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

STUDY ON SHEAR STRENGTH OF CONCRETE MIXED WITH WASTE TIRES STEEL WIRE

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 '**Study on Shear Strength of Concrete Mixed With Waste Tires Steel Wire'** presented by **Misgana Berhanu**, a candidate for the degree of **Master of Science** and hereby certify that it is worthy of acceptance.

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Advisor Signature Date

Internal Examiner Signature Date

External Examiner Signature Date

Chairperson Signature Date

UNDERTAKING

I certify that research work titled “Study on shear strength of concrete mixed with waste tires steel wire” 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.

Migana Berhanu

March 2020

ABSTRACT

In this research, an experimental study has devoted to study the behavioral shear strength mechanism of the plain concrete with waste tires steel wires in two methods; as a fiber by varying fiber volume amount (FB) and as a diagonally tied wire as stirrups (WB). The experimental laboratory research tries to investigate the possibility of using steel fibers and tied wires in enhancing shear capacity in reinforced concrete beams.

The Result of experimental beams shows that waste tire wires tied like a diagonal stirrup develop the shear capacity of the concrete significantly. However, the other scenario which is fibers mixed as an ingredient has negligible effects on shear strength enhancement in plain concrete. This is due to the plain geometry of fibers, which is weak in pull out strength. But, slight improvement in ductility property has observed.

Hence, from the collected experimental result, it is concluded that these materials can be used as a diagonally tied wire (WB) for enhancing the shear strength of concrete. Yet, further studies shall be made to improve the method and quantify the numerical formulation.

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LIST OF ABBREVIATION

ACI	American Concrete Institute
AAiT	Addis Ababa Institute of Technology
AR	Alkali Resistant
ASTM	American Standard Testing Method
BS	British Standard
EBCS	Ethiopian Building Code Standard
FC	First Crack
FRC	Fiber Reinforced Concrete
kN	Kilo Newton
MPa	Mega Pascal
PPC	Portland Pozzolana Cement
SFRC	Steel Fiber Reinforced Concrete
w/c	Water to Cement ratio
agg.	Aggregate
a/d	Span to Depth Ratio
m	Meter
cm	Centimeter
mm	Millimetre
V_c	First Crack Happening Concrete Shear Strength
V_{sd}	Design Shear Strength
Vs	Shear Strength of Stirups
Vay	Shear Due to Aggreagate Interlock
A_v	Cross Sectional Areas of Shear Reinforcement Bar
f_{yd}	Yield Strength of Reinforcement Bar

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CHAPTER 1 INTRODUCTION

Technology has become one of the major research activities in the world to make life easy. In construction technology using locally available materials is one of the methods that simplify the economy. Especially using waste as raw material is substantial activity to meet environmentally friendly and economical technology.

The quantity of waste tire worldwide is increasing highly which becomes a significant problem to be solved. It has been a major problem for managing waste for a few decades and in some cases has involved serious environmental pollution. According to Matador Addis Tyre Factory market demand prediction, Ethiopia's annual tire demand is estimated at around one million pieces. And it is believed that every three years at least one million tires will be discarded resulting in a little over ten thousand tons of waste tires annually (Nasir Bedewi, 2009). The use of wire in the wasted tires as a construction row martial is the major concern of this paper.

In this paper, it has been proposed to study the shear capacity of concrete by using waste tires as a raw material. As of concrete have brittle properties that make the failure sudden. However, it is capable to resist the failure by reinforcement i.e. in the case of collapsing stage the concrete is made to fail in flexure instead of shear which gives time for maintenance.

Accordingly, the experimental methodology is proposed to investigate the shear capacity of the concrete mixed with fibers and diagonally tied wires extracted from waste tires. Five beams are proposed where one of the beams is a control beam the others are experimental beams. Two of the experimental beams are mixed with 8cm pieces of cut wire ("fiber") and the rest are diagonally tied wires which are explained in the methodology part of this paper.

In this thesis diagonally tied wires beams refers to the types of the beam where the extracted tire wires used as shear resisting reinforcement tied from the top to bottom on longitudinal bars and fiber-reinforced beam refers to the beams which are mixed with 8cm extracted fiber wires. The paper is an experimental research to know how the capacities of the wires inside a waste tires can be used for resisting the shear stress.

1.1 Research objective

General objective

- To study the shear strength of concrete tied with extracted waste tires wire as a stirrup without shear reinforcement.
- To study the shear strength of concrete mixed with extracted waste tires wire as steel fiber without shear reinforcement.

Specific objective

- To investigate the shear mechanism of steel wires extracted from the waste tire in the concrete.
- To investigate the shear strength of concrete with different arrangements of wires tied on the reinforced concrete.
- To determine the theoretical equivalent shear strength of concrete with stirrups with experimental beams.
- To demonstrate the influence of steel fiber volume with those of shear cracking, shear strength, compressive strength, ultimate deflection and character of failure mode.

1.2 Research question

This research will answer the following question:

- Can waste tire steel wires be used as a structural part to resist the shear load as part of the concrete?
- Can waste tire steel wire replace the web reinforcement?
- If there is an increment in shear capacity, what will be the possible volume of steel fiber? And in what possible proportion should it be used?
- What will be the effect of waste tire steel fibers on the shear strength of the concrete?
- How can a diagonally tied wire improve the concrete mix?

1.3 Research significance

In reinforced concrete beams flexure is the first criteria to be satisfied depending on the size of the section and the arrangement of reinforcement to provide the necessary moment resistance. Flexural failure develops gradually which ensures warning to the occupant. But in the case of shear, the failure is more brittle and sudden hence most codes insure to have higher shear strength than a flexural strength to notify the failure before the collapse. Though researches have provided many mechanisms for the sake of insuring shear strength of the concrete, this study also add more method to resist enhance shear capacity.

Having another methodology for material is creating a comparative method for resolving a problem. Here in this paper, the main aim is to apply and check extracted wire waste tire materials for enhancing the shear strength of concrete. Though other methods have already responded by using different mechanisms to enhance the shear strength of concrete, like applying shear reinforcement, it is also important to add more methods to strengthen shear capacity.

Moreover, it is known that waste materials have to be controlled properly to control environmental pollution. Using a waste tire wire has a significant role in reusing the material as a row construction ingredient. In Ethiopia, waste tires are retreaded as a form of other products like shoes. Recorded data in the United Kingdom shows that 4.5 thousand tones have discarded annually from this 11 percent are retreaded 38.2 percent are recycled and 15.7 percent are reused as a form of energy. The rest will be wasted which will contribute to environmental pollution. In this research reusing waste tire, has an advanced environmental guaranty (Geo-syntec Consultants, 2009)

1.4 Research scope and limitation

The scope of this research:

- The wires used in this research are extracted by burning Horizon Addis waste tire.

- The research analyzes the shear capacity of waste tire wires in concrete in two scenarios described in the methodology part. Hence, the experimental beam is designed intentionally to fail in the inclined shear crack by increasing flexural strength infinitely.

This research has the following limitation:

- The beams in this study shall be simulated to monotonically-increasing loading. Other loading schemes such as cyclic, reversed cyclic and dynamic loading, which are substantially different from monotonic loading, will not be investigated. The loading shall also be restricted to a single concentrated load.
- This research shall not include the effect of flexural stress on the matrix concrete beam.
- The effect of fiber shape which may affect the bond in concrete and fiber is not included in this research rather only plain fibers will be studied.
- The analyses were done on simply supported beams.

1.5 Research methodology

Tools

- Laboratory experiment

Waste tires with a wire were collected, and then the wire extracted from the waste tires burnet to remove rubbers to arrange for 8cm fibers and stirrup wires. Two sets of beam prepared one a fiber concrete mix set and the other a concrete with arranged stirrup wire set. For the fiber beam scenario, 0.75 percent and 1.5 percent of the volume was mixed with concrete and the second scenario was the beam with the tied with wires as described in the chapter three portion of this paper.

Most literatures suggest different parameters that influence the shear strength. The parameters that have identified from literature are; shear span to effective depth ratio, beam size, length of the beam, and compressive strength of concrete, types of fiber, fiber amount and longitudinal bar. A further study shall be made to distinguish the fixed parameters and variable parameters so that an experimental test will be done.

Measurement of properties of steel fibers reinforced concrete that are extracted from tires will be very important for experimental studies. Therefore an overview of currently available and modified test methods used to evaluate the mechanical properties to study the shear resistance capacity of the mixed material. Though it was tried to study and understand the capacity of the steel used in this paper, the experiment is done only in Horizon Addis Tire which was a limitation for this paper,

The stiffness of fibers, workability of matrix, tensile strength of fibers, quality of sand, quality of aggregate and that of cement was checked by experiment. After all the control beam was designed to fail in shear. An experimental test was investigated on beams with different fiber amounts so the shear resistance capacity with a crack pattern will be studied

This research follows the ASTM standard procedure of experiment and construction laboratory test (Abebe Dinku, 2002). After assuring all the quality tests for the properties of the components used, an experimental study on center point load test was done.

From the experiment data output, detail result and analysis check weather steel wires could increase the shear carrying capacity or not. It is also expected to assess the appropriate amount of steel fibers in a concrete mix by volume which keeps up the shear stress that would be supported by the stirrups. Moreover, the effect of waste tire steel wires tied as inclined stirrups on the shear capacity of the concrete was analyzed.

CHAPTER 2 LITERATURE REVIEW

Beams resist loads primarily through internal moment and shear. In reinforced concrete beams flexure is the first criterion to be satisfied leading to the size of the section and the arrangement of reinforcement to provide the necessary moment resistance. Flexural failure develops gradually which ensures warning to the occupant (James Wight, James Macgregor, 1988). But the case of shear is the failure is more brittle and sudden hence most codes insure to have higher shear strength than a flexural strength to notify the failure before the collapse. The manner in which shear failures can occur varies widely depending on the dimension, geometry, loading, and properties of the members. In this section, the mechanism of shear failure, mechanical properties of SFRC, Properties of tire wire and some related researches result are revised as hereunder.

2.1 Shear failure mechanism

When a beam is subjected to a load, equal shear stress exists on both the horizontal and vertical plane. The principal stress trajectories are steeper near the bottom and flatter near the top of the beam as shown below. Since concrete cracks when the principal tensile stress exceeds the tensile strength of the concrete, the initial crack pattern should resemble the network of lines shown below. After then two types of crack patterns will generate, the vertical crack due to flexure and the inclined cracks due to a combination of shear and flexure which is known as incline cracks, shear cracks or diagonal shear cracks (James Wight, James Macgregor, 1988).

Shear stress in an un-cracked elastic beam can be determined using the moment of inertia of the cross-section, shear force on the cross-section, first moment about the cross-section and width of member where the stress is being calculated (Yoon-Keunkwk, et.al, 2002).

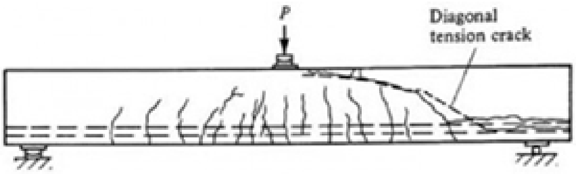


Figure 1: Diagonal crack stress trajectory

(James Wight, James Macgregor, 1988)

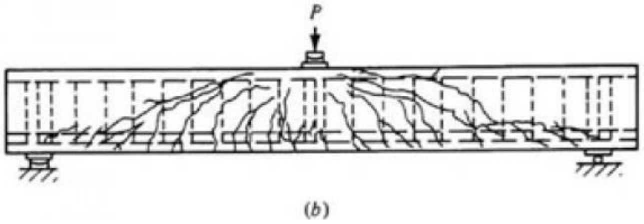


Figure 1: Diagonal crack stress trajectory

(James Wight, James Macgregor, 1988)

2.1.1 Shear failure in reinforced concrete beams

According to EBCS and most international codes agree that shear stress in reinforced concrete can be resisted by aggregate interlock, dowel action, and web reinforcement. The addition of longitudinal reinforcement, as well as web reinforcement, increases the capacity of concrete shear strength.

In the absence of web reinforcement, the tendency of shear capacity highly depends on the shear span to depth ratio. Shear span can be divided into four types: very short, short, slender, and very slender. Very short shear spans, with a/d from 0 to 1, develop inclined cracks joining the load and the support. These cracks, in effect, destroy the horizontal shear flow from the longitudinal steel to the compression zone and the behavior changes from beam action to arch action. The reinforcement serves as the tension tie of a tied arch and has a uniform tensile force from support to support. The most mode of failure in such a beam is an anchorage failure at the end of the tension tie. Short shear span a/d from 1 to 2.5, develop inclined cracks and, after a redistribution of internal forces, can carry additional load, in part by arch action. The final failure of such a beams will be caused by bond failure, splitting failure, or a dowel failure along the tension reinforcement. Because the inclined cracks generally extend higher into the bean than a flexural crack, failure occurs at less than the flexural moment capacity (James Wight, James Macgregor, 1988).

In slender shear span, (a/d) from about 2.5 to 6, the inclined crack disrupts equilibrium to such an extent that the beam fails at the inclined cracking load. Very slender beams with a/d greater than about will fail in flexure before the formation of inclined cracks (James Wight, James Macgregor, 1988).

In general, an RC beam can fail due to either moment or shear action. If the beam is slender, the beam is likely to fail in flexure due to the crushing of the compression region near the point of application of the concentrated load. Before crushing, the longitudinal reinforcement may or may not experience yielding, depending on the amount of reinforcement. If the reinforcement yields extensively, the beam will exhibit a ductile behavior and provide ample warning before failure occurs. If the amount of reinforcement is too small, on the other hand, the reinforcement may fracture before the concrete crushes.

A diagonally-cracked beam may carry shear force through dowel action of the tensile, aggregate interlock, and shear carried in the compression region. Tensile reinforcement carrying shear as a dowel, a mechanism referred to as dowel action, may split the lower portion of the beam from the upper portion over a short length. Aggregate interlock comes from the fact that the crack surface is not smooth, allowing the two protruding portions of the beam to bear against each other and hence, resist shear sliding (Hai Dhin, 2009). Shear resistance from aggregate interlock decreases as the width of the diagonal crack increases. The ability of the compression region to resist shear depends on the degree of penetration of the diagonal crack. There is an interaction between the three shear-resisting components. If any of them fails, a redistribution of internal stresses occurs until all of them fail (Yoon-Keunkwk, et.al, 2002).

2.1.2 Factors affecting shear strength of reinforced beam without shear reinforcement

Beams without web reinforcement will fail when inclined cracking occurs or shortly afterward. For this reason, the shear capacity of such members is taken equal to the inclined cracking shear (James Wight, James Macgregor, 1988). The inclined cracking load of a beam is affected by the following variables:

a. Tensile strength of concrete

The inclined crack load is a function of the tensile strength of the concrete. The stress state in the web of the beam involves biaxial principal tension and compression stress. Similar biaxial states of stress exist in a split cylinder tension test, and the inclined cracking load is frequently related to the strength from such a test. The flexural cracking which precedes the inclined cracking disrupts the elastic stress field to such and extends that inclined cracking occurs at the principal tensile stress.

b. Longitudinal reinforcement ratio

As per the experimental researches effect of reinforcement ratio on the shear capacity of beams without web-reinforcement has been studied and the practical range of reinforcement ratio developing shear failure is 0.0075 to 0.025. when it is small, flexural cracks extend higher into the beam and open wider than would be the case for large values. As a result, inclined cracking occurs earlier.

c. Shear span to depth ratio, a/d

This factor has some effect on the inclined cracking shears of shear span with a/d less than two that is for deep beams. For longer shear spans for slender and very slender, the effect will be less.

d. Size of the beam

As the overall depth of a beam increases, the shear stress at inclined cracking rends to decrease. As the depth of the beam increases, the crack width at points above the main reinforcement tends to increase. This leads to a reduction in aggregate interlock across the crack, resulting in earlier inclined cracking.

e. Axial forces

Axial tensile forces tend to decrease the inclined cracking load, while axial compressive forces tend to increase it. As the axial compressive forces tend is increased, the onset of flexural cracking is delayed and the flexural cracks do not penetrate as far into the beam.

2.1.3 Shear failure of the reinforced concrete beam with stirrups

Inclined cracks make the strength of the beam to drop below the flexural capacity. The purpose of stirrups is to ensure a full development in flexural capacity. Before incline cracking, the strain in the stirrup is equal to the corresponding strain in the concrete. Since, concrete cracks at very small strain, the stress in the stirrups before incline cracking. Stirrups do not prevent inclined cracks from forming; it come into play only after the crack has formed (James Wight, James Macgregor, 1988).

The main role of the stirrup reinforcement is to carry the redistributed shear stresses, mainly through tension, after the formation of diagonal cracks. This tension is transferred back to the concrete, which may lead to the formation of additional diagonal cracks. Stirrup reinforcement also slows down the propagation of diagonal cracks, which helps the compression region sustain shear force. It is also effective in preventing a premature splitting failure along the tensile reinforcement (Hai Dinh, 2009). Also, stirrup reinforcement controls crack opening, and hence, helps aggregate interlock resist shear. After the formation of diagonal cracks, there is an interaction among the four main contributors to shear resistance: tensile reinforcement through dowel action, concrete compression region, aggregate interlock, and stirrup reinforcement (Yoon-Keun Wak, 2002).

Before the flexural cracking, all the shear is carried by the untracked concrete. Between flexural and inclined cracking, the external shear is resisted by aggregate interlock (V_{ay}), compressive strength of concrete (V_{cz}) and dowel action (V_d). Eventually, the stirrup(V_s) crossing the crack yield stay constant for higher applied shear. As the inclined crack widens, V_{ay} decreases further, forcing V_d and V_{cz} to increase at an accelerated state until either a splitting (dowel) failure occurs, or the compression zone crashes due to a combination of shear and compression (James Wight, James Macgregor, 1988).

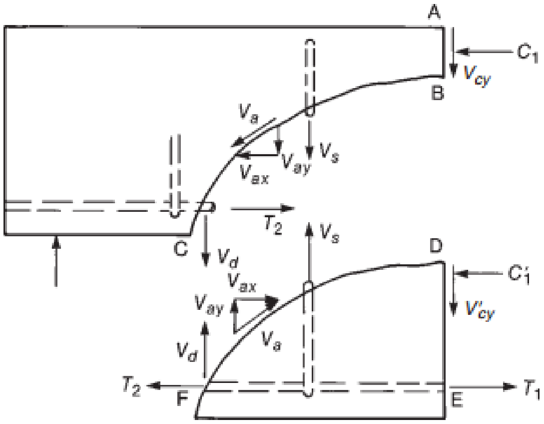


Figure 2: Internal force in a cracked beam with stirrups.

(James Wight, James Macgregor, 1988)

2.2 Fiber-reinforced concrete

Fiber-reinforced concrete (FRC) is concrete made primarily of hydraulic cements, aggregates, and discrete reinforcing fibers. Fibers suitable for reinforcing concrete have been produced from steel, glass, and organic polymers (synthetic fibers). As per ACI 554 code the length and diameter of fibers used for FRC do not be more than 76mm and 1mm respectively (ACI 544, 1997)

The primary role of steel fibers is to bridge cracks due to tension in the concrete. Depending on bond strength, the fibers can either fracture or pull out of the concrete as cracks open (Nasir Bedewi, 2009). The latter form of failure is more favorable because SFRC will be more ductile and absorb a greater amount of energy. The development of different types of steel fibers has been driven by the desire to improve bond characteristics between steel fibers and concrete (ACI 544, 1997).

The primary source of bond for fibers comes from the friction between the fibers and concrete. Therefore, fibers with a higher surface area to volume ratio have higher bond strengths. Thus, fibers with rectangular sections are more efficient than fibers with circular sections and for the same fiber length, fibers with smaller diameters are more efficient (Nasir Bedewi, 2009).

Bond strength between steel fibers and concrete can be greatly improved by introducing deformations in fibers. The common types of deformed steel fibers are crimped fibers with a sinusoidal shape along its length, stranded fibers with enlarged ends, hooked fibers with deformed ends, and twisted fibers (Nasir Bedewi, 2009).

When being pulled out, the ends of a hooked steel fiber must bend significantly and yield before the fiber can be pulled out of the concrete. This process allows SFRC with hooked steel fibers to absorb a great amount of energy before a complete failure. In this sense, a hooked steel fiber with a higher yield strength will produce a stronger composite. (ACI 544, 1997).

It should be noted that changing the fiber cross-section, increasing fiber aspect ratio, or introducing mechanical anchorage does not always improve the fiber-matrix bond strength because these changes may result in an SFRC mix with inadequate workability and fiber distribution.

2.2.1 Types of fibers

There are different kinds of fibers used in construction industries. Classifications have made depending on their material composite and shape of production. In each classification, there are some limitations and advantage.

Fibers can be classified as glass fibers, synthetic fibers, natural fibers, and steel fibers depending on the material they have made. Glass fiber is a predominantly used mineral fiber. Glass fibers have relatively high tensile strength and modulus of elasticity compared to polymeric fibers. Using the conventional mixing technique for normal concrete, it is not possible to mix more than about two percent by volume of fibers of length up to 25 mm. Synthetic fiber reinforced concrete utilizes fibers derived from organic polymers which are available in a variety of formulations. Even though these fibers have reasonably high tensile strength, the modulus of elasticity of most of them is quite low. Commercial use of SNFRC currently exists worldwide, primarily in applications of cast-in-place concrete such as slabs-on-grade, pavements, and tunnel linings and factory manufactured products such as cladding panels, siding, shingles, and vaults. Since in many parts of the world manmade fibers like steel or polymeric fibers are not available, attempts have been made to incorporate naturally occurring fibers extracted from plants in cement-based composites. A unique aspect of these fibers is the low energy needed for their extraction. A major problem in the use of these fibers in cement/concrete matrix is that they disintegrate in the alkaline environment and hence durability of the composite is the matter of concern. Since these fibers are economical, attempts have been made to overcome the problem of durability either by the use of admixtures in concrete to reduce its alkalinity or by protecting fibers by some special treatment. Steel fiber reinforced concrete is concrete made of hydraulic cement containing fine or fine and coarse aggregate and discontinuous discrete steel fibers. These fibers will be covered in the next section (ACI 544, 1997).

ASTM A 820 provides a classification for four general types of steel fibers based upon the product used in their manufacture (ASTM A820, 2004). This is cold drawn wire, cut sheet, melt extracted. The Japanese Society of Civil Engineers has classified steel fibers based on the shape of their cross-section as square section, circular section and crescent section (Hai Dinh, 2009). ACI 544 classifies fibers depending on their geometry, as straight deformed, crimped, flattened, machined and melt extracted (ACI 544, 1997).

2.2.2 Properties of steel fiber reinforced concrete

2.2.2.1 Physical property

The fiber strength, stiffness, and the ability of the fibers to bond with the concrete are important fiber reinforcement properties. Bond is dependent on the aspect ratio of the fiber. Typical aspect ratios range from about 20 to 100, while length dimensions range from 6.4 to 76 mm (ACI 544, 1997).

Steel fibers have a relatively high strength and modulus of elasticity, they are protected from corrosion by the alkaline environment of the cementitious matrix, and their bond to the matrix can be enhanced by mechanical anchorage or surface roughness (ACI 544, 1997). Long term loading does not adversely influence the mechanical properties of steel fibers. In particular environments such as high-temperature refractory applications, the use of stainless steel fibers may be required. Various grades of stainless steel, available in fiber form, respond somewhat differently to exposure to elevated temperature and potentially corrosive environments.

ASTM A 820 establishes minimum tensile strength and bending requirements for steel fibers as well as tolerances for length, diameter (or equivalent diameter), and aspect ratio. The minimum tensile yield strength required by ASTM A 820 is 345 MPa (ASTM A820, 2004).

2.2.2.2 Mechanical properties of steel-reinforced concrete

a. Direct tensile strength

A tension specimen of that size often poses difficulty in the design of fixtures to grip the ends of the specimen. Therefore, direct tensile test results are usually significantly scattered. The strain is also difficult to interpret because after cracking, the average strain is due primarily to local crack opening. Therefore, the selection of gauge length also affects the measured average strain. In recent direct tensile test results, researchers tend to report the deformation in terms of crack width or extension, particularly for strain-softening materials.

As per ACI 544, direct tension improvement in strength is significant, with increases of the order of 30 to 40 percent reported for the addition of 1.5 percent by volume of fibers in mortar or concrete (ACI 544, 1997).

b. Flexural strength

Increases in the flexural strength of SFRC are substantially greater than in tension or compression because the ductile behavior of the SFRC on the tension side of a beam alters the normally elastic distribution of stress and strain over the member depth. The altered Stress distribution is essentially plastic in the tension zone and elastic in the compression zone, resulting in a shift of the neutral axis toward the compression zone (ACI 544, 1997).

A summary of corresponding strength data shows that the flexural strength of SFRC is about 50 to 70 percent more than that of the unreinforced concrete matrix in the normal third-point bending test (ACI 544, 1997). The use of higher fiber volume fractions, or center-point loading, or small specimens and long fibers with significant fiber alignment in the longitudinal direction will produce a greater percentage increases up to 150 percent. At lower fiber volume concentrations, a significant increase in flexural strength may not be realized using beam specimens.

c. Compressive strength

As per the ACI 544 code, the ultimate compressive strength slightly affected by the presence of fibers, with observed increases ranging from 0 to 15 percent for up to 1.5 percent by volume of fibers (ACI 544, 1997).

d. Shear and torsion strength

Steel fibers generally increase the shear and torsion strength of concrete, although little data are dealing strictly with the shear and torsion strength of SFRC, as opposed to that of reinforced beams made with an SFRC matrix and conventional reinforcing bars. The increase in strength of SFRC in pure shear has been shown to depend on the shear strength testing technique and the consequent degree of alignment of the fibers in the shear failure Zone. For one percent by volume of fibers, the increases range from negligible to 30 percent (ACI 544, 1997).

Steel fibers have several potential advantages when used to augment or replace vertical stirrups in beams. The random distribution of fibers throughout the volume of concrete at much closer spacing than is practical for the smallest reinforcing bars which can lead to distributed cracking with reduced crack size. The first-crack tensile strength and the ultimate tensile strength of the concrete may be increased by the presence of fibers and the shear-friction strength is increased by resistance to pull-out and by fibers bridging cracks (ACI 544, 1997).

e. Bond between steel fibers and concrete

In composite systems such as FRC, the mechanical behavior depends not only on the properties of the fibers and the cementations systems but also on the bonding between them. For properly designed FRC mixtures, the primary mode of failure is by fiber pullout, since this consumes much more energy than is involved in breaking the fibers and leads to much better utilization of the fibers. For steel fibers, there is a combination of adhesion, friction, and mechanical interlock. For glass fibers, there is a chemical reaction between the cement and the glass; in particular, alkali attack tends to weaken the fiber reinforcement, though to a much lesser extent with the alkali-resistant glasses. With the organic fibers, the bond is primarily due to mechanical interlock. (ACI 544, 1997).

From the pullout tests of fibers embedded in a cement-based matrix, an increase in matrix strength resulted in an increase in bond strength and a faster deboning. Pulling out a hooked steel fiber required a work that was four times greater than that required for a smooth steel fiber. The slip at peak load when pulling out a hooked steel fiber was up to two times greater than that for a smooth steel fiber (ACI 544, 1997).

2.2.2.3 Properties of tires wire

The diameter of the wire is 0.89mm. From a former research on tires, an average tensile strength of 970.2 and 1892.6 MPa has found for the extracted tires wire and Original tires wires respectively (Nasir Bedewi, 2009). The tensile strength of the extracted tires has decreased nearly by half, 48.7 percent, from that of original tire wires (Fauzan Fauzan, 2018). The lower value is mainly due to the burning process. The test results obtained for the extracted tires wire is highly variable compared to the Original tires wires, as the tires were burnt under uncontrolled temperature. However, the obtained results are in good agreement with specification in ASTM A820 which stated, 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 (ASTM 820, 2004).

Generally, the addition of steel fibers significantly improves many of the engineering properties of concrete. Though modest improvements in strength can be obtained, the primary purpose of steel fiber inclusion to concrete is to increase toughness and ductility. Steel fiber inclusion also increases the resistance to dynamic loading (Nasir Bedewi, 2009). Properties of SFRC in both the freshly mixed and hardened state, including durability, are a consequence of its composite nature. Today steel is the most commonly used fiber type for concrete reinforcement. SFRC has a wide range of applications ranging from industrial floors to airport runways, from cast in place application to precast elements, from vaults and safes to heavy machinery foundation (ACI 544, 1997).

2.2.2.4 Factors affecting the shear strength of steel fibered reinforced concrete

The shear strength of SFRC can be affected by different factors. Some of the factors that affect the shear strength of the concrete are listed below:

i. Fiber stiffness

The modulus of elasticity of matrix in most cases is lower than that of fiber for efficient stress transfer. The interfacial bond between the matrix and the fibers also determines the effectiveness of stress transfer, from the matrix to the fiber. A good bond is essential for improving the tensile strength of the composite. The interfacial bond could be improved by a larger area of contact, improving the frictional properties and degree of gripping and by treating the steel fibers (Hai H. Dihn, 2009)

ii. Fibers volume

The effect of using steel fibers in the concrete is typically studied by varying fiber volume fraction and the type of fiber, which includes changing the fiber aspect ratio, fiber length, and fiber strength. The effect of fiber volume fraction has been intensively investigated (ACI 544, 1997). The strength of the composite largely depends on the number of fibers used in it. The increase in the volume of fibers, increase approximately linearly, the tensile strength and toughness of the composite. It has been reported that the use of a higher percentage of fibers is likely to cause segregation and harshness of concrete and mortar.

iii. Fibers aspect ratio

It has been reported that up to an aspect ratio of 75, an increase in the aspect ratio increases the ultimate strength of the concrete linearly. Beyond 75, relative strength and toughness is reduced (Nasir Bedewi, 2009)

iv. Fibers orientation

One of the differences between conventional reinforcement and fiber reinforcement is that in conventional, bars are oriented in the direction desired while fibers are randomly oriented. To see the effects of randomness, mortar specimens reinforced with a 0.5 percent volume of fibers were tested. In one set specimens, fibers were aligned in the direction of the load, in another along the direction perpendicular to that of the load, and in the third randomly distributed. It was observed that the fibers aligned in the direction of the applied load offered more tensile strength and toughness than randomly distributed or perpendicular fibers (Fauzan Fauzan,2018).

v. Shear span to depth ratio

Beams with a smaller span-to-depth ratio can resist more shears. This is due to arch action, which is the direct transfer of the load to the support through a compressive strut (Yoon-Keun Kwak, et.al, 2002)

vi. Longitudinal reinforcement ratio

The effect of reinforcement ratio on the shear capacity of beams without web reinforcement has been studied and the practical range of reinforcement ratio developing shear failure is 0.0075 to 0.025 (ACI 318, 2003). When it is small, flexural cracks extend higher into the beam and open wider than would be the case for large values. As a result, inclined cracking occurs earlier.

vii. Concrete grade

Increasing the concrete grade increases the bond between fibers and the matrix. From the pullout tests of fibers embedded in a cement-based matrix, an increase in matrix strength resulted in an increase in bond strength and a faster deboning. Pulling out a hooked steel fiber required a work that was four times greater than that required for a smooth steel fiber. The slip at peak load when pulling out a hooked steel fiber was up to two times greater than that for a smooth steel fiber (Hai Dinh, 2009).

viii. Size of coarse aggregate

Concerning the effect of aggregate size, it is commonly believed that beams made of concrete containing greater aggregate sizes have higher shear resistance due to increased aggregate interlock. However, in reinforced SFRC beams, this might not necessarily be conservative because smaller aggregate sizes tend to cause less disturbance to the bond between fibers and the concrete matrix and thus, may lead to an increase in shear strength (ACI 544, 1997).

CHAPTER 3 EXPERIMENTAL PROGRAM

3.1 General

In this experimental research methodology, two methods were taken into consideration; the first method studies the concrete mixed with fibers with volume amount fraction of 0.75 percent and 1.5 percent whereas the second method was concrete with a diagonally tied wire made from extracted tires with center to center spacing 15cm and 30cm. To be consistent in the experimental research all other parameters were made to be fixed. The control beam was used as a benchmark to compare with the other experimental beams. It is nominated as CB.

The experimental program strives to answer the following question:

- Is there a shear strength improvement in the matrix of concrete with fibers/wires extracted from the tire?
- Is there a shear strength dependency in the concrete mix with varied fiber volume in the mix?
- Can fibers extracted from tire be used in the replacement of stirrups? If positive, how?
- What is the relation between the volume amount fraction of fibers and inclined stirrup wire with the shear strength of the concrete mix?
- How the shear mechanism does held in fiber reinforced concrete and diagonal wire stirrups?

3.2 Fixed and variable parameters

As it is discussed in the literature review part different parameters affect the shear capacity of concrete. Cross-section, effective depth, concrete grade, steel grade, fiber type, fiber orientation, fiber geometry, fiber volume, shear span to effective depth, reinforcement grade, reinforcement ratio are the identified parameters from the literature. Measurement of the properties of these parameters is very important for controlling the experiments. Accordingly, separating the fixed and variable parameters helps to know the difference between the control beams with that of the other beams. Hence, in this experimental methodology fixed parameters for studies are listed as below in the table.

Table 1: Fixed parameters

Fixed parameters	Description	Remark
Cross-section	Rectangle	
Depth (D)	250mm	
Breadth (B)	200mm	
Concrete Grade	C-25/20	EBCS-code
Steel Grade	S-400	EBCS-code
Types of fiber	Extracted from tire	
Fiber Length	80mm	
Fiber orientation	Random	
Fiber Geometry	Straight	
Shear span to effective depth ratio (a/d) of beam	3.0	Slender Beam

In this research, the variable parameters were fiber volume in the first method and wire spacing in the second method. All the other parameter was made to be fixed. Properties of each experimental beam specimen will be discussed in the next section.

3.3 Design of beam specimen

To meet the objective of this research all beams designed to fail in shear as to know the difference with the control beams. The capacity of the shear and flexure in the fixed parameters above is checked in appendix A. The control beam CB concrete shear strength is 3.14 times lower than the flexural strength. Accordingly, the beam is expected to fail in shear before the flexural failure load is happening.

As is indicated in the figure below the second and third beams which are nominated by FB-1 and FB-2 were mixed with fibers with a volume amount ratio of 0.75 percent and 1.5 percent respectively. This beam shows the capacity of fibers to resist the diagonal shear stress. The fourth and fifth experimental beams which are nominated by WB-1 and WB-2 were diagonally tied wire beams with a spacing of 300 mm and 150mm respectively.

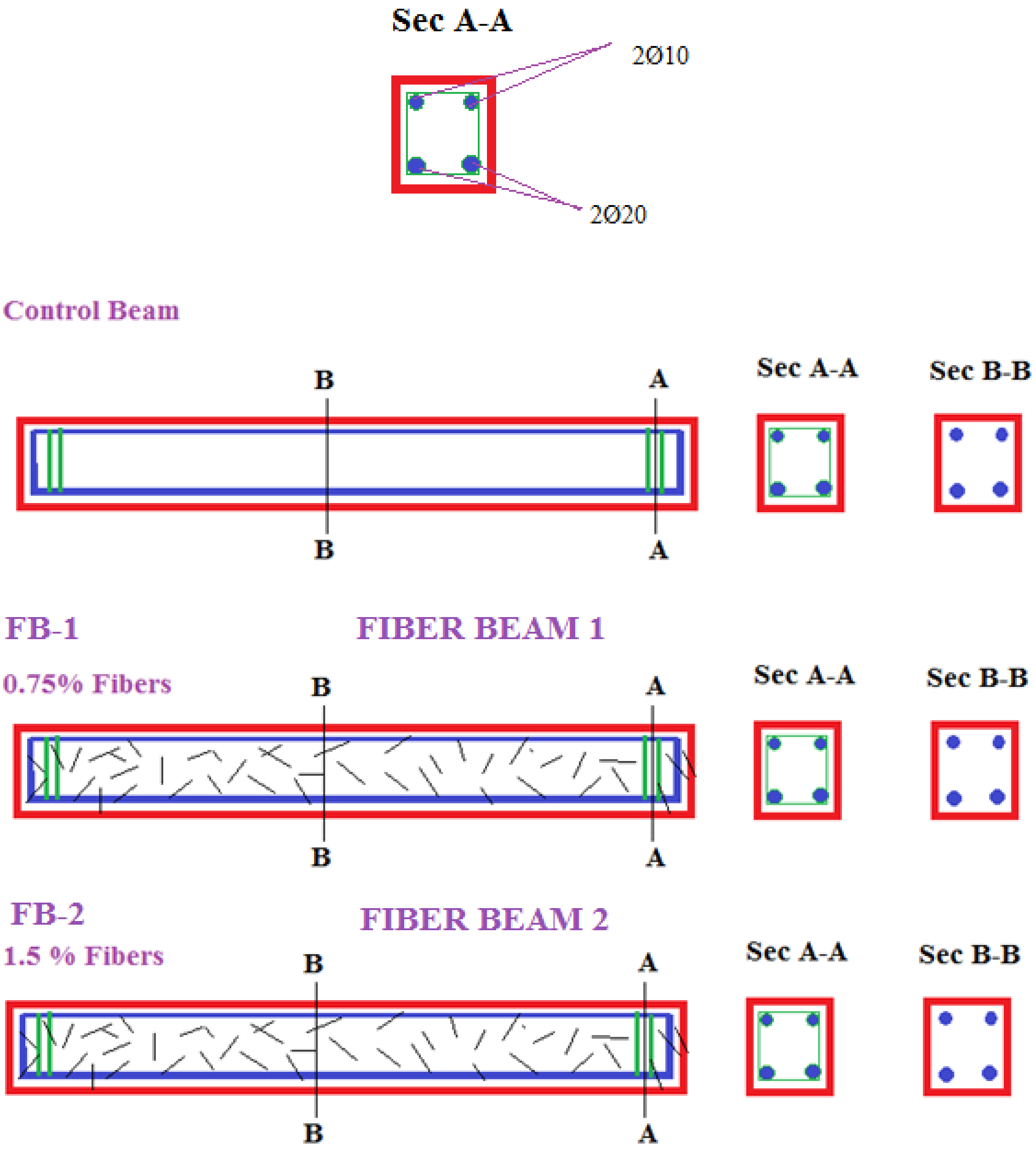
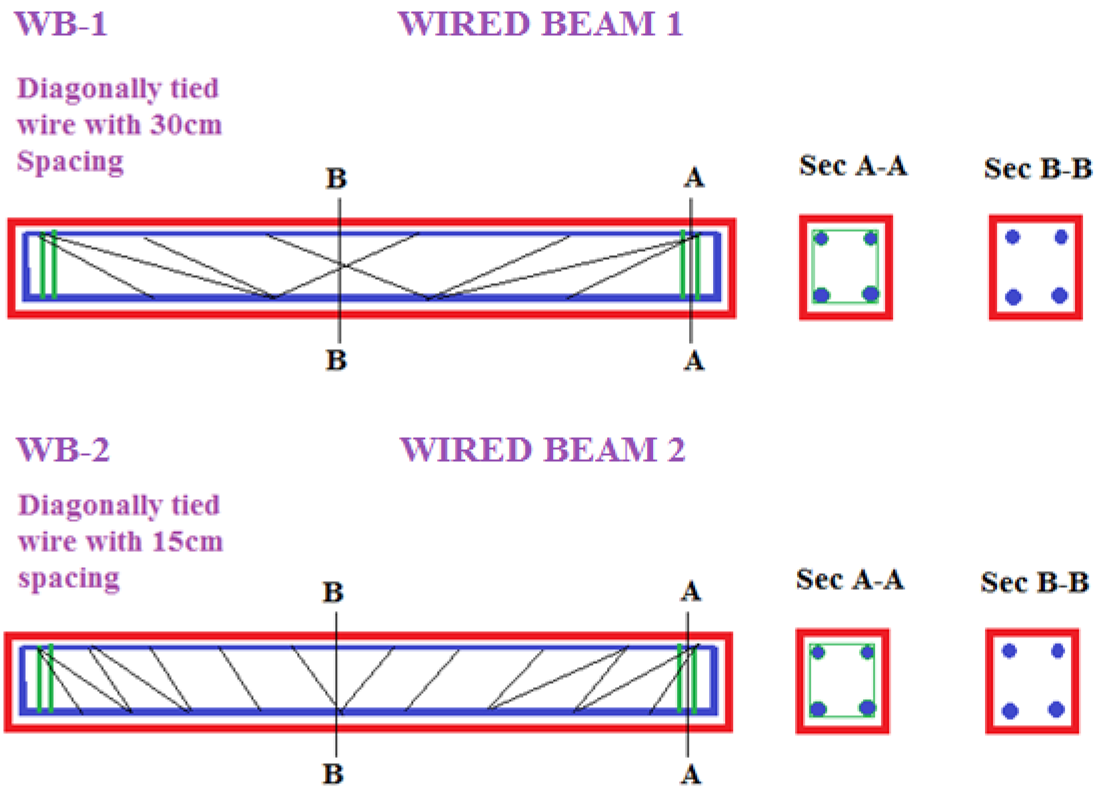


Figure 3: Proposed experimental beam representative sketch



Proposed experimental beam representative sketch (Cont'd)

3.4 Experimental materials

3.4.1 Concrete

The quality of the materials used to make the concrete was checked in the laboratory. OPC cement in the fabrication of Debra Cement is mixed to make a C-25 concrete. ACI mix design is adopted to proportion the mixes. The concrete mix designed with a slump of 7 to 10 cm with a 28 days compressive strength of 25MPa with water to cement ratio of 0.62. Appendix B shows the mix design procedures.

Table 2: Mix design and preparation of materials

Standard	Value	Remark
Concrete grade	C-25	
Compacted unit weight coarse agg.	1651.74gm	
Bulk specific gravity fine agg.	2.58	
Fines modulus	2.54	
Slump	7cm to 10cm	Beam
Max size of agg.	25mm	
Air content	Non-air-entrained	
w/c	0.62	C-25
Dry rod coarse agg. volume	0.65	Finesse modulus & max agg. size
Concrete	2375kg/m^3	C-25
Weight of water	193kg/m^3	Slump with max agg. size
Weight of cement	314.52kg/m^3	Weight of water
Weight of coarse aggregate	1073.63kg/m^3	Dry rod with compact unit weight
Weight of fine aggregate	791.85kg/m^3	

3.4.2 Aggregates

Locally available aggregates have been used as a raw material. The silt content of the original sample in the fine aggregate was found to be 9 percent which is well higher than the allowable limit. As a result, it was washed and dried in the laboratory. Thereafter, it was blended to meet the qualified requirements of the Ethiopian standard.

Table 3: Physical property of coarse aggregate and fine aggregate

Physical property	Coarse aggregate	Fine aggregate
Silt content: Before washed		9.00
Silt content: After washed		1.32
Moisture Content	1.16	0.81
Absorption Capacity	1.60	0.80
Bulk Specific Gravity	2.64	2.60
Apparent Specific Gravity	2.63	2.70

The coarse aggregate used for the preparation of the specimens was crushed basaltic stone with a maximum size of 25mm. The aggregate was initially screened using a 19mm sieve. And then it was washed and dried and kept in the laboratory. Sieve analysis results, specific gravity, and absorption, unit weight, moisture content, silt content are presented in appendix C.

Table 4: Sieve analysis for coarse aggregate and fine aggregate

Sieve size	Percentage passing	
	Coarse aggregate	Fine aggregate
37.5mm	100	
25mm	95.4	
19mm	55.0	
12.5mm	25.4	
9.5mm	03.1	100
4.75mm	00.1	98.6
2.36mm		94.6
1.18mm		84.8
600 µm		56.0
300 µm		10.0
150 µm		01.4
Pan		0
Fines Modules		2.55

3.4.3 Water

Portable water has been used for all concrete mixes.

3.4.4 Cement

Ordinary cement (OPC) fabricated from Derba cement has been used.

3.4.5 Reinforcement bars

The experimental design beam specimen is expected to fail in shear rather than in flexure to satisfy the objective of this research. Hence the proposed beam has 20mm and 10mm diameter longitudinal tension and compression zone reinforced bars respectively. For the case of resisting crushing on the end of the beams, 8mm stirrups were fitted. The bars product of turkey except 8mm bars which were Akakis Factory Product. The strength of the bars was checked as the table.

Table 5: Tensile strength result for reinforcement bar

Specimen code	Specimen No	Diameter(mm)		Yield Load (kN)	Yield stress (kN)	Failure Load (kN)	Failure stress (kN)	Elongation (%)
		D1	D2					
1	1	19.2	22.3	183.6	634.13	216.5	747.77	12.5
	2	19.02	22.26	182.9	643.73	214.8	756.00	12.3
	3	19.07	22.32	180.03	630.31	211.7	741.19	11.3
	mean	19.10	22.29	182.18	636.06	214.33	748.32	12.03
2	1	9.18	10.65	37.33	523.56	46.13	690.52	9.5
	2	9.3	10.93	38.1	545.28	53.31	676.21	11.1
	3	9.2	10.69	35.2	530.21	52.12	655.12	10.4
	mean	9.23	10.76	36.87	533.02	50.52	704.05	10.33

Figure 4: Reinforcement bar test

3.4.6 Fibers/Wires

To be consistent with the diameter and the strength of the extracted wires the production of the tires has to be from the same source which is Horizon Addiss Tyre Factory. The tires were purchased from suppliers who use the rubber as raw material for different products like toilet walls as a septic tank. The raw rubber is then burnet to extract wires.

Figure 5: Extraction of wires from waste tire

Three types of steel fiber diameters are investigated depending on the type of cord used in the tires which are steel cords twisted together into a core strand of 0.81 and 0.83 mm as well as a bead wire with a diameter of 0.84 mm. Among these, only the latter was used in this research to have a consistent diameter.

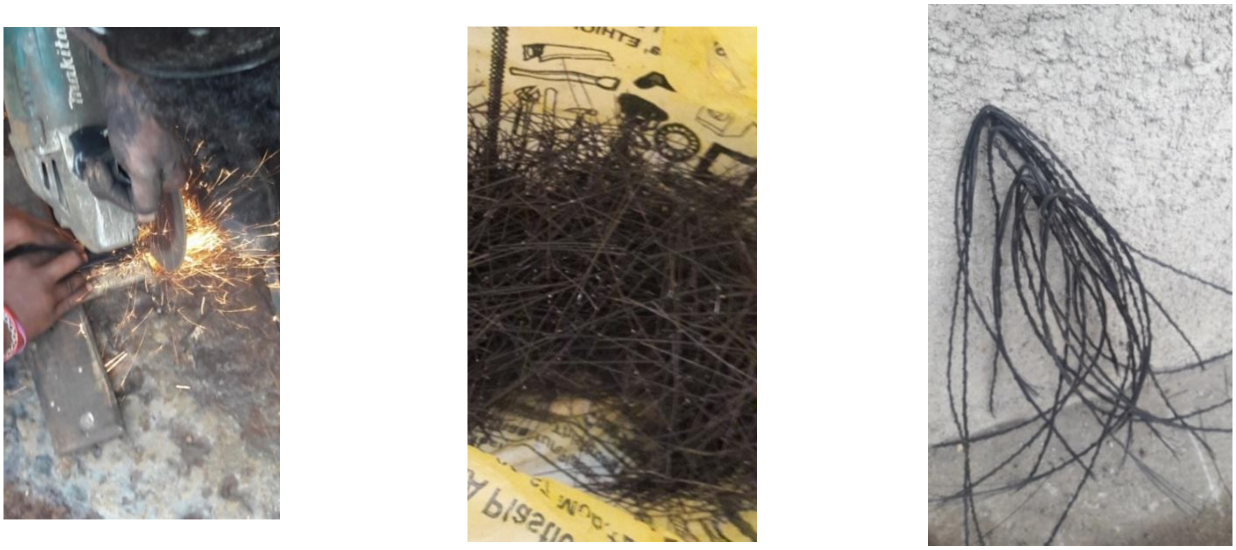


Figure 6: Preparation of fibers and tied wires

The fibers were prepared by cutting the bead wire into a length of 80 mm. the wires are sensitive to moisture which will rust easily. Accordingly, the placement is a very dry place where it is not exposed to moisture.

The wires that will replace as stirrups for the second method are prepared as in the figure shown. There are ten wires in each tie. Black wire is tied to hold the wires together.

3.5 Experimental specimen fabrication

Reinforcements were prepared as per the design proposed. Formwork was oiled and blocked before the placement of the reinforcement cage. A concrete cover of 2.5mm was prepared to tie on the reinforcement bars.

The quality of the material has been checked for each gradient as per the mix design proposed on the appendix C. Each ingredient that is the water, cement, fine and coarse aggregate were weighed and prepared. The figure shows the laboratory site ready for casting.

Figure 7: Preparation of concrete and reinforcement beam

3.6 Experiment specimen preparation

3.6.1 Mixing

For concrete mixed, cement and sand were mixed until a uniform color was seen throughout the mix. Coarse aggregates were then thrown in the mixing drum and mixed until they blended well with the cement and sand. Water was next gradually poured into the mixing drum and mixed until reaching a uniform consistency. Similar to the inclusion of water, steel fibers were added to the rotating drum gradually until they were well-dispersed in the fresh concrete.

Figure 8: Mixing and casting

3.6.2 Casting

Concrete was poured and compacted layer by layer. Each layer had a thickness of approximately 10cm. Even though good workability was obtained for all mixes, fiber congestion was observed in the regions with clear spacing between reinforcing bars substantially less than the fiber length.

3.6.3 Curing

After casting, all beam specimens were moist-cured. Despite the humid weather condition, the beams were watered day-to-day. Side formwork was dismantled after 16 hour's days and cured until 28 days test.

3.6.4 Instrumentation

All beams were fully instrumented to measure the applied loads and deflections on the beams. In brief, the instrumentation consisted of a load cell which measures the applied load, deflection measurement tool to measure the mid-span deflection. All of the instrumentations were connected to a data logger and the experimental data was directly obtained in a disk.

Figure 9: Measuring tools for center point load test

3.7 Experimental test setup

The experimental beams are positioned on roller support connected with steel plate for test. Hydraulic jack which is supported by infinitely stiffened steel from above is made to apply concentrated load in the center of the beam. The maximum capacity of the Hydraulic jack is 320 kN. The load cell which was under the hydraulic gauge records the amount of load applied to the specimen beam. The rate of the load applied to the beam is 0.233 to 0.65 kN/s, which means the loading rate was in between the static and earthquake loading effect. A bar was hanged on beam which is drilled on the support where no deflection is expected. The deflection and load cells are connected to the data logger to collect the data recorded.

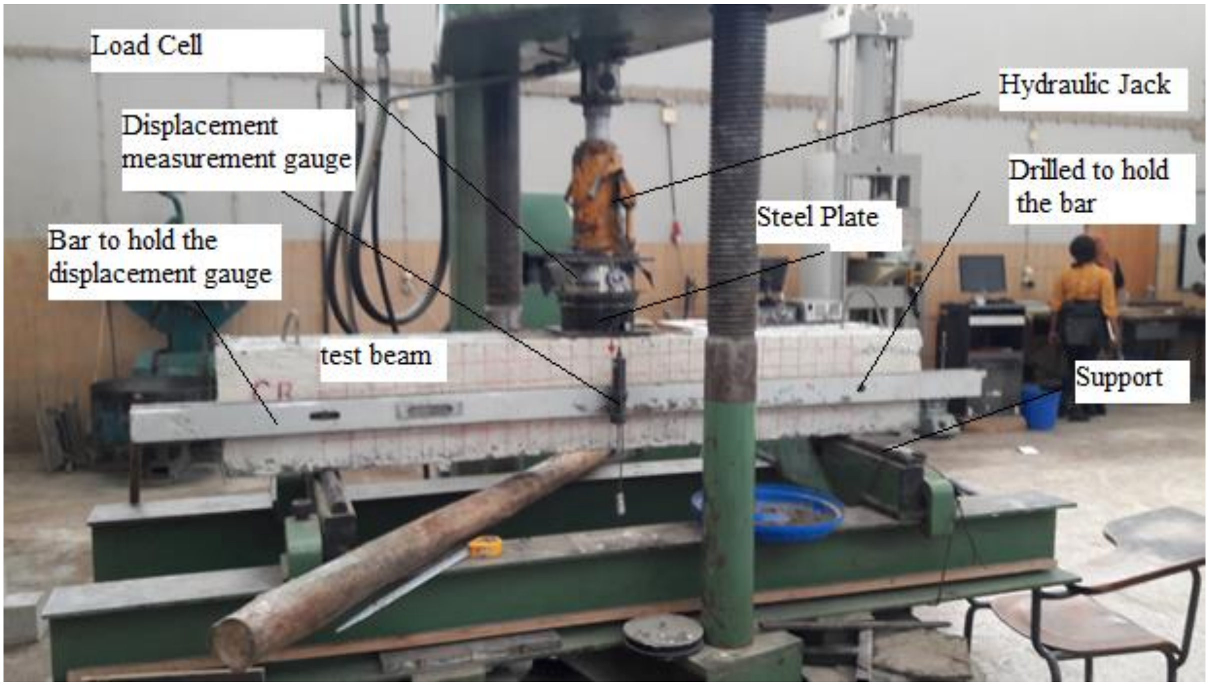


Figure 10: Test setup of one-point load test

Figure 11: Specimen ready for center point test

CHAPTER 4 RESULT AND DISCUSSION

4.1 Discussion on experimental specimen

All the experimental beams are made to fail in inclined shear as it is described in the methodology part of this paper. The beam has strengthened in flexure by increasing the reinforcement to be extremely high so that the specimen can fail in shear before it reaches its strength for flexure. The addition of fibers or wire to concrete without shear reinforcement can clearly show the difference in strength with the control beam.

Center point load test was conducted for each experimental specimen. From the experimental result, it is found that the addition of fiber material has no significant effect on the shear strength of plain concrete while adding this material as a stirrup increases its strength.

Five beams specimen for the experiment has been taken; the first beam is the control beam which has no stirrup or any other material to resist the shear stress except plain concrete with longitudinal bars.

Figure 12: Control beam

In this beam two types of crack happened, hair-like vertical cracks begun just at the bottom of the concentrated load around the center of the beams with a load of 56.2 kN, then after a while inclined cracks generated from the right support with a load of 121.5 kN. The beam does not sustain for a long time. It collapses suddenly with a maximum wide crack of 23mm at a load of 151.06 kN. The first inclined crack happened with an angle of 11.3^0 and finish with an angle of 38.65^0.

In the second and third beam, which is FB1 and FB2 where concrete beams mixed with steel fibers that are extracted from tires in a volume amount of 0.75 percent and 1.5 percent respectively, the former percentage volume is selected concerning the ACI 544.1R96 recommendation while the latter is because of bowling observed which affect the workability.

Figure 13: Fiber beam (FB-1)

As it is proposed in the methodology section the first scenario of the experimental beam is beams with 8cm fibers which are extracted from tire wires. FB1 beams which have an additional 0.75 percent fibers test was carried out. The first cracks at the load and deflection of 124.88kN and 2.3mm respectively. And the other beam FB-2 performs better resistance with a first inclined crack load of 141.3kN at a deflection of 2.6 mm.

Figure 13: Fiber beam (FB-1) (count'd)

This beam shows less difference in resistance for the shear crack, almost negligible effect on the cracking resistance capacity but the beams modified the ductility property of the concrete.

Figure 14: Fiber beam (FB-2)

The other set of experimental beams has an inclined tied wire as stirrups. In the first beam which is 15cm spacing (WB-1) first flexural cracks happened at the load of 136.8 kN with a deflection of 2.6 mm. As the hairy flexural cracks get wide the inclined cracks start to generate from the left support, meanwhile, hairy inclined cracks generate at the right also with a load of 148.5 kN and a deflection of 2.8 mm. In this beam inclined cracks generate from two different points both in the left and right side of the beam, the first one in the angle of 35.5^0 and the other one in the angle of 63.4^0 Then the two inclined cracks meet at a vertical distance of 110 mm from the bottom of the beam. A meanwhile a wide sudden crack happened at a load of 208.58 kN and deflection of 6.1mm.

Figure 15: Wire tied beam (WB1)

The second beam of this scenario is beams with 30cm spacing nominated as WB-2. This beam has a greater resistance capacity more than all of the experimental beams. In this beam, the first flexural crack happened at the load of 142.06kN and a deflection of 2.535mm. Six flexural cracks are observed which can notify maintenance for the host. An inclined crack happened at a load and deflection of 197.44kN and 4.34mm respectively.

The experimental result shows there is an improvement in the shear capacity of the beam better than the control beam. All the other specimen beams take place the first crack at a greater load than the control beam.

Figure 16: Wire tied beam (WB2)

4.2 Compressive strength

Concrete cubes of 15cmx15cmx15cm have been tested to check the effect of compressive strength in the case of concrete mixed with fibers. The concrete is poured in the mold and tempered properly so as not to have any voids. After 24 hours these molds are removed and were allowed for curing in a curing tank for 28 days and they were tested.

As it is shown in the table below the compressive strength 0 percent, 0.75 percent mix, and 1.5 percent mix of the concrete. From the experimental data, the result for compressive strength cube test of 0 percent, 0.75 percent and 1.5 percent volume of fibers is shown in the above table. The average compressive strength of 1.5 percent fiber has better strength with 28.34 MPA. Moreover the addition of the fiber increase the compressive strength of the concrete. This is because of the surface bondage strength formed by the fiber to connect two elements of concrete gives the concrete additional binding strength.

Table 6: Result for compressive strength

Type	Trial	Curing day	Dimension (cm)			Weight (gm)	volume (cm3)	Failure Load (kN)	Comp. Strength MPa	Unit weight (gm/cm3)
			L	H	W					
0 percent	1	28 days	15	15	15	8134	3375	606.25	26.94	2.41
	2		15	15	15	8146	3375	587.96	26.12	2.41
	3		15	15	15	8184	3375	573.26	25.47	2.42
	Mean							589.19	26.17	2.41
0.75 percent	1	28 days	15	15	15	8372	3375	633.26	28.14489	2.48
	2		15	15	15	8341	3375	617.28	27.43467	2.47
	3		15	15	15	8551	3375	621.98	27.64356	2.53
	Mean							624.1733	27.74104	2.5
1.50 percent	1	28 days	15	15	15	8462	3375	667.7	29.67556	2.51
	2		15	15	15	8521	3375	603.56	26.82489	2.52
	3		15	15	15	8582	3375	641.81	28.52489	2.54
	Mean							637.69	28.34178	2.52

Figure 17: Compressive strength test

4.3 Load-deflection curve

From the data logger which collects data from the load cell and deflection gauge, a chart has drawn, which explains how each specimen has mechanized before failure taken place. As it is explained in the chart below the maximum resistance from all specimens is observed in WB-2 specimen and WB-1 which clearly show the methods applied in this scenario has effective result in resisting shear.

The ultimate capacity of the fiber-reinforced concrete FB-1 and FB-2 has a negligible effect on the concrete shear capacity. However, this beam scenario has a slightly moderate ductility improvement than the control beam.

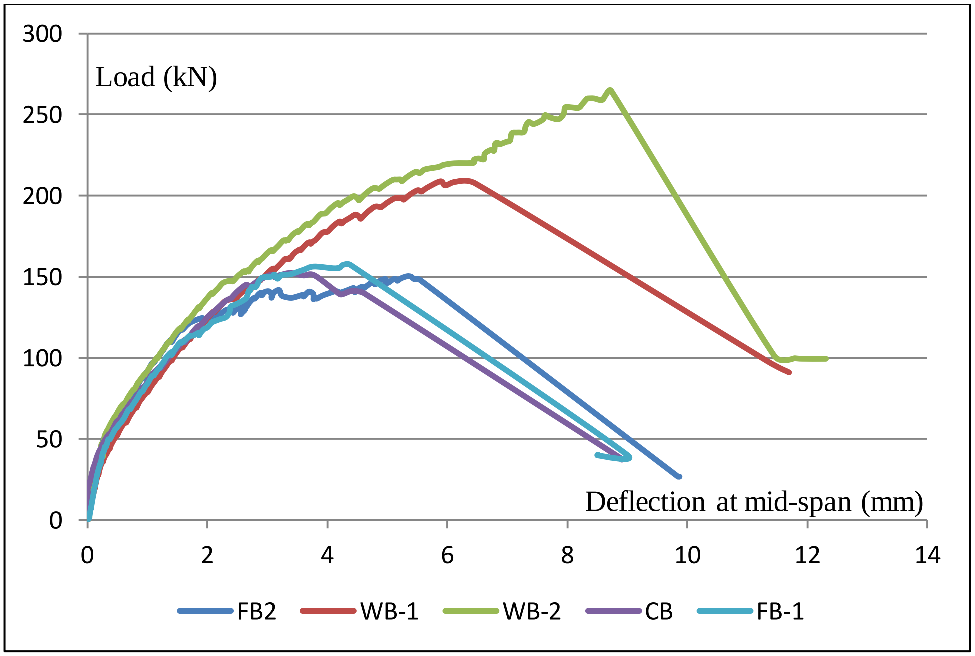


Chart 1: Load-deflection curve

The maximum resisting capacity of the beam is 158.95 kN as seen on the control beam but WB specimen beams resist an additional load. This additional resisting capacity is due to the presence of inclined wire tied on the longitudinal bars. The length of the wire in this scenario has its effect on reaching the stress level to react for resistance.

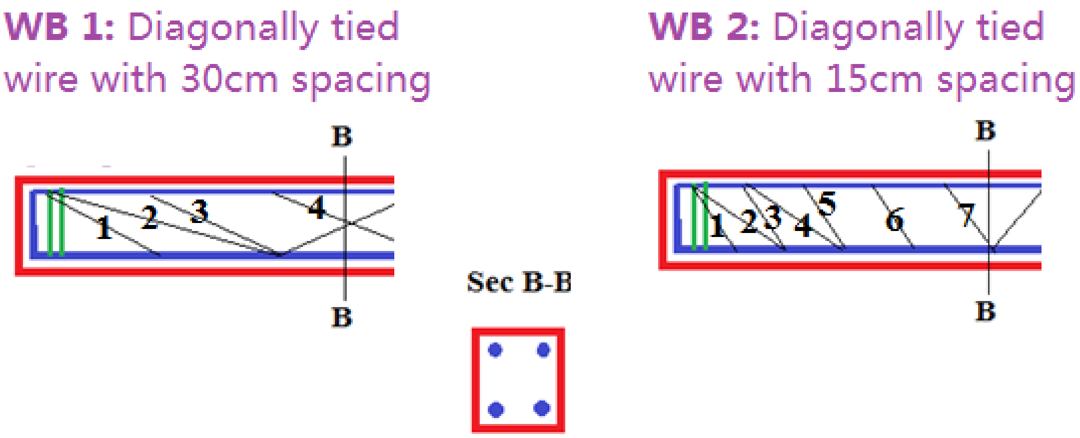


Figure 18: Diagonally tied wire length and setup

Table 7: Diagonally tied wire length and setup

BEAM	Wire	Length (mm)
WB-1	1,3,4	36.06
WB-1	2	63.24
WB-2	1,3,5	25
WB-2	2,4,6,7	36.06

Since the wires are tied manually, it doesn’t gain full stress until the applied load makes it in a full tensile level. Hence, the length of the wire has its effect on reaching the maximum level of stress. The length of the wire has inversely proportional to reaching the full stress level. That means when the length of the wire is long, the stress level in the wire will be late. Making the wire shorter will be important to the wire to respond to the applied load. Unless the wire will reach the level of stress after cracks happened.

The table below shows that the modes of failure, number of flexural cracks loads and deflection. All the experimental beams failed in shear crack, but the WB beam scenario shows more flexural cracks than the others. Especially WB-2 has a better tendency in resisting shear because the beam has many flexural cracks though it failed in shear.

Table 8: First crack and ultimate crack load for experimental beams

Beams	First crack (kN)	Def. in first crack (mm)	Ultimate load (kN)	Def. in ultimate (mm)	Number of flexural cracks observed	Max opening of crack (mm)	Modes of failure	Remark
CB	120.80	1.9	151.06	3.7	0	14	Shear	
FB-1	124.88	2.3	150.31	4.3	0	8	Shear	
FB-2	141.32	2.7	157.06	5.4	1	8	Shear	
WB-1	136.80	2.6	208.58	6.1	4	9	Shear	
WB-2	142.06	2.5	220.21	6.4	7	3	Shear	

4.4 Comparison of beam specimen with a control beam

In this section, a comparison of the experimental result with the control beam result has been done. The theoretical shear for the design of the control beam has been calculated as it is explained in appendices A. The table below shows the relative comparison of beams with the Control beam.

Table 9: First crack reference strength of experimental beams with control beams

Beam type	Description	Experimental Vc (kN)	Reference Vc strength (with CB)	Remark
CB	Control beam	120.8	1.00	
FB-1	Fiber beam (0.75 percent fibers)	124.88	1.03	
FB-2	Fiber beam (1.5 percent fibers)	141.32	1.17	
WB-1	Wire beam (30cm spacing wire)	136.80	1.13	
WB-2	Wire beam (15cm spacing)	142.06	1.18	

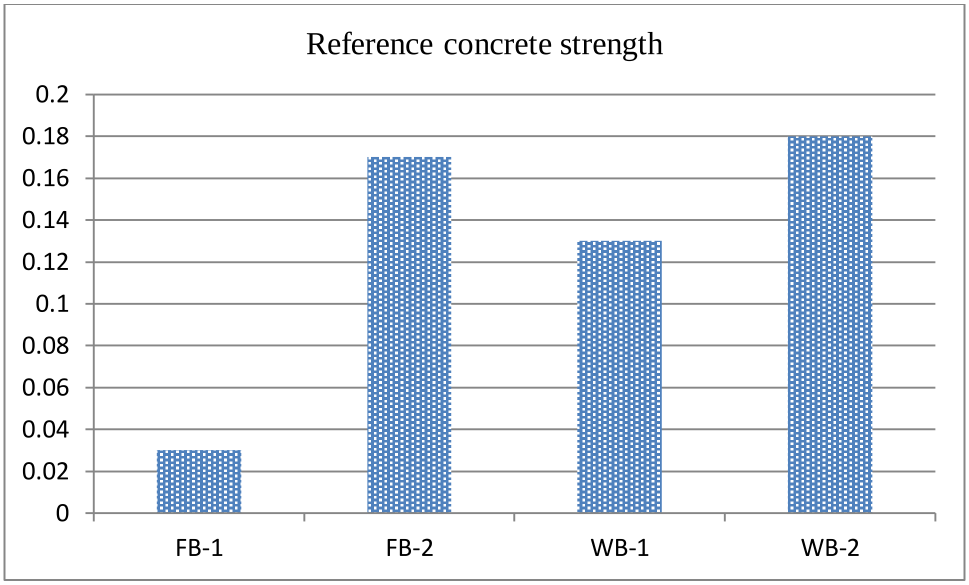


Chart 2: Reference concrete strength of experimental beams comparing with control beam

As the chart below shows the ultimate shear capacity of WB1 and WB-2 shows 38 percent and 46 percent capacity increment. However, the capacity of concrete mixed with fibers shows ignorable capacity.

Table 10: Reference ultimate load strength of experimental beams with a control beam

Beam Type	Description	Experimental ultimate capacity (kN)	Relative ultimate capacity (with CB)
CB	Control Beam	151.06	1.00
FB-1	Fiber Beam (0.75 percent fibers)	150.31	1.00
FB-2	Fiber Beam (1.5 percent fibers)	157.06	1.04
WB-1	Wire Beam (30cm wide wire)	208.58	1.38
WB-2	Wire Beam (15cm spacing)	220.21	1.46

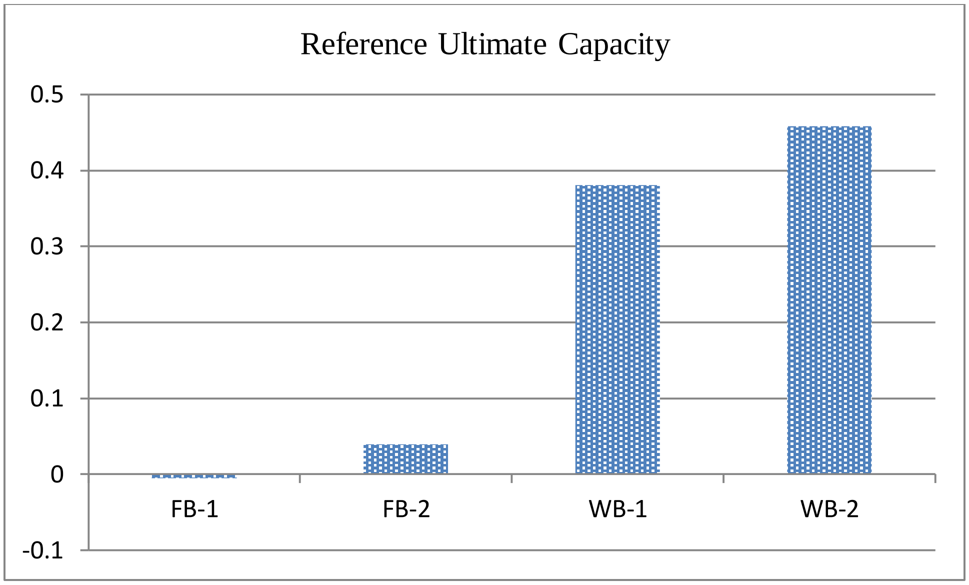


Chart 3*: Reference ultimate strength of experimental beams with a control beam*

4.5 Crack pattern in experimental beams

The crack patterns for the diagonally tensioned wire beam WB and Fiber-reinforced concrete beam FB were distinctly different. While the control beams without transverse reinforcement exhibited a single inclined crack followed by a brittle shear failure, both FB beams showed at least two diagonal cracks. At first diagonal cracking, a minor reduction in stiffness was observed for the FB beams. Before the failure, these beams may or may not have exhibited flexural yielding. The degree of flexural yielding was primarily defined by the amount of longitudinal reinforcement and fibers.

A minor improvement in cracking pattern was observed for FB compared to the RC beam without stirrups. For each beam pair, the FB beam with diagonal cracks throughout the critical shear span exhibited higher shear strength than its counterpart.

However, in WB experimental beams a lot of flexural cracks have been observed in the WB-2. The experimental beam has higher longitudinal reinforcement that resists the flexural load, even if the beam has deflected at the center with a lot of flexural cracks. Yet the beam failed in shear.

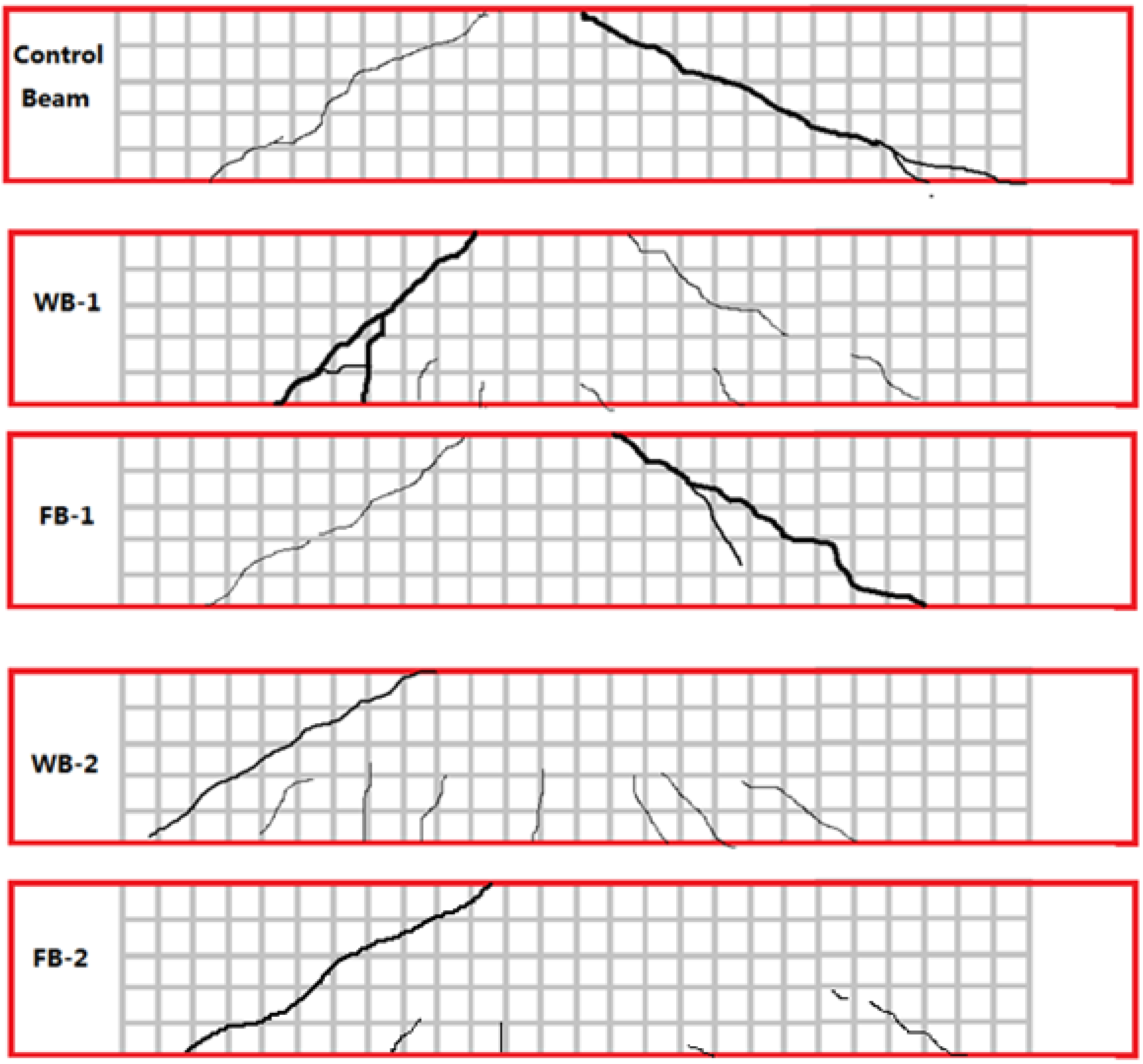


Figure 19*:* Crack pattern representative sketch

4.6 Comparison of experimental beam (WB-2) with minimum shear reinforcement provision

The max spacing for shear reinforcement requires for a beam is 0.75d or 600mm. That means for the case of this research, the minimum reinforcement shall be provided with a spacing of 0.75 × 220, which is 165mm.

Assuming experimental shear capacity of WB-2, 220.21kN, as a design shear load and calculating the equivalent reinforcement to satisfy the shear load required by the same stress as an experimental beam WB-2.

Vc= 120.8 kN $v_c = 120.8kN$ experimental shear force of control beam

$v_{sd} = 220.21kN$ (assumed result as a design load from the WB-2)

the required equivalent load by stirrup of 10 mm dia bar; $v_{sd} - v_c = 99.41kN$

Spacing for this bar = $\frac{A_v d f_{yd}}{v_s} = \frac{100.48\times250\times451}{100\times99.41} = 122.4mm$

Comparing the minimum spacing provision by EURO-Code with the result found, it can be concluded that the material can be used by replacing the minimum reinforcement provision.

4.7 Effect of extracted wire and fibers in concrete

The methodology used in the WB experimental beam is an inverse diagram for Truss and tie model. It is one of the best models for shear analysis especially to analyze the discontinuous regions (D-regions). In the strut tie model, the compressions in the beam is assumed to be resisted by the bottleneck strut which is designed as prismatic truss member. The tensile stresses are assumed to be resisted by the reinforcements that are stirrups and longitudinal bars.

Inclined cracks follow the trajectory of tensile stress, usually from the location where the load concentrated to the support. The essence of this crack formation depends on the tensile load carrying capacity of the material used to connect the struts in strut analogy. In the case of reinforced concrete with web reinforcement, this capacity is dependent on the load-carrying capacity of the webs. In the model, the webs are assumed to yield before the concrete reach yielding point, so that the concrete is assumed to carry only compression stress as a strut.

Usually, cracks are formed between two struts, because cracks follow the weak path. It is known that concrete has a weakness in tension, Connecting this adjacent strut strengthens the load-carrying capacity of the concrete. Tensile load, that forms an inclined crack, carrying capacity of the concrete depends on the strength of the connection between two struts. That means as we increase the number of wires which connect the adjacent struts, it will increase the resistance capacity of the concrete.

In the case of reinforced concrete mixed with fibers FB-1 and FB-2 fibers are expected to play this role. The importance of fiber is a random distribution inside the concrete elements, which can able the element of concrete material to be attached with adjacent concrete elements. But the strength of the extracted fibers inside the concrete is highly dependent on the pull out strength of the fibers. For fibers to increase the capacity of the pull-out strength, that attach the concrete elements with fibers, the diameter of the fiber, length of fiber and the surface texture of fiber are the major factors. Hence in this research texture of fiber used to resist the inclined crack is plane which makes less friction with the concrete material.

Reinforced concrete with wires gave a better resistance capacity because the inclined wire which is embedded into this beam makes the adjacent struts to connect and hold each other before the collapse. The flexibility of the wires is better than stirrups so that wires can be used at any angle. Usually, most codes recommend using inclined stirrups of 25 to 65 degrees. But it is not easy to use the stirrups not workable to wrinkle. However, extracted wires can be used in any direction it is needed.

The resisting stress of the wires in the structure is in the same direction as the inclined stress. This makes the wires to carry loads, which resist inclined crack formation. To yield wires first before the concrete yields the wires shall be pre-stressed.

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this experimental research two techniques have been used to determine the shear capacity of concrete mixed with extracted waste tire wire. The experiment was done with two scenarios, extracted wire have been used as a fiber and as a diagonally tied wire. From these the conclusion is made as follows;

- The wire beam both as WB-1 and WB-2 have effective resistance capacity, Referencing with the control beam the presence of the wires increases the capacity of resisting load more than 30 percent.

- Fiber beams FB-1 and FB-2 comparing with control beams have no significant increment in load capacity. Moreover, the increasing fibers by double amount has no significance in enhancing the shear load. This is because the shape of fibers is plane and pull out strength of the fiber is weak.

- Waste tire steel fibers can be use as a structural material in resisting shear as a method used in the second scenario but it cannot be used as fiber material to enhance shear strength of concrete.

- Theoretically comparing the same cross-section and concrete material properties beams with the two experimental wire beams WB-2 are equivalent with 8mm diameters steel bar stirrup with 122mm center to center spacing.

5.2 Recommendations

Depending on the study made on this research it is important to note the following recommendation;

- Waste steel wire can be used as strengthening material by diagonally tie with stirrup as an additional material as shown in WB specimen. So study has to be made to understand the strengthening effect of using these materials in reinforced concrete with stirrups.

- Though in this research the use of wastes tire materials as 8cm fiber has an insignificant result on shear strength because of weak bond strength, study has to be made by changing the shape of fiber, like hooked or twisted.

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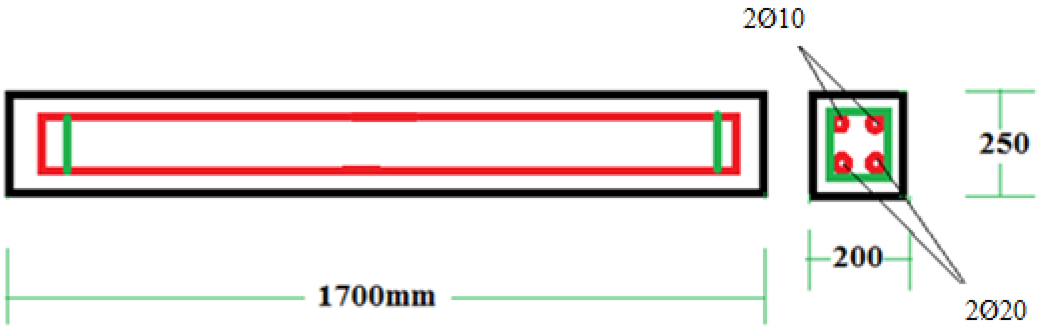
APPENDIX A: Beam design for test

- The control beam shall be made to fail in shear (inclined crack) intentionally;



- Shear Capacity of Concrete; V_c

$$V_c = 0.25 f_{ctd} . k_1 . k_2 . b_w . d$$

$$k_1 = (1+50\rho) \leq 2.0$$

$$\rho = \frac{A_s}{b_w . d} = \frac{2 * \pi * 20^2 / 4}{250 * 200} = 0.0146$$

$$k_1 = (1+50[0.0146]) = 1.731 < 2.0$$

$$k_2 = (1.6 - d) \geq 1.0 \qquad (d\ in\ meters).$$

$K_2 = 1.6 - 0.215 = 1.385 > 1$ Hence ok

$$f_{ctd} = \frac{0.21(f_{cd})^{2/3}}{\gamma_c} = \frac{0.21(20)^{2/3}}{1.5} = 1.0315 MPa$$

Therefore, $V_c = 0.25 * 1.0315 * 1.731 * 1.385 * 200 * 250 * 10^{-3} = 26.57$ kN

$V_c = P/2$; $P = 2\ V_c = 2 * 26.57 = 53.15$ kN

P = 53.15kN

- Moment Capacity;

Concrete grade;

C-25/ 20

$$f_{cd} = \frac{0.85 f_{ck}}{\gamma_c} = \frac{0.85*20}{1.5} = 11.33 \text{ MPa}$$

For steel f_{yk} = 400 MPa,

$$f_{yd} = \frac{f_{yk}}{\gamma_s} = \frac{400}{1.15} = 521.83 MPa$$

Assuming that steel yields,

$$x = \frac{(A_s - A_{sc}) f_{yd}}{0.8 b f_{cd}} = \frac{\left(\frac{2*\pi(20)^2}{4} - \frac{2*\pi(16)^2}{4}\right)}{0.8*300*11.33}*521.83$$

=135.58 mm

$$\varepsilon_{sc} = 0.0035*\frac{x - d_2}{x} = 0.0035*\frac{135.58 - 35}{135.58} = 0.002596$$

$\varepsilon_{yd} = f_{yd}/E_s = 0.0024$ OK

$M_u = 0.8x.b.f_{cd} (d – 0.4x) + A_{sc}f_{yd} (d – d_2)$

$= \{0.8*135.58*200*11.33*[250 – 0.4(135.58)] + (2*\pi*20^2/4)*521.74[250 – 35]\}*10^{-6}$

= 54.28 kN.m

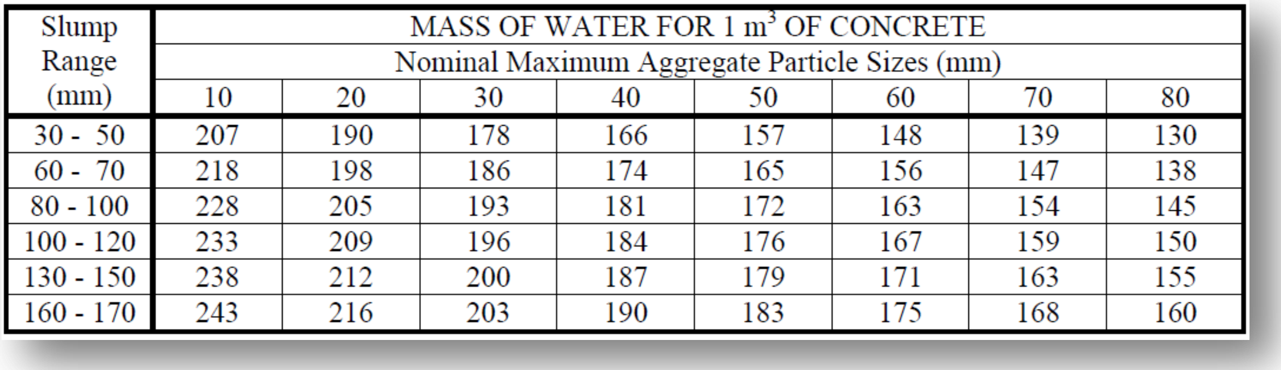
M_u = PL/4 ; P=4M/L = 167.01kN

P = 167.01; Since the failure load in shear is less than in moment the beam is expected to fail in shear at a load of 53.15 kN before flexural failure.

APPENDIX B: ACI mix design procedure

- Mix component properties:
    - Concrete grade: C-25
    - Cement:
        - Type: Ordinary Pozzolana Cement
        - Fabrication: Derba Cement Fabrics
        - Specific Gravity: 3.15
    - Coarse Aggregate:
        - Nominal Maximum Size: 25mm
        - SSD bulk Specific Gravity: 2.64
        - Percent absorption Capacity: 1.605
        - Unit Weight: 1485.27Kg/m^3
    - Fine Aggregate:
        - SSD bulk Specific Gravity: 2.60
        - Percent absorption Capacity: 0.80
        - Fineness Modulus: 2.55
    - Air:
        - Non-air-entrained
    - Slump:
        - For beams and reinforced walls, the recommended slump value is within the range of 2 to 10cm. In this research the sieve value is 8cm.
    - Maximum aggregate size:
        - As per the sieve analysis, the maximum size of the coarse aggregate is 25cm.

- Estimating mix:
  - Weight of water:
    - For non-air-entrained concrete with a slump of 8 to 10cm and 25cm maximum aggregate size, the recommended weight of water is 195Kg/m3 of concrete.



Slump Range (mm)	MASS OF WATER FOR 1 m^3 OF CONCRETE							
	Nominal Maximum Aggregate Particle Sizes (mm)							
	10	20	30	40	50	60	70	80
30 - 50	207	190	178	166	157	148	139	130
60 - 70	218	198	186	174	165	156	147	138
80 - 100	228	205	193	181	172	163	154	145
100 - 120	233	209	196	184	176	167	159	150
130 - 150	238	212	200	187	179	171	163	155
160 - 170	243	216	203	190	183	175	168	160

- Water cement ratio:

For 25MPa compressive strength at 28 days and non-air entrained concrete, the recommended value of the water-cement ratio is 0.62. Accordingly, the content of cement should be 314.5kg/m^3 of concrete.

Compressive strength (28 days in MPa)	Water cement ratio (w/c)
45	0.38
40	0.43
35	0.48
30	0.55
25	0.62
20	0.7
15	0.8

- Weight of Coarse Aggregate:
    - For a fineness modulus of 2.55 and 25cm maximum size of aggregate, the volume of dry rod coarse aggregate is 0.695. Accordingly, for 1485.27kg/m^3 unit weight of aggregate 1032.24 Kg/m^3 is expected.

Maximum Size (mm)	FINENESS MODULUS						
	2.4	2.5	2.6	2.7	2.8	2.9	3.0
10	0.50	0.49	0.48	0.47	0.46	0.45	0.44
20	0.66	0.65	0.64	0.63	0.62	0.61	0.60
30	0.71	0.70	0.69	0.68	0.67	0.66	0.65
40	0.75	0.74	0.73	0.72	0.71	0.70	0.69
50	0.77	0.76	0.75	0.74	0.73	0.72	0.71
60	0.79	0.78	0.77	0.76	0.75	0.74	0.73
70	0.80	0.79	0.78	0.77	0.76	0.75	0.74
80	0.82	0.81	0.80	0.79	0.78	0.77	0.76

- Weight of Fine Aggregate:
    - For non-air entrained the 25mm aggregate size the weight of concrete is 2375kg/m^3 hence subtracting the entire ingredient the estimated weight of fine aggregate will be 833.26 kg/m^3.

Nominal max size of Aggregate (mm)	Non-air-entrained concrete (kg/cube m)
10	2280
12.5	2315
20	2355
25	2375
40	2420
50	2445
70	2465
150	2505

- Moisture Adjustment:

Moisture property	Coarse aggregate (percentage)	Fine aggregate (percentage)
Free Moisture Content	1.163	0.8

Ingredient	Before adjustment (kg)	Adjustment (kg)	After adjustment (kg)
Fine Aggregate	0833.26	+ 833.26*0.008	0839.92
Coarse Aggregate	1032.24	+1032.24*0.01163	1044.25
Water	0195.00	-18.67	0176.33

- Experimental Mix Ratio

Ingredient	Weight (kg)	Ratio with cement
Water/Cement	0176.33	0.62
Cement	0314.50	1.00
Fine Aggregate	0839.92	2.67
Coarse Aggregate	1044.25	3.32

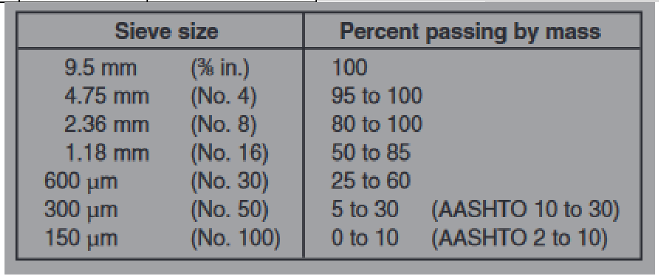
Appendix C: Material Preparation:

- Sieve Analysis

Coarse aggregate sieve analysis									
Sieve size (mm)	weight of sieve (g)	weight of sieve and retained(g)	retained (g)	passing (g)	percentage retained	percentage passing	cumulative retained	cumulative passing	Percent Passing (ASTM C33)
37.5	1083	1083	0	2000	0	100.0	0	100.00	95 to 100
25	1164	1256	092	1908	04.60	95.4	04.6	95.40	-
19	1390	2198	808	1100	40.40	55.0	45.0	00.55	35 to 70
12.5	1158	1749	591	0509	29.55	25.4	74.5	25.45	-
9.5	1163	1610	447	0062	22.35	03.1	96.9	03.10	10 to 30
4.75	1174	1234	060	0002	03.00	00.1	99.9	00.10	0 to 5
pan	0742	0745	002	0	00.10	0			
		Total (Kg)	2000	Total (%)	100				

Fine aggregate sieve analysis

Sieve size (mm)	Weight of sieve (g)	Weight of sieve and retained (g)	Retained (g)	Passing (g)	Percentage retained	Percentage passing	Cumulative retained	Cumulative passing	Percent passing (ASTM C-33)
9.5	460	460	0	500	0	100	0	100	100
4.75	426	433	007	493	01.4	98.6	01.40	98.6	95 to 100
2.36	380	400	020	473	04.0	94.6	05.40	94.6	80 to 100
1.18	373	422	049	424	09.8	84.8	15.20	84.8	50 to 85
0.6	326	470	144	280	28.8	56.0	44.00	56.0	25 to 60
0.3	303	533	230	050	046	10.0	90.00	10.0	5 to 30
0.15	283	326	043	007	08.6	1.40	98.60		0 to 10
pan	241	248	007	0	01.4	0			
		Total (kg)	500	Total (%)	100	Total	254.6		
						Fineness Modulus	2.546		



Sieve size		Percent passing by mass	
9.5 mm	(⅜ in.)	100	
4.75 mm	(No. 4)	95 to 100	
2.36 mm	(No. 8)	80 to 100	
1.18 mm	(No. 16)	50 to 85	
600 μm	(No. 30)	25 to 60	
300 μm	(No. 50)	5 to 30	(AASHTO 10 to 30)
150 μm	(No. 100)	0 to 10	(AASHTO 2 to 10)

(ASTM C-33 standard specification for fine aggregate)

- Specific gravity and absorption capacity

Fine aggregate	Weight (g)
Weight of the sample	0500
Weight of pycnometer	0321
Weight of pycnometer+ water (B)	1294
Weight of pycnometer + sample	0842
Weight of pycnometer+ sample+ water	1602
Weight of container	0739
Weight of container + sand oven-dry	1233
Weight of sand oven-dry (A)	0496
Bulk specific gravity	2.58
Bulk specific gravity (SSD)	2.60
Apparent specific gravity	2.63
Absorption	0.80

Coarse aggregate	Weight (gm)
Weight of cont. + the sample SSD in air	5493
Weight of container	0493
Weight of the sample SSD in the air (B)	5000
Weight of cont. + sample SSD in water	3491
Weight of container	0388
Weight of the sample SSD in water	3103
Weight of oven-dry sample in air (A)	4921
Bulk specific gravity	2.5
Bulk specific gravity (SSD)	2.6
Apparent specific gravity	2.7
Absorption	0.6

- Unit weight

Coarse aggregate	Values	Unit
Weight of agg.+ cylinder	26.2	kg
Weight of cylinder	04.8	kg
Weight of aggregate	21.4	kg
Length	28.0	cm
Diameter	25.6	cm
Volume of cylinder	0.01	m^3
Compacted unit weight of aggregate	1485.2	kg/m^3

- Moisture Content

Description	Fine Aggregate (gm)	Coarse Aggregate (gm)
Aggregate and container	2498	5494.0
Container	0492	0494.0
Aggregate original	2006	5000.0
Oven-dried aggregate and container	2464	4793.2
Oven-dried aggregate	1972	4299.2
Water content (percentage)	0.8	1.163

- Slump

A slump test has been made to check the workability as well as the mix. All mixes are within the range.

APPENDIX D: Laboratory pictures

Sieve analysis

Sand washing

Oiling and preparing molds

Casting

Prepared olds

Curing

Compressive strength

Tensile strength test for bars

Extraction of wires from waste tire

Preparation of wire stirrup and fibers

Cutting and preparing of fibers

Mixing

Painting and preparing experimental beams

Deposing tested beam

Preparing setup and data recording