading at right side of beam and the steel fibers pulled out.



Figure 5-12 S50V1.5%C after failure

## Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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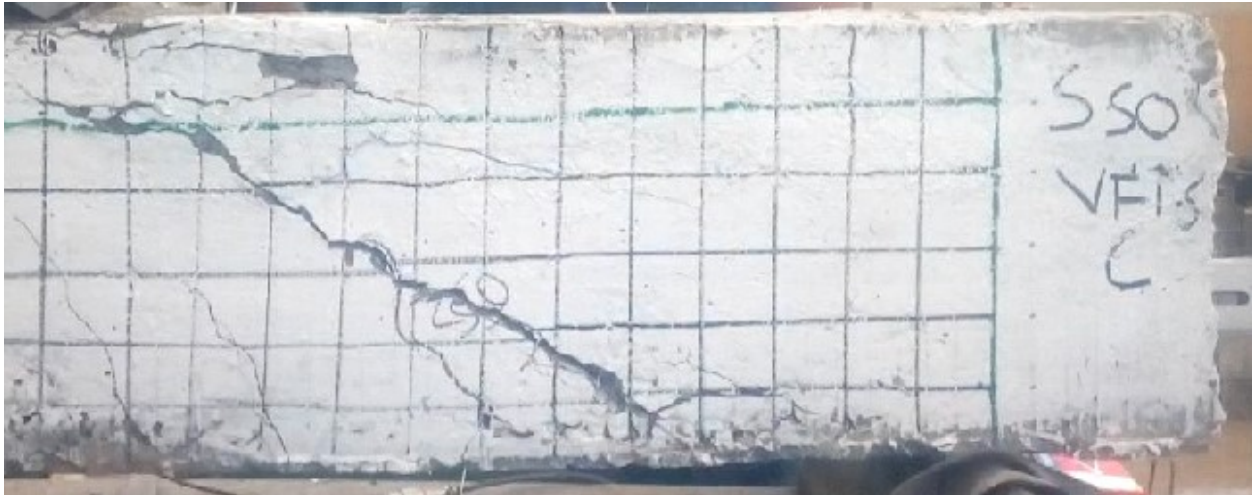


Figure 5-13 S50VF1.5%C after failure (close up view)



Figure 5-14 S50VF1.5%C after failure (close up view)

### ***5.1.1.7 S100VF0.5%C***

S100VF0.5%C is a steel fiber reinforced concrete beam, with 0.5% steel fiber and the shear spacing increased by 100% was tested under one side cyclic loading. Its section capacity was taken from vector 2 finite element analysis which is 326.163kN. The section capacity of S100VF0.5% was lower than all types of beam .The number of transversal reinforcement is lower than CB by half.

Specimen S100VF0.5% loaded monotonically up to its 90% of section capacity reached ,which is 293.55 kN had lower stiffer than other types of steel fiber reinforced concrete beam. During the first cycle of loading of the beam surface cracks appeared at the bottom

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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and diagonal cracks occurred .At 15<sup>th</sup> cycle of loading the beam faces shear failure at right side of the beam.



Figure 5-15 S100 VF 0.5C after failure



Figure 5-16 S100VF0.5%C after failure (close up view)

## **5.1.1.8 S100VF1%C**

S100VF1%C is a steel fiber reinforced concrete beam, with 1% steel fiber and the shear spacing increased by 100% was tested under one side cyclic loading. Its section capacity was taken from vector 2 finite element analyses which is 339.154kN.

Beam S100 VF1%C was tested monotonically up to its 90% predicted section capacity .This beam was stiffer than their shear spacing increased by 100% beams. But slightly less stiffer than their shear spacing increased by 50%.During the first five cycles initial

## Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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and diagonal cracks were occurred after that the crack pattern didn't perform significant change until 30<sup>th</sup> cycle .At 40<sup>th</sup> cycle of loading the beam fail at left support of beam and the steel fibers pulled out. But the cracking width of the beam not widen as control beams and S100VF0.5%C.

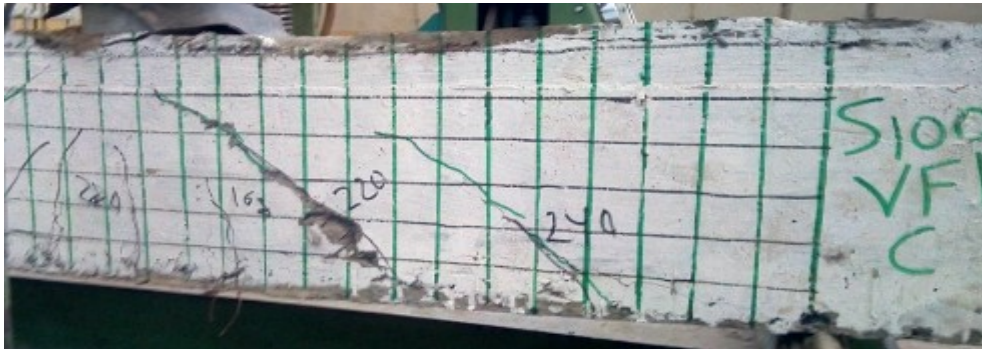


Figure 5-17 S100VF1%C after failure



Figure 5-18 S100VF1%C after failure (close up view)

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

## 5.1.1.9 S100VF1.5%C

S100VF1.5%C is a steel fiber reinforced concrete beam, with 1.5% steel fiber and the shear spacing increased by 100% was tested under one side cyclic loading. The section capacity obtained from vector 2 was 335.69kN.

Specimen S100VF1.5%C loaded monotonically until its 90% of section capacity attained. This beam exhibited stiffer response in the first cycle of loading than S100VF0.5%C. Evenly distributed flexure-shear cracks were initiated in the first cycle. Starting from fifteenth cycle, the initial stiffness of the beam was reduced. When the 30<sup>th</sup> cycle was reached, a pronounced crack degradation and stiffness degradation started being observed. The beam had failure on 33<sup>th</sup> cycle at left side.

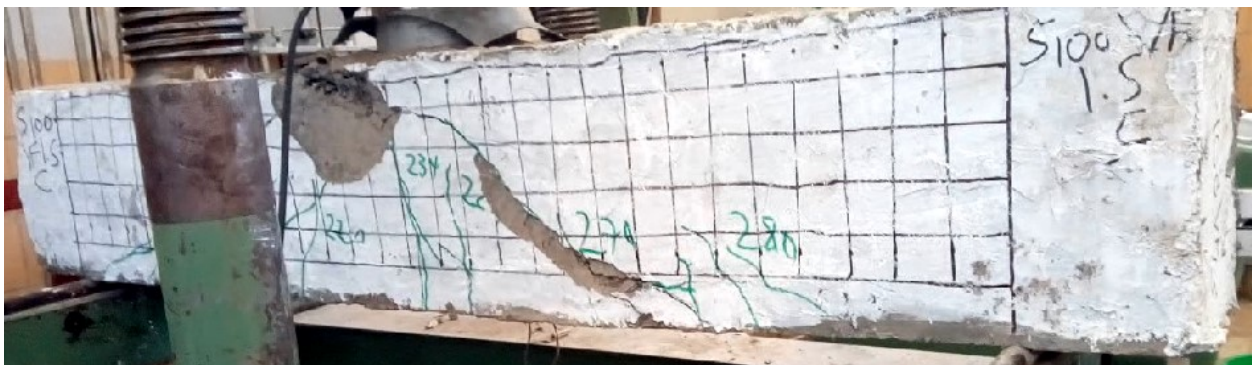


Figure 5-19 S100VF1.5%C after failure



Figure 5-20 S100VF1.5%C after failure(close up view)

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

## 5.1.2 Experimental results

### 5.1.2.1 Load deflection curves

All experimental beams exhibited diagonal shear failure as can be concurred from their load deflection diagrams. The experimentally obtained load deflection diagrams were presented below for all specimens.

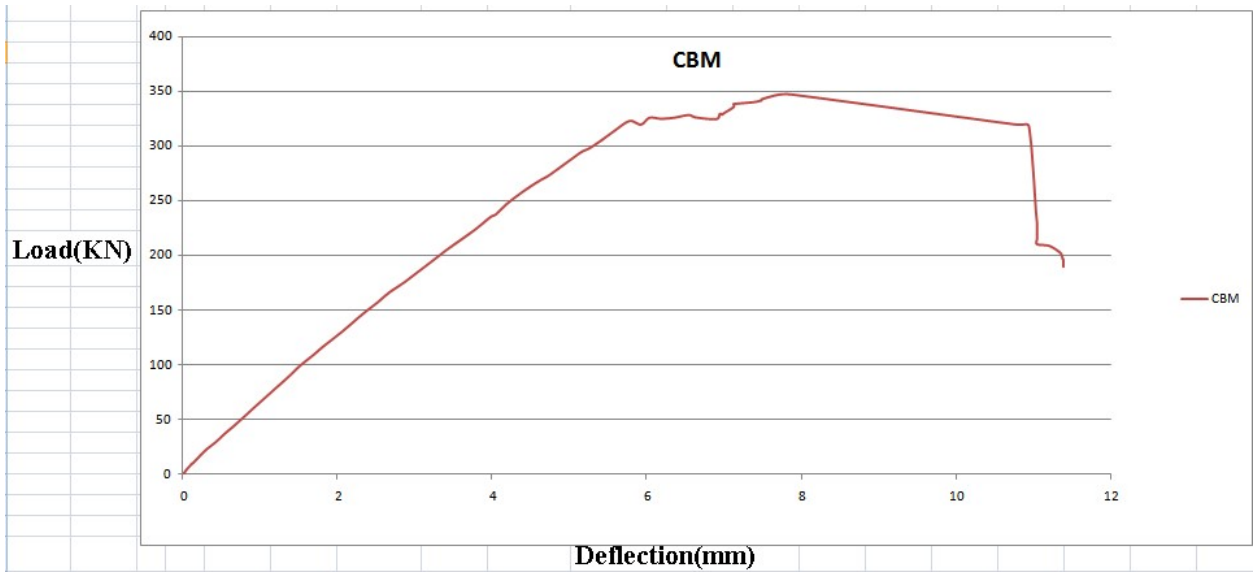


Chart 5-1 Load deflection for CBM

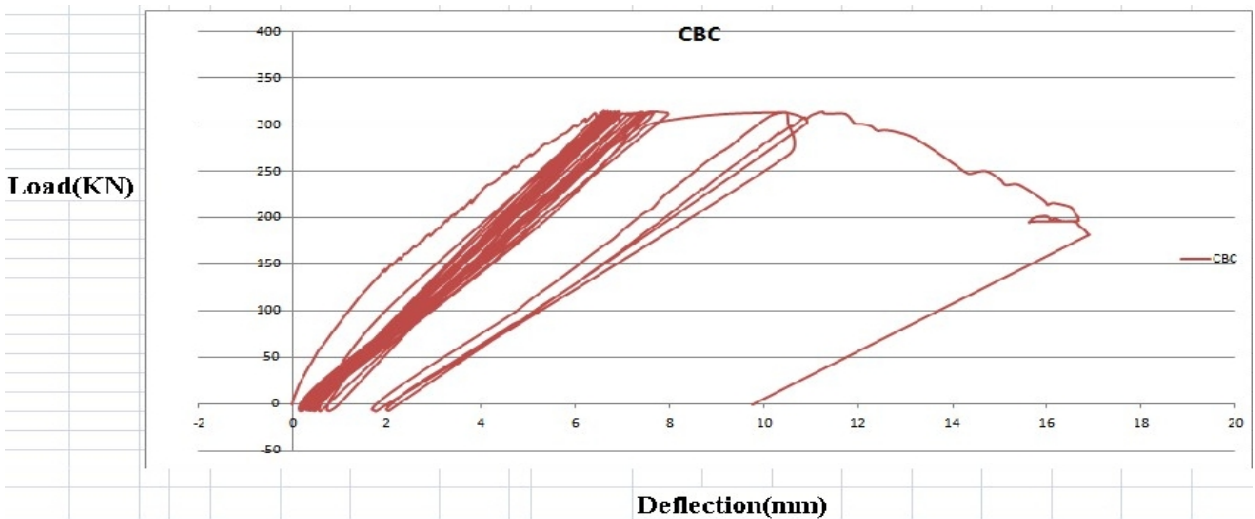


Chart 5-2 Load deflection for CBC

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

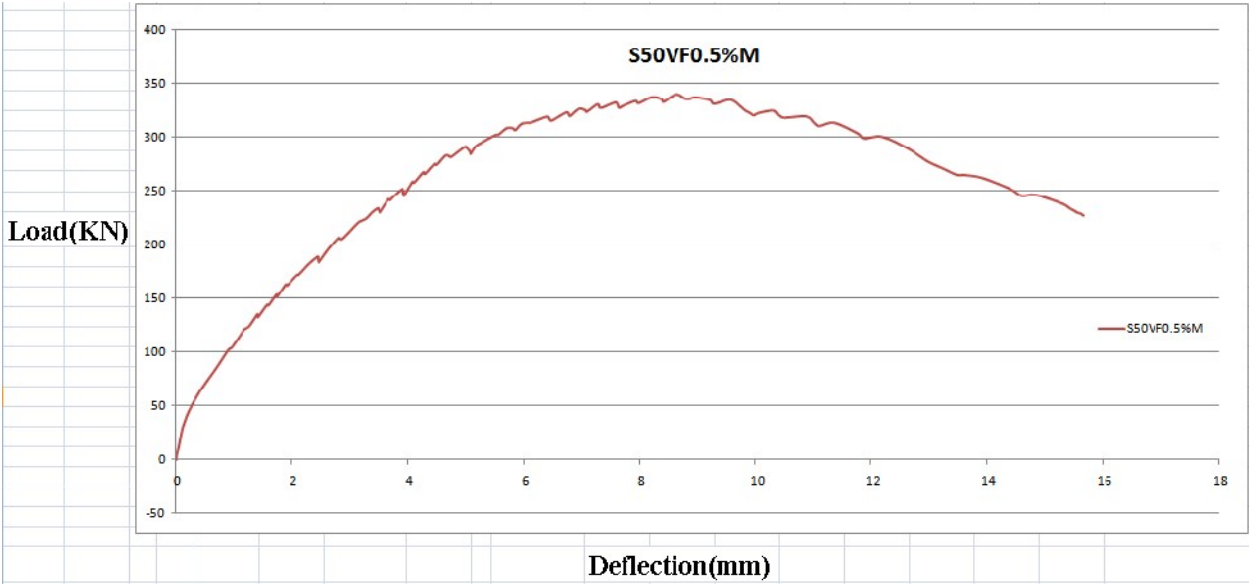


Chart 5-3 Load deflection for S50VF0.5%M

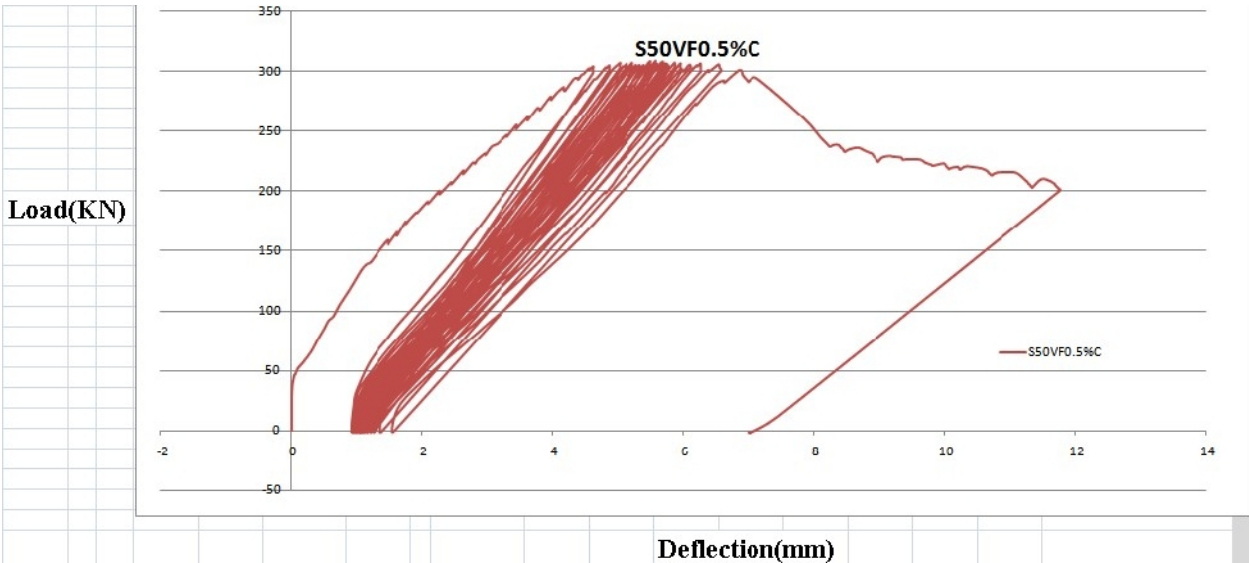


Chart 5-4 Load deflection for S50VF0.5%C

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

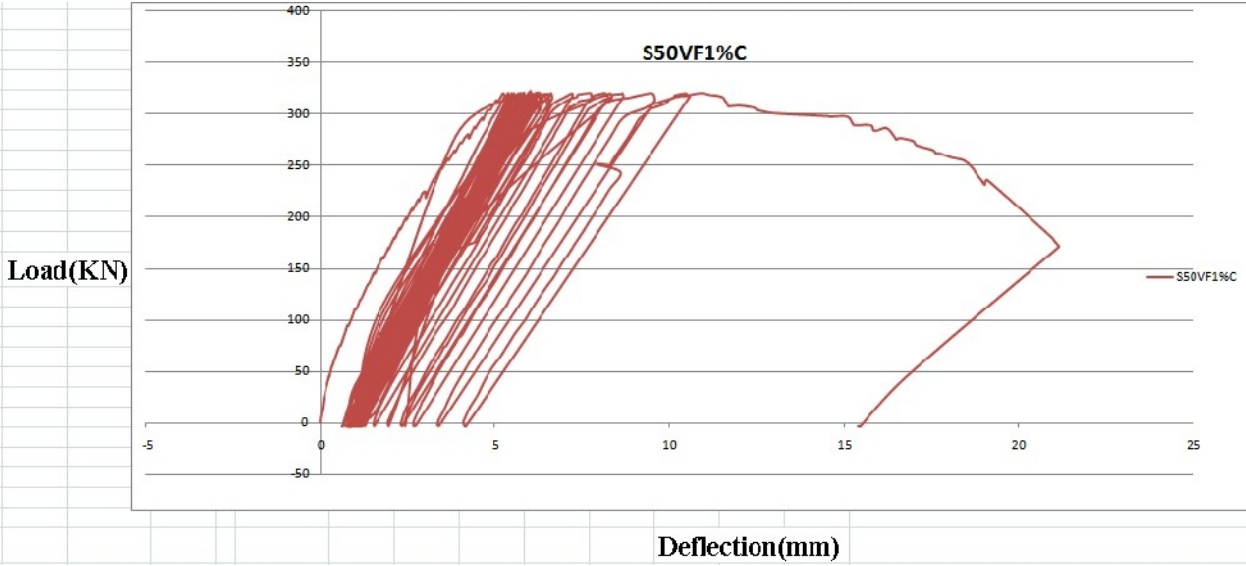


Chart 5-5 Load deflection for S50VF1%C

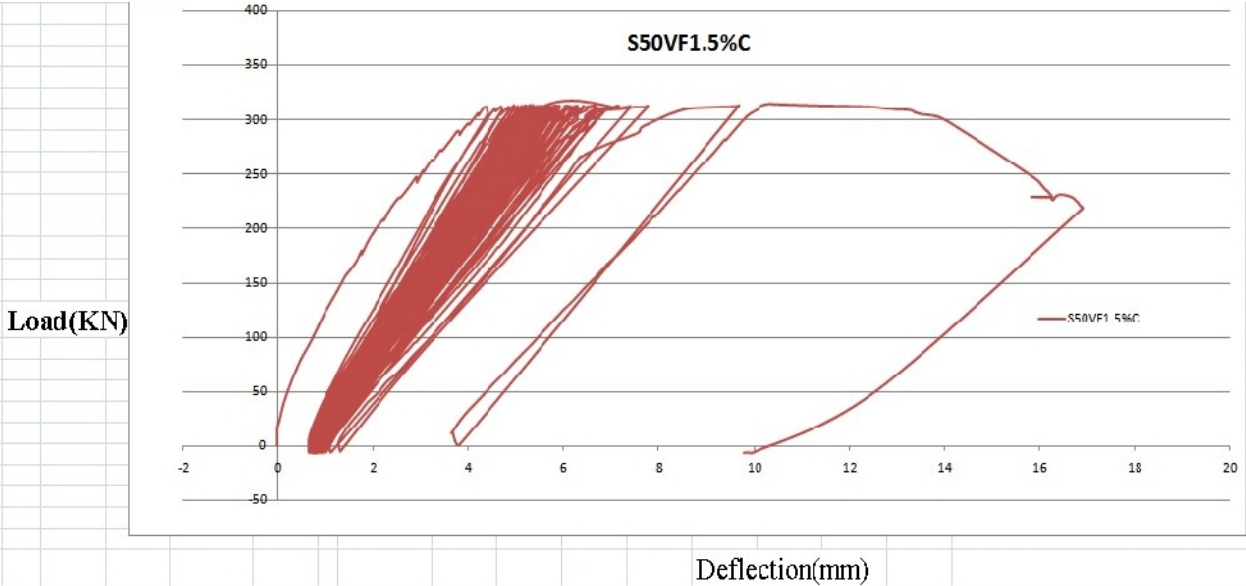


Chart 5-6 Load deflection for S50VF1.5%C

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

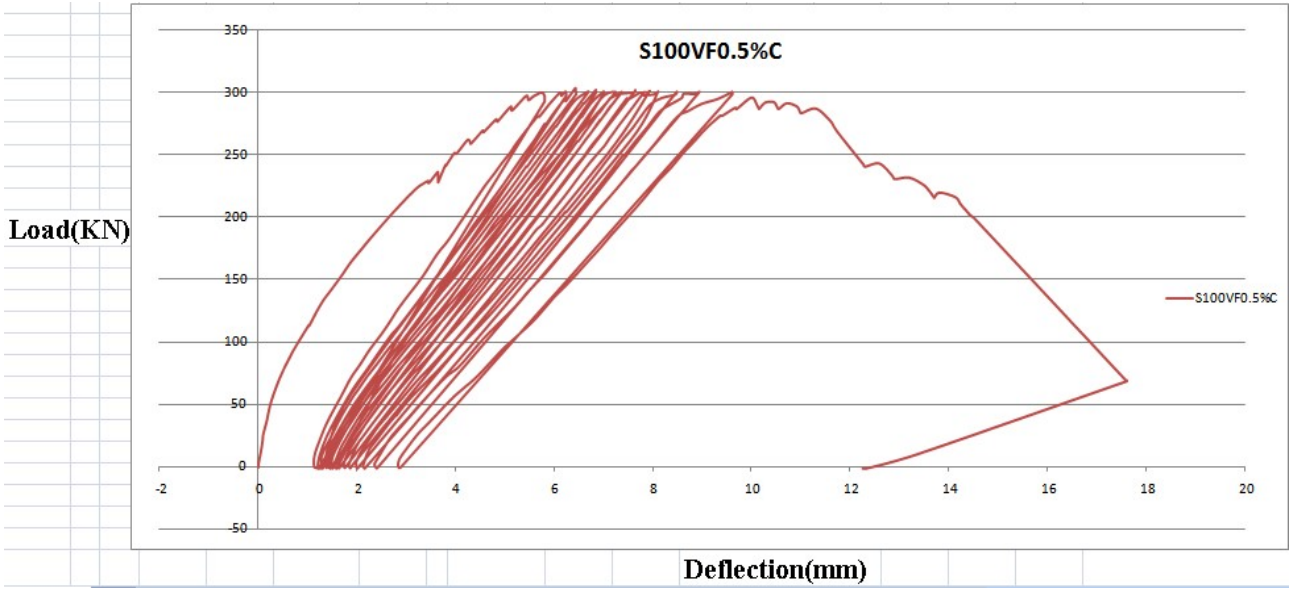


Chart 5-7 Load deflection for S100VF0.5%C

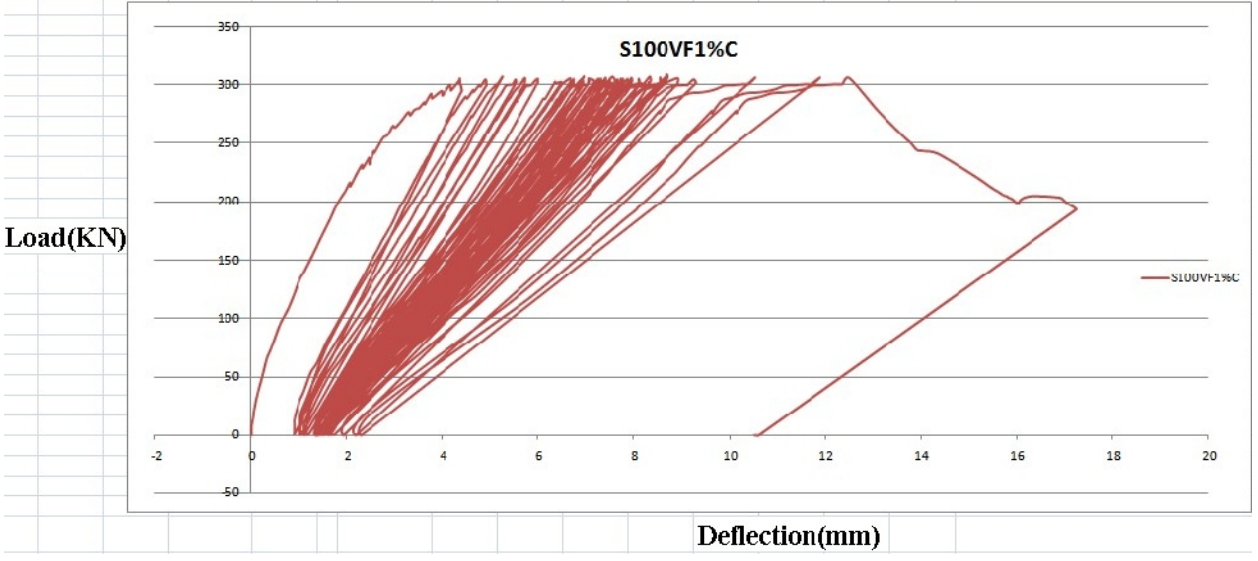


Chart 5-8 Load deflection for S100VF1%C

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

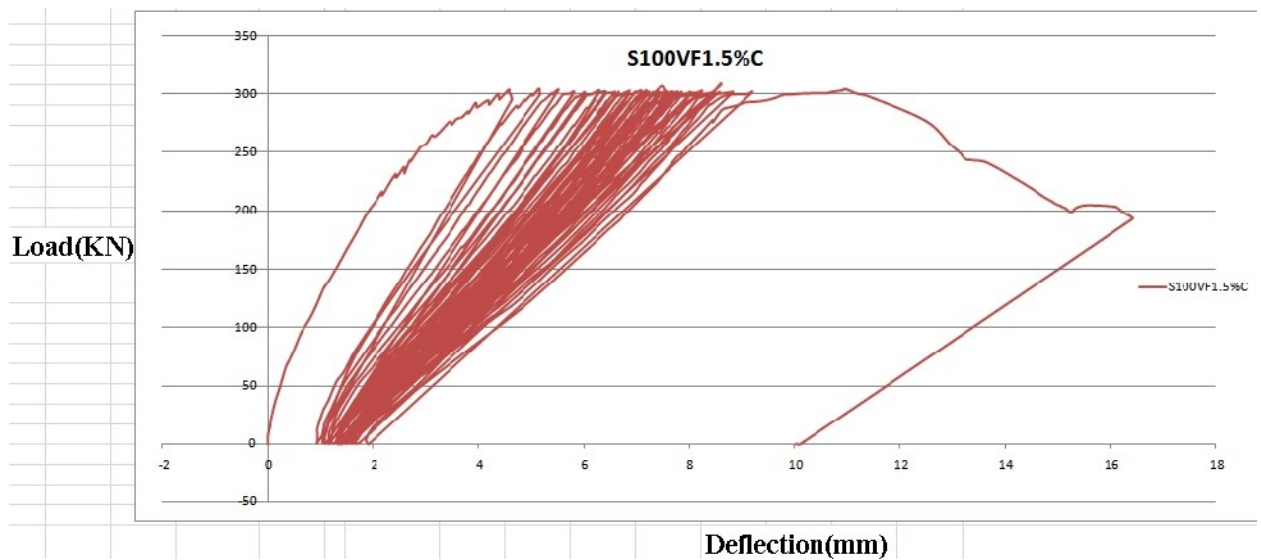


Chart 5-9 Load deflection for S100VF1.5%C

### 5.1.3 Analytical Result

The FE models were numerically stable until the peak load decreased by approximately 10 – 30%.

Overall, the behavior of the beams was well predicted using VecTor2. The force capacity prediction was reasonably accurate. All specimens exhibited typical characteristics of shear failure based on their load deflection curves.

Analytical computation outputs were verified by using experimental results of the beams in this research, under monotonic loading. After verifying analytical modeling as a close match to experimental results, loading pattern was the only parameter varied for the fatigue experiments. Table 5.2 offers a numerical overview of the analytical simulation results, which shall be discussed in detail in the following sections.

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

**Table 5-2 : Summary of analytical results**

Specimen	Cylindrical compressive strength(Mpa)	Shear reinforcement ratio( $\rho_w$ )	Maximum load( $P_{max}$ )(kN)
A-CBM	29.984	0.264	346.693
A-S50VF0.5%M	30.792	0.18	339.965
A-S50VF1%M	34.24	0.18	355.953
A-S50VF1.5%M	28.852	0.18	347.588
A-S100VF0.5%M	30.348	0.132	326.163
A-S100VF1%M	33.989	0.132	339.154
A-S100VF1.5%M	28.725	0.132	335.69

### 5.1.3.1 Load deflection curves

The Load deflection charts obtained from analytical simulation on Vector 2 are presented as follows.

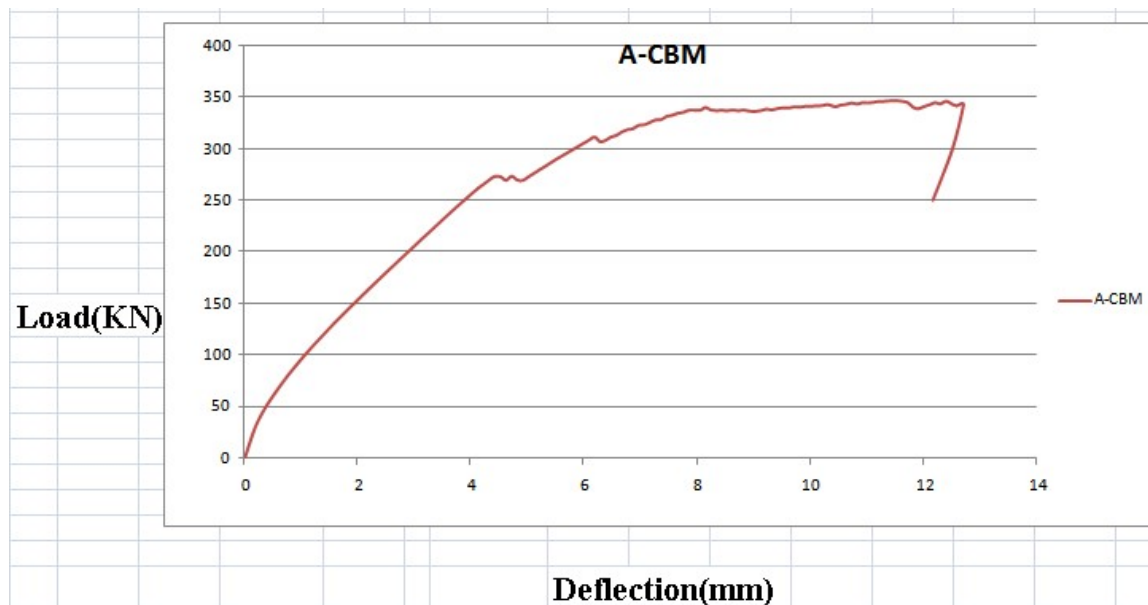


Chart 5-10 Load deflection for A-CBM

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

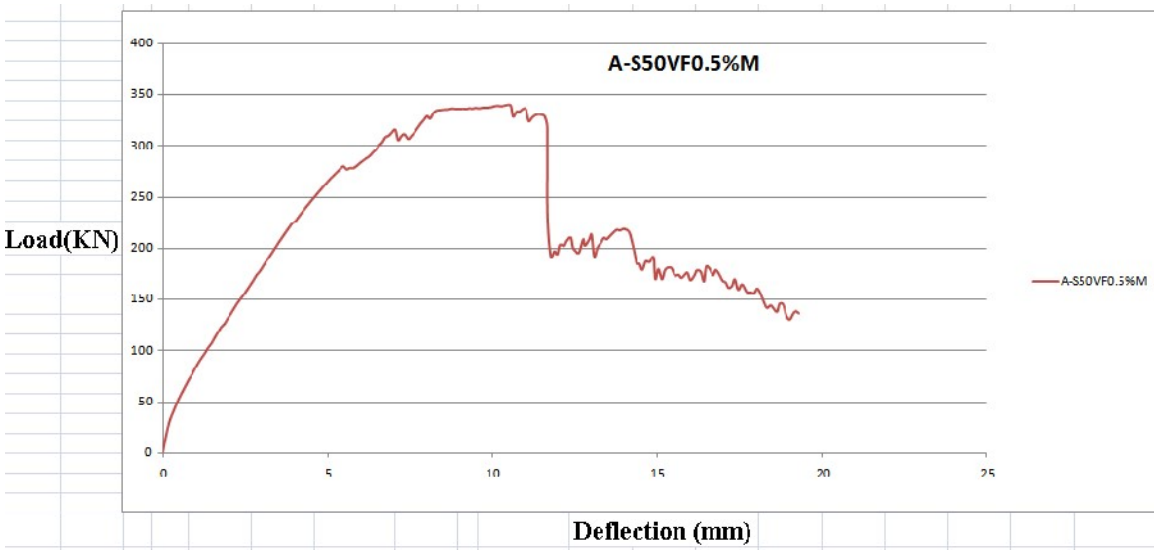


Chart 5-11 Load deflection for A-S50VF0.5%M

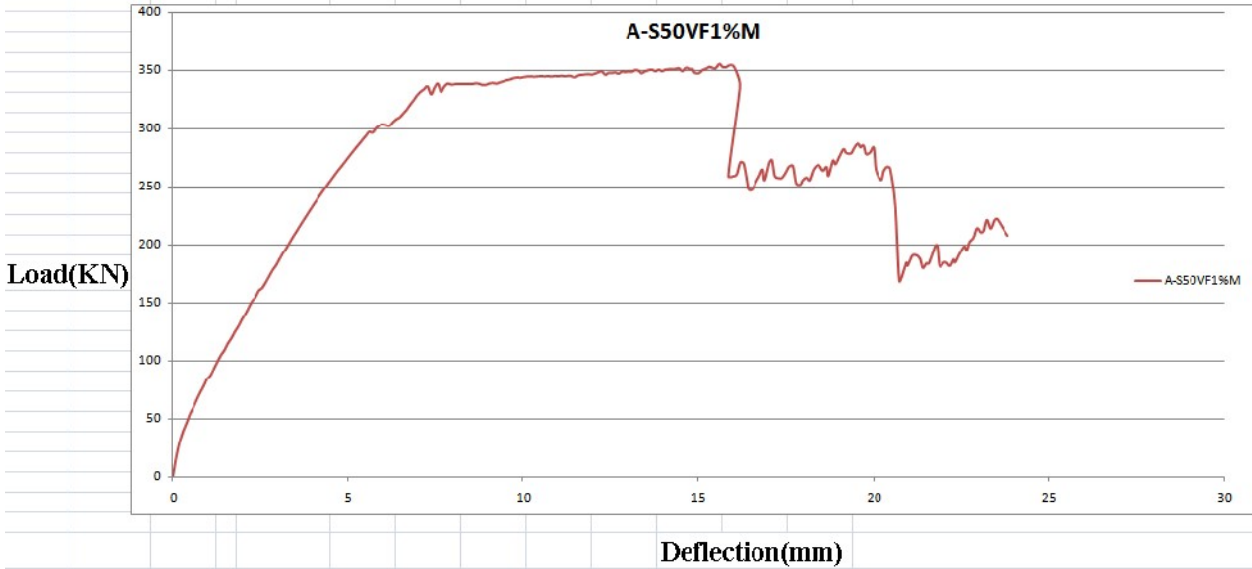


Chart 5-12 Load deflection for A-S50VF1%M

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

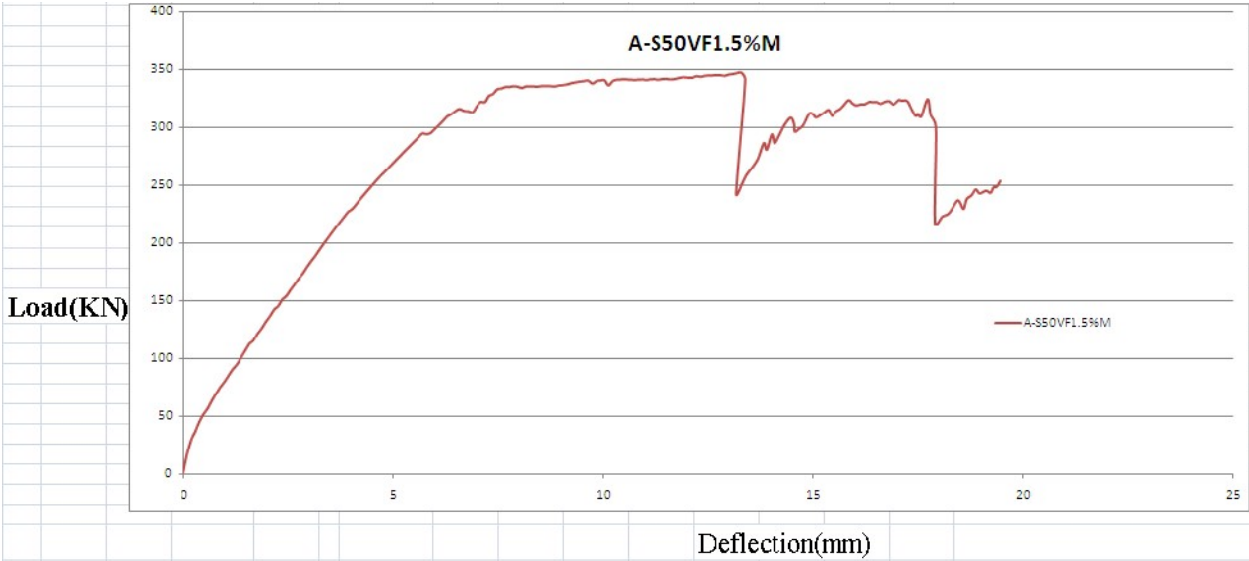


Chart 5-13 Load deflection for A-S50VF1.5%M

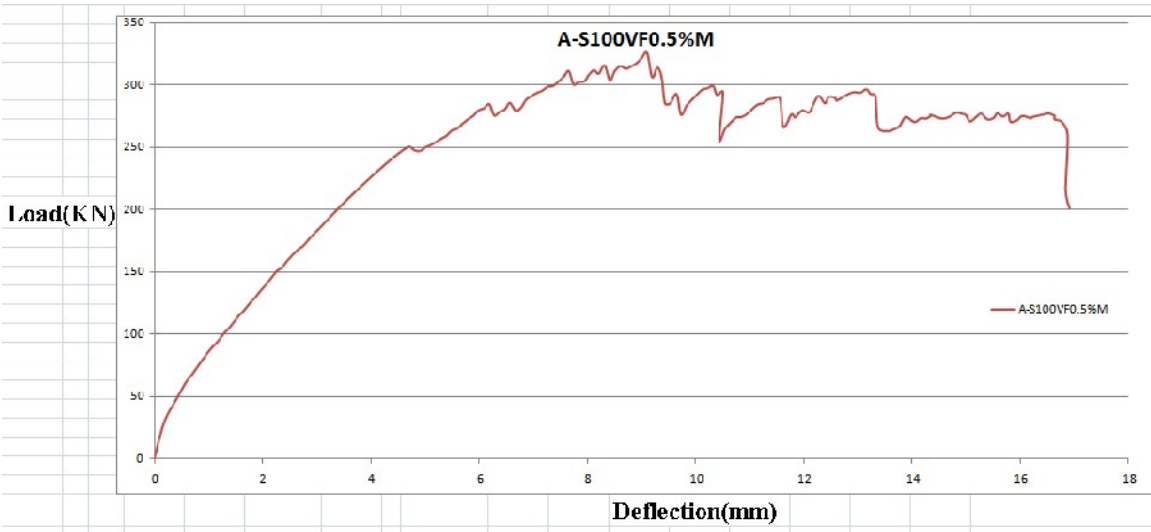


Chart 5-14 Load deflection for A-S100VF0.5%M

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

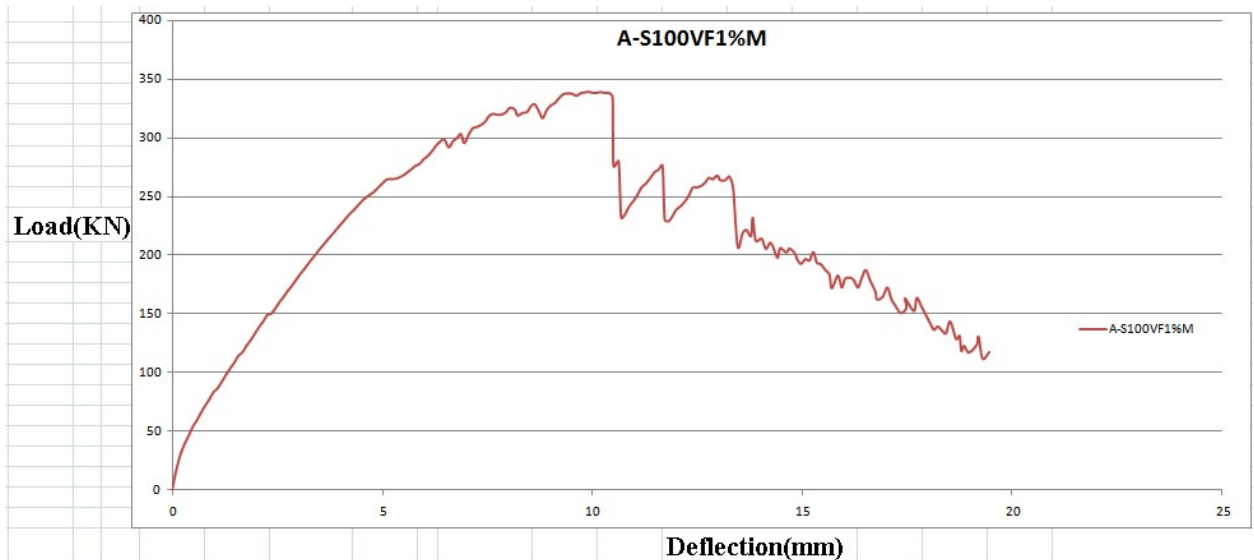


Chart 5-15 Load deflection for A-S100VF1%M

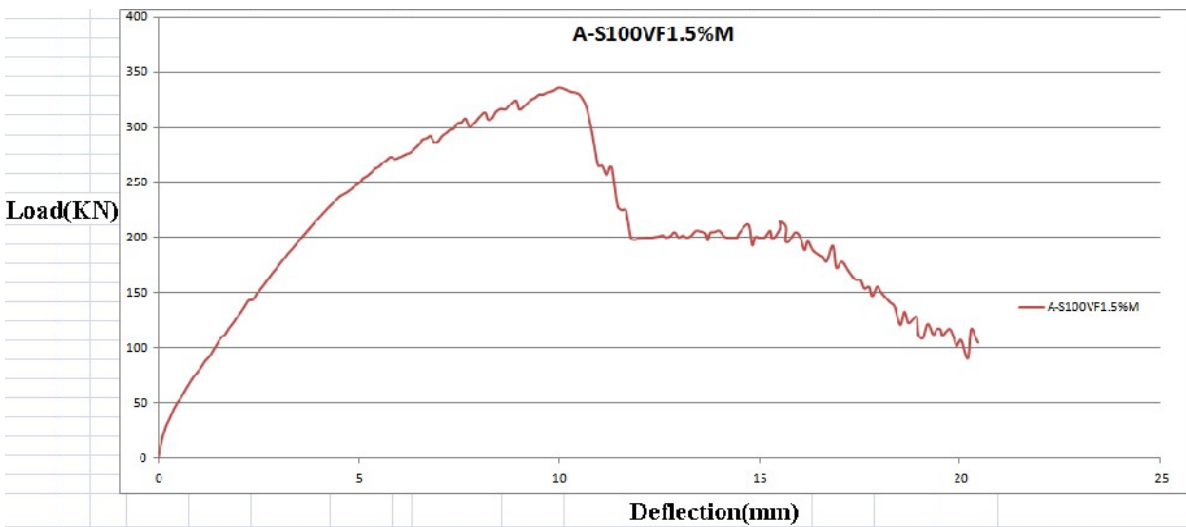


Chart 5-16 Load deflection for A-S100VF1.5%M

## 5.2 Discussion

### 5.2.1 Shear behavior of experimental beams

Having a clear view of experimental and analytical simulation results, let's proceed to intent observation of this research's outputs and their implication on the shear behavior of reinforced and steel fiber reinforced concrete beams under monotonic and cyclic loading. The following sections will compare the load deflection diagrams of the experimental and

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

analytical specimens, tensile and compressive test results, the effect of steel fiber volume fraction and increasing of shear spacing and comment on their overall behavior.

## 5.2.1.1 Comparison in response of CBM and CBC

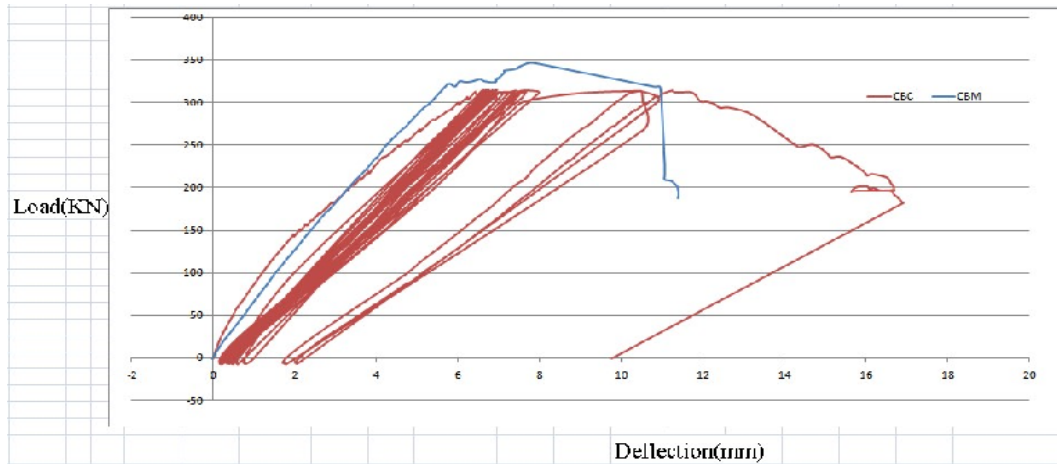


Chart 5-17 Load deflection of CBM and CBC

Specimen CBM and CBC differs only in type of loading. Their tensile and compressive strength were almost similar. CBC exhibited stiffness degradation after the ninth cycle of loading. The life cycle of the specimen CBC at 90% of its maximum capacity is observed to be 20 cycles. This is analogous to fatigue analysis of many Reinforced Concrete beams. Their mode of failure was similar. Type fails in brittle shear failure.

## 5.2.1.2 Comparison in response of S50VF0.5%M and S50VF0.5%C

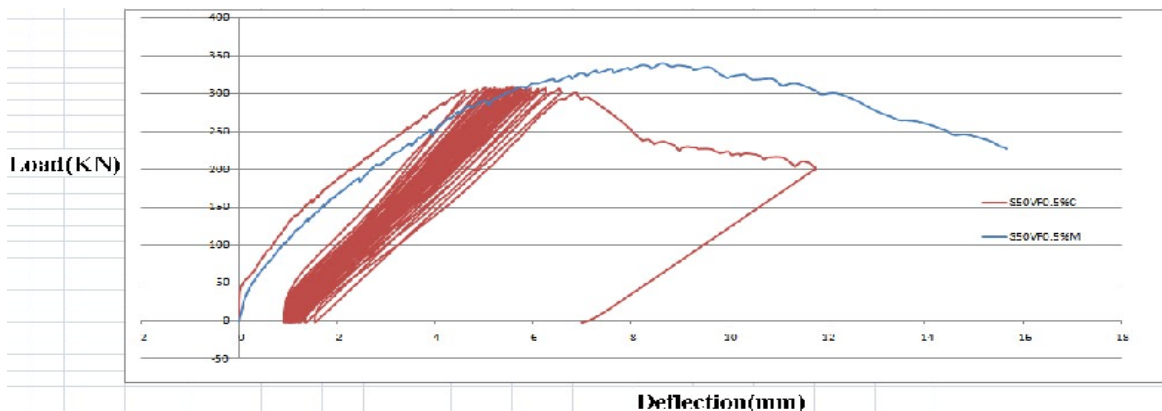


Chart 5-18 Load deflection for S50VF0.5%M and S50VF0.5%C

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

Specimen S50VF0.5%C exhibited slightly stiffer response in the first cycle than S50VF0.5%M. In each cycle of loading, the stiffness of S50VF0.5%C reduced. At 21<sup>th</sup> cycle the S50VF0.5%C fails in shear.

### 5.2.1.3 Comparison in response of CBM and S50VF0.5%M

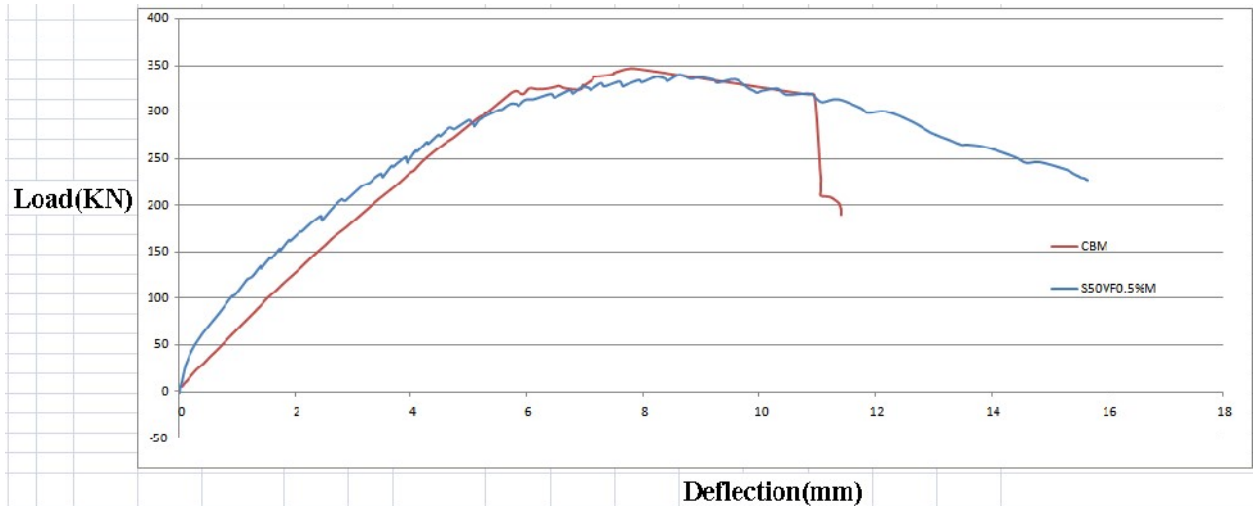


Chart 5-19 Load deflection for CBM and S50VF0.5%M

Beam S50VF0.5%M response stiffer in the first loading stage than CBM and also its tensile and compressive strength results higher than CBM. But the section capacity of CBM higher than S50VF0.5%M. CBM fails in brittle shear whereas S50VF0.5%M fails in shear gradually and steel fibers pulled out.

### 5.2.1.4 Comparison in response of CBC and S50VF0.5%C

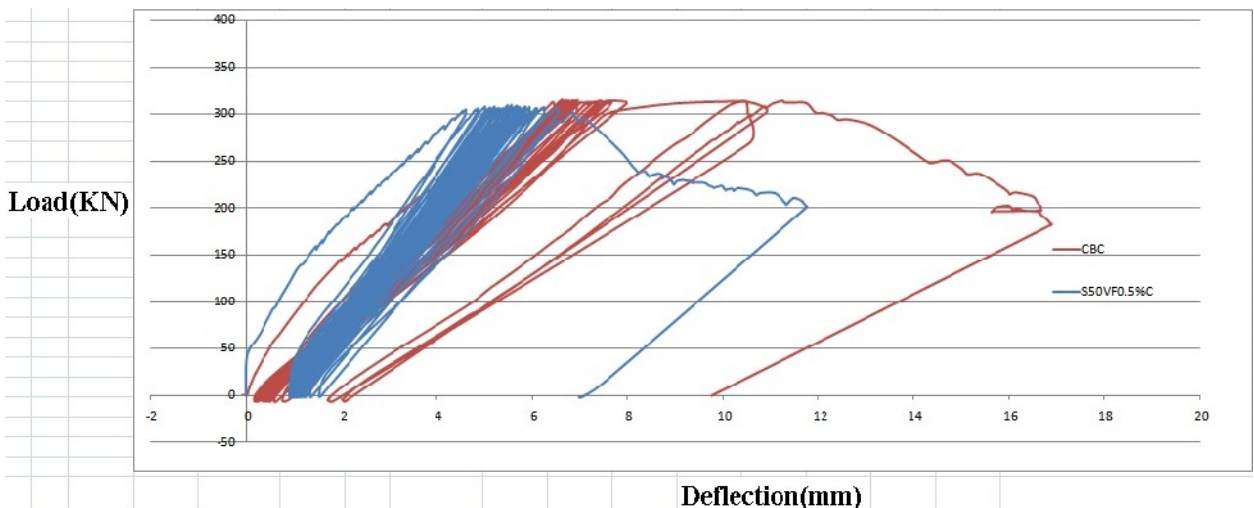


Chart 5-20 Load deflection for S50VF0.5%C and CBC

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Initially S50VF0.5%C exhibited stiffer response than CBC. At 20<sup>th</sup> cycle of loading CBC fail in brittle shear and S50VF0.5%C lasted for 21<sup>th</sup> cycle.

Specimen S50VF0.5% would not be substitute CB because from the starting its section capacity was less than the controls. This result indicated the number of stirrups decreased by half and 0.5% steel fibers added cannot be satisfactory.

## 5.2.1.5 Comparison in response of CBC and S50VF1%C

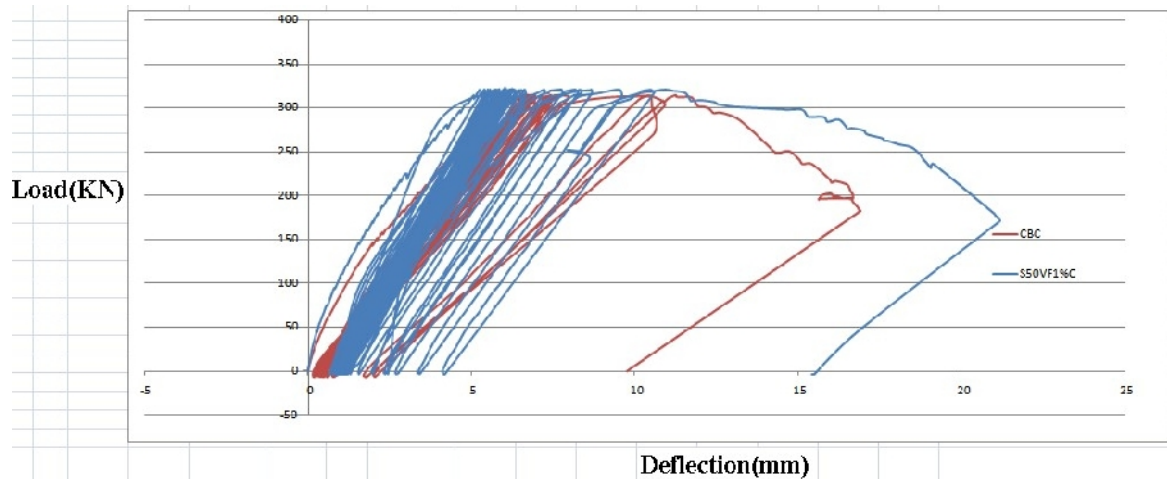


Chart 5-21 Load deflection for CBC and S50VF1%C

Specimen S50VF1%C had greater section capacity, tensile and compressive strength than CBC. It also responds with higher stiffness than CBC during 90% section capacity of cyclic loading. S50VF1% failed at 60<sup>th</sup> cycle in shear gradually whereas CBC failed at 20<sup>th</sup> cycle of loading. The higher number of cycles indicated the capacity of energy dissipation, which is crucial for seismic design.

This clearly shows that the proper amount of steel fiber with decreased stirrups by 50% enhances shear strength and energy dissipation under cyclic loading and the important role of steel fibers in energy dissipation during seismic events.

S50VF1% fully substitutes control beams with increasing capacity, shear strength, tensile strength, and number of cycles before failure.

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

## 5.2.1.6 Comparison in response of CBC and S50VF1.5%C

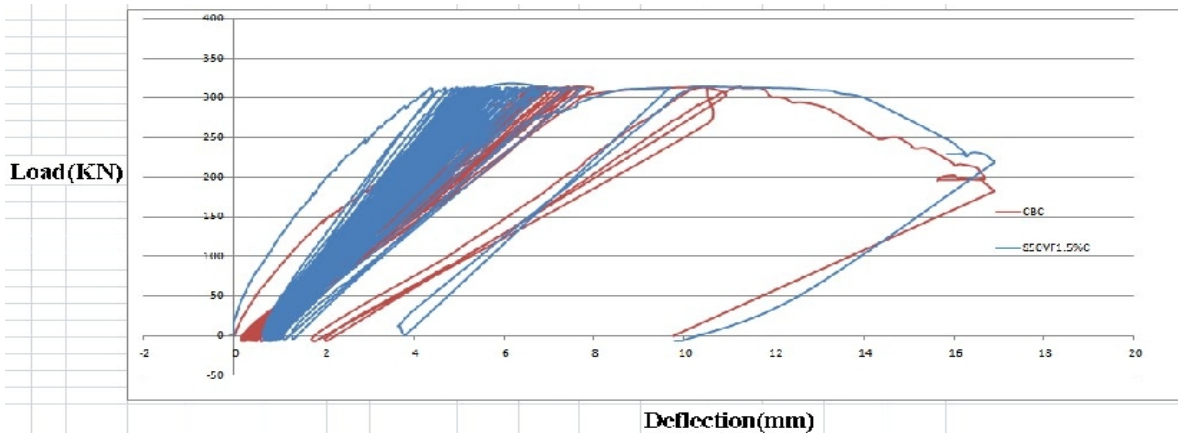


Chart 5-22 Load deflection for CBC and S50VF1.5%C

The section capacity of S50VF1.5% and CBC had a little difference. But S50VF1.5% response higher stiffness than CBC. And also its tensile strength was higher than CBC. When come to the number of cycle, S50VF1.5% fails at 49<sup>th</sup> cycle.

The results of specimen S50VF1.5% C indicated that it can fully substitute the controls but S50VF1.5% C had more ability than that of S50VF1.5% C.

## 5.2.1.7 Comparison in response of CBC and S100VF0.5%C

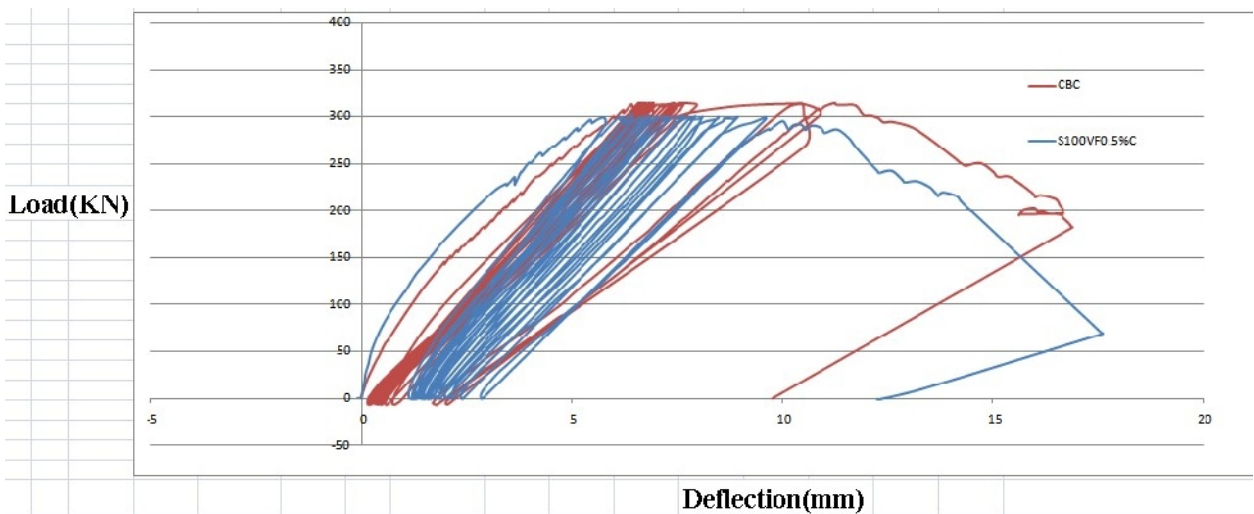


Chart 5-23 Load deflection for CBC and S100VF0.5%C

S100VF0.5% exhibited lower section capacity than all beams. In the first cycle of loading its stiffness was good as compare to CBC but after that the response of stiffness decreased and at 15<sup>th</sup> cycle it failed in shear.

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

The results of S100VF0.5%C indicated that its number of stirrups and amount of steel fibers not adequate.

## 5.2.1.8 Comparison in response of CBC and S100VF1%C

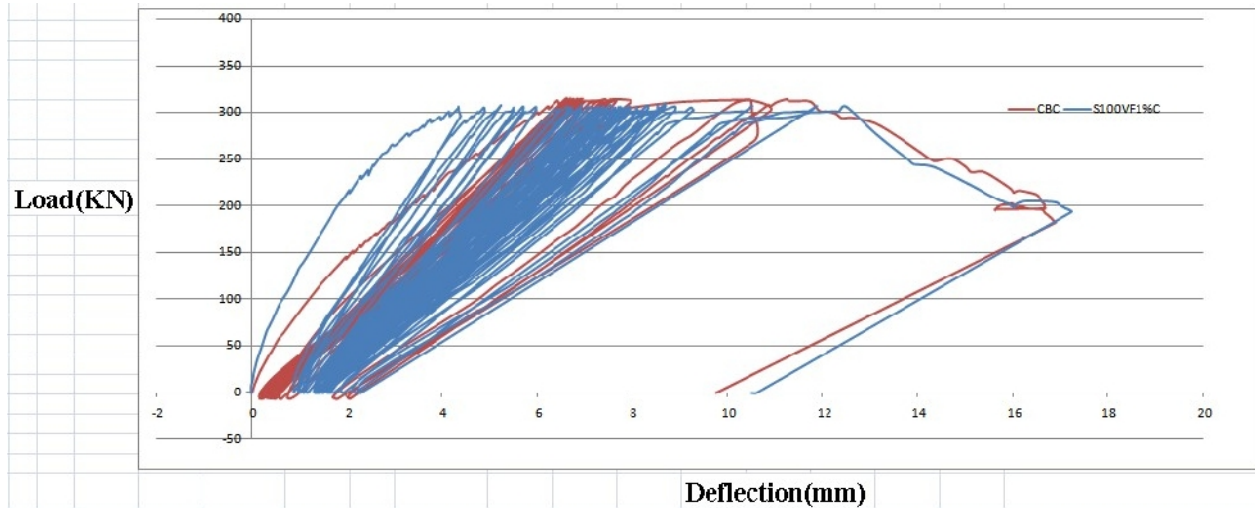


Chart 5-24 Load deflection for CBC and S100VF1%C

During in the initial loading, specimen S100VF1%C exhibited good stiffness than CBC. The results of tensile and compressive strength of S100VF1%C were higher than CBC. At 40<sup>th</sup> cycle of loading S100VF1%C fails gradually and the steel fibers form bridging the between concrete .

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

## 5.2.1.9 Comparison in response of CBC and S100VF1.5%C

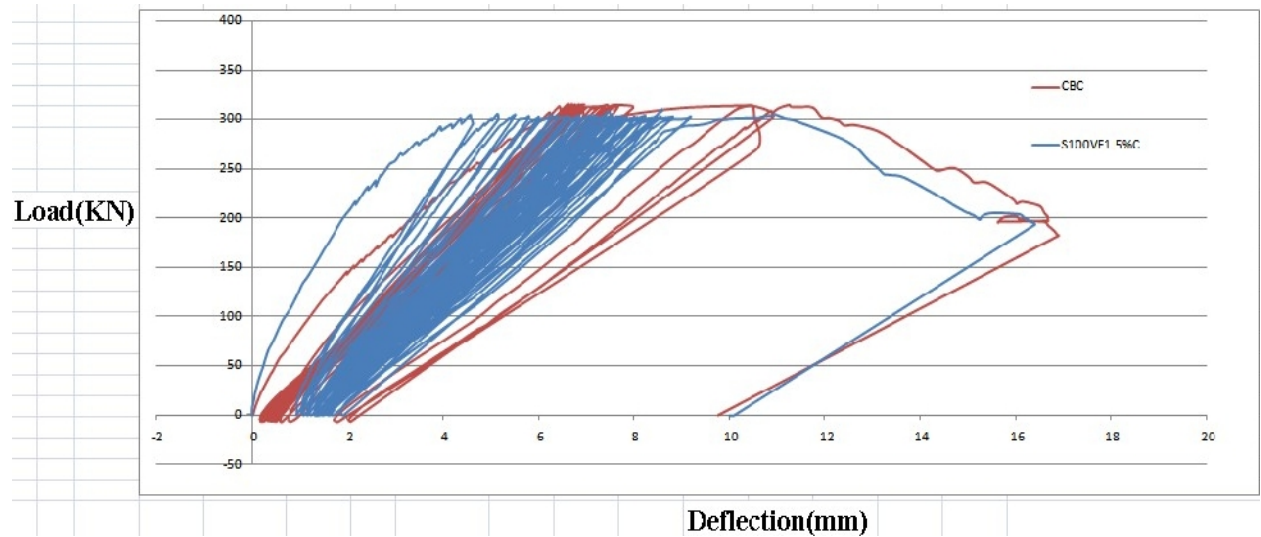


Chart 5-25 Load deflection for CBC and S100VF1.5%C

The section capacity and compressive strength of Specimen S100VF1.5% was less than the control beam. But its tensile strength was higher than CBC. During the initial cycle its stiffness response better than CBC. At 33<sup>th</sup> cycle of loading the beam fails in shear gradually and the steel fibers pulled out.

## 5.2.1.10 Diagonal cracking path

In the early stage of diagonal crack development, the addition of steel fiber reduced the growth rate of the diagonal crack width. However, in the later stage, the diagonal crack width of SFRC beams grew faster than before. In addition, when the fiber volume fraction of the beam increased, the effect of steel fiber on the diagonal crack width increased significantly, but it had less growth while the fiber volume fraction increased from 1% to 1.5%.

For SFRC beam, the steel fiber could also reduce the width of the diagonal crack, and the larger the steel fiber volume fraction was, the more the crack width decreased. The diagonal crack width of SFRC beams with stirrups developed slowly at the beginning, and gradually became fast at the later stage. Due to the joint action of the stirrups and the steel fibers, the slow increase stages of the crack width for SFRC beams with stirrups were significantly longer. For the former were greater than that of the latter, that is, the diagonal crack width increased slower. From SFRC beams S100VF0.5%C exhibited

## Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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wider crack width than other SFRC beams. For control beams their crack path develops faster.

### ***5.2.1.11 Failure Mode***

In the test, it was found that all the beams had a similar failure process, and the failure modes were not affected by the steel fiber. The main process can be described as follows: when in the initial loading stage, small vertical cracks first appeared at the bottom of the beam; as the load increased, more vertical cracks came out, and vertical cracks began to appear at the bottom of the shear span. When the load increased further, the vertical cracks in the shear span develop diagonally forming flexure-shear cracks, and then the diagonal cracks were formed at the web of the beam in shear span. After this, the diagonal crack at the web continuously extended to the directions of support as the load increased. When the applied load was close to the ultimate load, the diagonal crack at the web of the beam extended to the vicinity of the loading point and support, and the width of the diagonal crack increased rapidly. Finally, the steel fibers were gradually pulled out until the concrete was crushed at the loading point.

The addition of steel fiber caused more vertical cracks and diagonal cracks in the test beam, and the crack spacing was reduced because the steel fiber transferred the higher stress at the crack section to the surrounding concrete matrix. In the process, more cracks are generated between existing cracks, or more branch cracks are generated. At the same time, steel fiber reduced the crack height.

The control specimens exhibited diagonal brittle shear failure, when the beam was damaged, the concrete of the beams had spalling at the loading point, but the deformation capacity of concrete in SFRC beams were improved by the bridging effect of steel fibers. This effectively prevented the concrete crushing and spalling at the compression zone.

### ***5.2.1.12 Steel fiber volume fraction***

With the same shear spacing the shear capacities of the beams were improved by increasing the fiber volume fraction, except the beam with 1.5% volume steel fiber. The tensile strength of SFRC beam, with steel fiber volume of 1% increase from 0.5% and 1.5%.

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

Under cyclic loading within the same shear spacing the SFRC beam with 1% steel fiber volume exhibited higher number of cycle.

## 5.2.1.13 Shear spacing

The stirrups had a great role on shear capacity of beams. Within the same steel fiber volume if the shear spacing increases its shear capacity decrease. In this thesis the shear spacing increase by 50% and 100%. From the results of experimental investigation the SFRC beam of its shear spacing increased by more than 50% its shear capacity decreased. S50VF1%C exhibited higher capacity.

## 5.2.2 Comparison between experimental and analytical results

The analytical simulation had fully captured the monotonic response of the experimental investigations of CBM and S50VF0.5%M. There was a strong correlation in analytical and experimental outputs with regards to maximum capacity of beams. The load deflection diagrams of the specimens obtained from experimental and computational analysis are presented below for comparison.

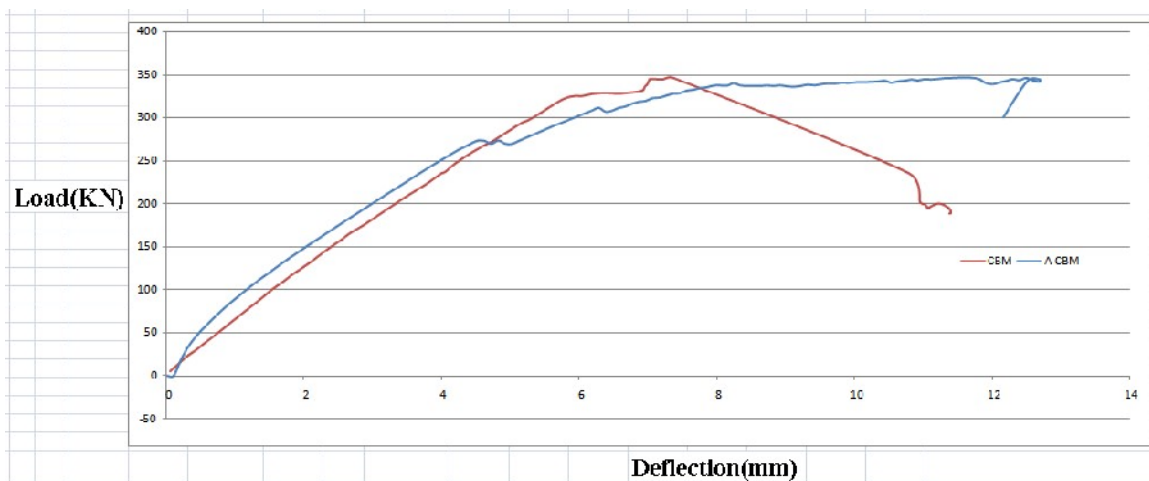


Chart 5-26 Load deflection for ACBM and CBM

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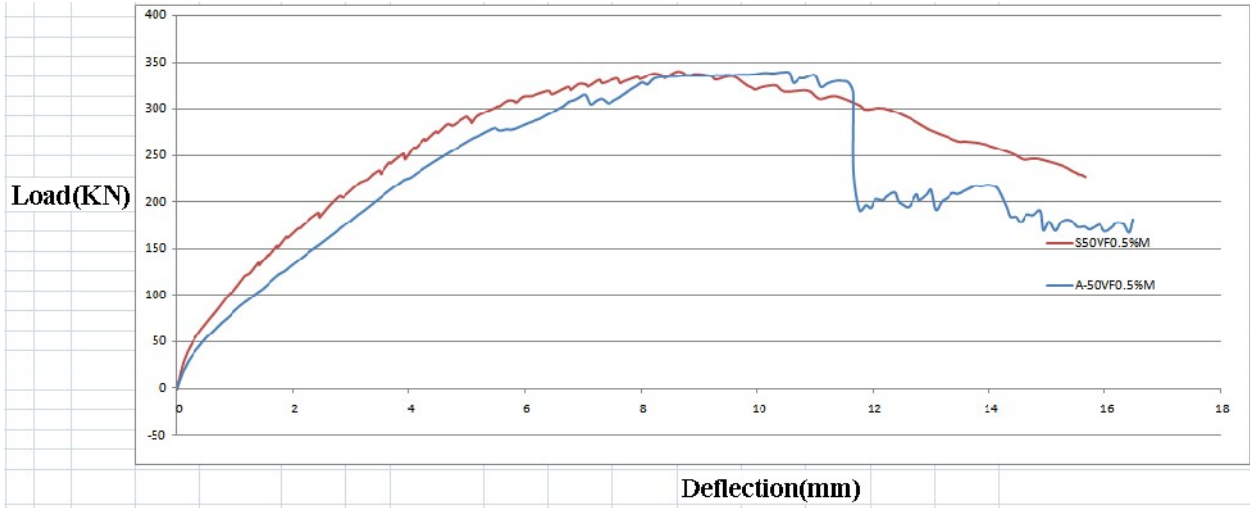


Chart 5-27 Load deflection for AS50VF0.5%M and S50VF0.5%M

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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## CHAPTER 6 CONCLUSION AND RECOMMENDATION

### 6.1 CONCLUSION

The objective of this thesis was to investigate the behavior of SFRC beam under cyclic loading. An experimental study was undertaken accordingly, to examine the monotonic and cyclic shear behavior of SFRC. For this purpose nine specimens were tested. The parameters of the study included the fiber volume fraction, shear spacing and loading protocol. To supplement the beam tests, the mechanical properties of the concrete used were also experimentally studied. Specifically, compression tests and split tensile tests were performed to study the compressive and tensile strength respectively.

The analytical study undertaken was intended to investigate the accuracy of currently available constitutive models in capturing the monotonic behavior of shear-critical SFRC members. The study was performed using a nonlinear finite element analysis program, VecTor2. The results from the beam tests were used to verify the adequacy of the program at the element level. The monotonic results obtained from analytical study of control specimen and its shear spacing increased by 50% with 0.5% steel fiber volume were similar to experimentally tested. Therefore, for the rest five types of SFRC beams their section capacity would be taken from vector 2 result.

Based on experimental and analytical investigation outputs the following conclusions have been drawn.

1. Based on the load deflection responses, the cracking and the failure modes of the tested beams, it can be deduced that the overall performance of the RC beams with volume of steel fiber 1% and 1.5% was improved with respect to the behavior of the reference specimen without fibers.
2. The addition of steel fibers leads to an increase in shear capacity and tensile strength and also an increase in number of cycles achieved before failure when it is used in proper manner.

## Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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3. The control specimen demonstrated shear diagonal cracking failing in a brittle manner, whereas for SFRC beam the steel fibers were gradually pulled out until the concrete was crushed at the loading point, and the test beam was damaged.
4. Steel fibers reduce the width of the diagonal crack due to the bridging effect at the crack. In addition, Steel fibers reduces the crack height and crack spacing.
5. The concrete with 1% steel fiber had higher compressive and tensile strength than other mixes.
6. The SFRC beam, with 1% steel fiber volume and its shear spacing increased by 50% from the control beam exhibited improved section capacity, cyclic response, ductility, mode of failure and overall performance than all tested beams.

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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## 6.2 Recommendation

This thesis presented the investigation of steel fiber reinforced concrete beams that exposed to one sided cyclic loading. Based on the experimental investigation and finite element software simulation the results were better in comparison with control beams.

Regarding to the results of this thesis, the following recommendations are made.

1. The good results obtained from the application of steel fibers extracted from used tyres in reinforced concrete, gives positive initiation for further investigation. In addition it is available easily and it will be good waste management of used tyre.
2. The different material property of this steel fiber should be studied to use practically. And to substitute industrially manufactured steel fibers.
3. A more comprehensive database of cyclically loaded SFRC beam tests should be collected to further assess the influence of fiber aspect ratio, fiber volume and fiber diameter on the cyclic behavior of SFRC specially doing with Vector 2 analysis.
4. It is recommended that further investigation in the application of this steel fiber as a substitute material of minimum reinforcement of ground slab.

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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## APPENDIX A

### Material tests on component of concrete

Material tests were performed on the component of concrete according to ASTM standards.

The results in this section were used as input for the mix design.

#### Sieve size Analysis

For fine aggregate

Sieve Size (mm)	Weight of sieve (gm)	Weight of sieve+retained (gm)	Weight of retained (gm)	%retained	Cummulative Coarse%	Cummulative passing %	ASTM 33%
9.5	585	585	0	0	0	100	100
4.75	430	430	0	0	0	100	95-100
2.36	385	425	40	7.84	7.84	92.16	80-100
1.18	370	450	80	15.7	23.54	76.46	50-85
600 $\mu$ m	325	470	145	28.4	51.94	48.06	25-60
300 $\mu$ m	305	475	170	33.3	85.24	14.76	10-30
150 $\mu$ m	280	345	65	12.7	97.96	2.06	2-10
pan	240	250	10	1.96	100	0	0

## Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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For coarse aggregate

Sieve Size (mm)	Weight of sieve (gm)	Weight of sieve + retained (gm)	Weight of retained (gm)	%retained	Cumm-ulative Coarse%	Cumm-ulative passing%	ASTM 33%
25	1160	1354.174	194.174	4	4	96	95-100
19	1390	2725.125	1335.125	27.5	31.5	68.5	30-70
9.5	1165	3715	2550	52.52	84.02	15.98	10-35
4.75	1175	1945.701	770.701	15.87	99.89	0.11	0-35
pan	735	740	5	0.103	100	0	0

Specific gravity and absorption

For fine aggregate	
W1(oven dry)=0.48kg	Bulk specific gravity=2.34
W2(SSD)=0.5kg	Bulk specific gravity SSD=2.44
W3(water immersed)=0.295kg	Apparent specific gravity=2.59
	Absorption capacity=4.17%

For coarse aggregate	
W1(oven dry)=4.923kg	Bulk specific gravity=2.793
W2(SSD)=5.063kg	Bulk specific gravity SSD=2.87
W3(water immersed)=3.3kg	Apparent specific gravity=3.03
	Absorption capacity=2.84%

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

## APPENDIX B

### Concrete strength test result data

#### Specimen CBM

##### Cubic compressive test result

Specimen	Mass(kg)	Density(kg/m <sup>3</sup> )	f <sub>cu</sub> (Mpa)
1	8.054	2386.37	36.48
2	8.068	2390.52	37.58
3	8.080	2394.07	38.38
Mean	8.067	2390.32	37.48

##### Split tensile test result

Specimen	Maximum load(P)(kN)	$\sigma_t$ (tensile stress) (Mpa)	f <sub>ctk</sub> (EC2) (Mpa)
1	192.28	2.72	2.448
2	178.72	2.528	2.275
3	175.2	2.478	2.23
Mean	182.07	2.575	2.3177

#### Specimen CBC

##### Cubic compressive test result

Specimen	Mass(kg)	Density(kg/m <sup>3</sup> )	f <sub>cu</sub> (Mpa)
1	8.142	2412.44	35.16
2	8.009	2373.037	40.28
3	8.094	2398.22	37.72
Mean	8.0817	2394.578	37.72

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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## Split tensile test result

Specimen	Maximum load(P)(kN)	$\sigma_t$ (tensile stress) (Mpa)	$f_{ctk}$ (EC2) (Mpa)
1	184.184	2.605	2.345
2	170.82	2.416	2.175
3	193.89	2.742	2.468
Mean	182.965	2.588	2.329

## Specimen S50VF0.5%M

### Cubic compressive test result

Specimen	Mass(kg)	Density(kg/m <sup>3</sup> )	$f_{cu}$ (Mpa)
1	8.189	2426.37	36.83
2	8.088	2396.44	38.43
3	8.110	2402.96	40.21
Mean	8.129	2408.59	38.49

## Split tensile test result

Specimen	Maximum load(P)(kN)	$\sigma_t$ (tensile stress) (Mpa)	$f_{ctk}$ (EC2) (Mpa)
1	253.66	3.588	3.2292
2	253.1	3.58	3.222
3	252.54	3.572	3.215
Mean	253.1	3.58	3.222

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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## Specimen S50VF0.5%C

### Cubic compressive test result

Specimen	Mass(kg)	Density(kg/m <sup>3</sup> )	f <sub>cu</sub> (Mpa)
1	7.95	2355.56	39.024
2	8.087	2396.148	40.476
3	8.135	2410.37	39.11
Mean	8.057	2387.36	39.54

### Split tensile test result

Specimen	Maximum load(P)(kN)	$\sigma_t$ (tensile stress) (Mpa)	f <sub>ctk</sub> (EC2) (Mpa)
1	257.72	3.645	3.28
2	246.77	3.49	3.14
3	258.57	3.657	3.291
Mean	254.353	3.598	3.238

## Specimen S50VF1%C

### Cubic compressive test result

Specimen	Mass(kg)	Density(kg/m <sup>3</sup> )	f <sub>cu</sub> (Mpa)
1	8.185	2425.185	42.72
2	8.222	2436.148	45.14
3	8.178	2423.111	40.56
Mean	8.195	2428.148	42.807

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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## Split tensile test result

Specimen	Maximum load(P)(kN)	$\sigma_t$ (tensile stress) (Mpa)	$f_{ctk}$ (EC2) (Mpa)
1	301.015	4.257	3.832
2	315.02	4.456	4.010
3	321.765	4.551	4.096
Mean	312.6	4.421	3.98

## Specimen S50VF1.5%C

### Cubic compressive test result

Specimen	Mass(kg)	Density(kg/m <sup>3</sup> )	$f_{cu}$ (Mpa)
1	8.305	2460.74	35.281
2	8.219	2435.26	36.177
3	8.271	2450.67	36.74
Mean	8.265	2448.89	36.065

## Split tensile test result

Specimen	Maximum load(P)(kN)	$\sigma_t$ (tensile stress) (Mpa)	$f_{ctk}$ (EC2) (Mpa)
1	298.89	4.228	3.805
2	303.95	4.299	3.87
3	309.01	4.37	3.93
Mean	303.95	4.299	3.87

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

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## Specimen S100VF0.5%C

### Cubic compressive test result

Specimen	Mass(kg)	Density(kg/m <sup>3</sup> )	f <sub>cu</sub> (Mpa)
1	8.0295	2379.11	37.44
2	8.12	2405.93	38.833
3	8.06	2388.148	37.523
Mean	8.07	2391.11	37.935

### Split tensile test result

Specimen	Maximum load(P)(kN)	$\sigma_t$ (tensile stress) (Mpa)	f <sub>ctk</sub> (EC2) (Mpa)
1	256.569	3.629	3.2661
2	255.528	3.614	3.253
3	244.671	3.46	3.115
Mean	252.256	3.568	3.211

## Specimen S100VF1%C

### Cubic compressive test result

Specimen	Mass(kg)	Density(kg/m <sup>3</sup> )	f <sub>cu</sub> (Mpa)
1	8.096	2398.815	40.256
2	8.184	2424.89	42.399
3	8.2	2429.63	44.8
Mean	8.16	2417.78	42.4862

# Investigation of the use of steel fibers extracted from used tyres for reinforced concrete beams under cyclic loading

## Split tensile test result

Specimen	Maximum load(P)(kN)	$\sigma_t$ (tensile stress) (Mpa)	$f_{ctk}$ (EC2) (Mpa)
1	320.94	4.539	4.086
2	314.2	4.444	3.999
3	304.12	4.301	3.871
Mean	313.09	4.428	3.986

## Specimen S100VF1.5%C

### Cubic compressive test result

Specimen	Mass(kg)	Density(kg/m <sup>3</sup> )	$f_{cu}$ (Mpa)
1	8.29	2456.3	35.126
2	8.21	2432.6	36.018
3	8.24	2441.48	36.58
Mean	8.247	2443.457	35.9

## Split tensile test result

Specimen	Maximum load(P)(kN)	$\sigma_t$ (tensile stress)(Mpa)	$f_{ctk}$ (EC2) (Mpa)
1	300.01	4.243	3.819
2	308.4	4.362	3.926
3	305.95	4.327	3.895
Mean	304.78	4.31	3.878