Jimma University

School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Structural Engineering MSc Program

Mechanical Performance and Shear Behavior of Synthetic Fiber Reinforced Concrete Beam

By:

Ameyu Abeyo

A Thesis Submitted to School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Structural Engineering

November 2019

Jimma, Ethiopia

Jimma University

School of Graduate Studies

Jimma Institute of Technology

Faculty of Civil and Environmental Engineering

Structural Engineering MSc Program

Mechanical Performance and Shear Behavior of Synthetic Fiber Reinforced Concrete Beam

By:

Ameyu Abeyo

A Thesis Submitted to School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Structural Engineering

Advisor: Temesgen Wondimu (Ph.D.)

Co-advisor: Kefiyalew Zerfu (MEng.)

November 2019

Jimma, Ethiopia

DECLARATION

I, the undersigned, declare that this thesis is my original work and has not presented for a degree in this or any other university, and all sources of materials used for this thesis have been duly acknowledged.

Name: **Ameyu Abeyo Deresa**

Signature: ____________ Date: ____________

Place: Jimma University, Jimma Institute of Technology

This thesis has been submitted for examination with my approval as a University advisor.

TemesgenWondimu (Ph.D.)	________________	________________
Advisor	Signature	Date

This thesis has been submitted for examination with my approval as a University Co-advisor.

Kefiyalew Zerfu (MEng.)	________________	________________
Co-Advisor	Signature	Date

ABSTRACT

The potential use of fiber reinforcement for enhancing the mechanical properties and shear capacity of fiber reinforced concrete beams had been clearly established and recognized that fiber reinforcement is an effective way to enhance the mechanical performance, shear behavior and fracture toughness of concrete in all modes of failure. An experimental study was performed to investigate effect of two different types of fibers: micro and macro synthetic fiber on the workability, compressive strength, splitting tensile strength, flexural strength and shear behavior of synthetic fiber reinforced beam with concrete strengths,25and 40 MPa, and fiber volume fractions,0.2,0.35 ,0.50, and 0.65% of concrete volume. The test results showed that the workability of concrete decreases as the volume of fibers and concrete strength increases. The micro SNFRC beams with a strength of 25MPa at 0.2,0.35,0.5, and 0.65% volume fractions decreases the compressive strength by 12,12.31,23.96, and 44.6%, while macro synthetic fibers improved the compressive by at least 3.87, 5.16,5.3 and 5.39%, respectively compared to the control specimen. Likewise, the compressive strength of fiber reinforced concrete with 40MPa decreases by 2.17 % for 0.35%fiber content and, 72% for 0.65% fiber content and 10.48 % for 0.65% of both micro and macro SNFRC beam respectively. As the volume of micro synthetic fibers increases the tensile strength of micro SNFRC beam constantly decreases up to 14.93% and 61.33% for 0.65%fiber content in both 25 and 40MPa concrete strength respectively. However, macro SNFRC beam with a strength of 25MPa at 0.20,0.35, and 0.50% volume fractions enhanced the tensile strength by 4.75,5.88 and 7.0% respectively and in the same way it increases by 10.47% at 0.35% fiber content and by 5.71% at 0.65% fiber content in concrete with 40MPa strength. The micro SNFRC with a concrete strength of both 25 and 40 MPa showed a decreases in flexural strength particularly for a fiber volume fraction of greater than 0.35%. With the addition of macro synthetic fiber, the flexural strength of concrete with 25 MPa increases by 0.46,2.77,2.3 and 7.39% at 0.20,0.35,0.50, and 0.65% fiber content and decreases by 35.1at 0.35%and 38.9% at 0.65% fiber content in SNFRC with strength of 40MPa. Average shear strength of micro and macro synthetic FRC greatly enhanced as the fiber volume content of the concrete increases. The flexural and shear toughness behavior of the SNFRC is highly boosted and more effective in higher strength concrete (40 MPa) than in normal strength concrete (25 MPa).

Key Words: SNFRC; shear strength; flexural toughness; compressive strength; beam.

ACKNOWLEDGMENT

This research was submitted to Jimma Institute of Technology in partial fulfillment of the requirements of Masters of Science in Structural Engineering. First and foremost, I would like to thank the Almighty God for his unending blessing.

I would like to express my deepest gratitude to Assistant Professor Temesgen Wondimu, who has supported and mentored me with love and care during this thesis work; I have a great appreciation for his guidance, unreserved assistance, constructive and timely comments on this research.

My great thanks goes to Mr. Kefiyalew Zerfu who has provided me with knowledge in all the procedures and guidance during the experimental part and on writing this research. Thank you for your encouragement, support, and expert advice.

Besides, I would like to acknowledge the support of Associate Professor Engr. Elmer C. Agon, the chairman of the structural engineering stream, for his patience and guidance in timely scheduling the presentation and throughout the courses in the class.

I would also like to extend my appreciation to the members of the Material Research and Testing Center, Matewos and Behailu Belta, who tested many beams of this research. I also recognize the contribution of technicians of Jimma Institute of Technology Construction Material Laboratory for their help to cast and test several specimens.

Appreciation is also extended to Mr. Annand Babu, and to the fellow undergraduate and graduate students, who offered help during the experimental phase of this research.

I am deeply indebted to my mother, Derebu G., my father, Abeyo D., and my beloved family for affording me the opportunities in life to be able to attend university and for their unyielding support and encouragement.

Finally, the research was financially supported by the School of Graduate Studies, Jimma Institute of Technology Structural Engineering for which they should deserve a great credit.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

ACI	-	American Concrete Institute
ASTM	-	American Society for Testing and Material
b	-	Width
BS EN	-	British Standard European Norm
d	-	Diameter
FRC	-	Fiber Reinforced Concrete
h	-	Height
HRWR	-	Higher Range Water Reducing
JSCE	-	Japan Society of Civil Engineers
kg	-	Kilogram
kPa	-	Kilo Pascal
l	-	Length
LVDTs	-	Linear Variable Displacement Transducers
min	-	Minute
mm	-	Millimeter
MPa	-	Mega Pascal
SFRC	-	Steel Fiber Reinforced Concrete
SNFRC	-	Synthetic Fiber Reinforced Concrete
TR	-	Technical Report
UTM	-	Universal Testing Machine

CHAPTER ONE

INTRODUCTION

1.1.Background of the study

Concrete is essentially a mixture of cement, aggregate, and water. It is widely used in the construction industry because all the raw materials required are widely available and are of low cost. Concrete is very strong in compression; however, it has a very low tensile strength. To improve its tensile strength, reinforcing steel is often used in the concrete. Apart from traditional steel reinforcement, various fibers are also used to improve the properties of concrete, mainly for enhancing the tensile strength. There are mainly four types of fibers which can be used to reinforce concrete: steel fiber, glass fiber, natural fiber and synthetic fiber (Yin *et al.*, 2015).

Fiber-reinforced concrete (FRC) is an innovative material that improves many engineering properties of concrete. (Wafa, 1990) synthetic fibers, typically made of polypropylene, have primarily been used in concrete materials to control shrinkage cracking and, to a limited extent, to improve toughness and impact resistance. In recent years, however, increasing efforts have been devoted toward the development of a new generation of macro synthetic fibers that impart significant toughness and ductility to concrete comparable to commonly used steel fibers. Accordingly, the application of micro and macro synthetic fibers in the concrete industry has extended beyond shrinkage and thermal cracking control to structural applications (Altoubat *et al*.,2010).

Developments on fiber addition in concrete mixtures have grown significantly in recent decades as they offer several advantages to the mechanical properties of concrete. Short discrete fiber addition modifies the brittle characteristic response of the concrete leading to a significant increase in toughness and ductility compared to plain concrete (Rosidawani *et al.*, 2015).

In recent years, many studies have been conducted in the mechanical properties of such as tensile, compressive, flexural, and impact strength of synthetic fiber reinforced cement composites. Such concrete is also used in retrofitting and repairing the covering of concrete structure, tunnels, etc. Polypropylene fibers (at relatively low volume fractions <0.3%) are used for: secondary temperature shrinkage reinforcement, overlays and pavements, slabs, flooring systems, precast pile shells and shotcrete for tunnel linings, and reservoirs (Ramujee, 2013).

Although the majority of previous works on the shear of FRC has been performed with steel fibers, there are few studies reporting results on shear with synthetic fibers. (Maalej and Li, 1995) tested beams reinforced with flexural bars that contained several types of synthetic (acrylic, aramid, and polyethylene) and steel fibers. Two of the three synthetic fibers (polyethylene and aramid) showed significant improvements in the shear strength of the concrete beams.

The effect of fiber reinforcement on shear strength of concrete is attributed to two main factors: the first one is a direct factor imposed by the post cracking strength at the inclined shear crack (in a similar way to stirrups); and the second one is an indirect factor that increased the contribution of concrete to shear strength by improving aggregate interlock and dowel action of flexural reinforcement (Altoubat *et al*.,2010).

There is limited research on mechanical performance and shear behavior with synthetic fibers is attributed perhaps to the small increase in toughness and associated structural performance of concrete when low-modulus synthetic fibers are added to concrete. This study is part of a comprehensive experimental program that will focus on the mechanical performance and shear behavior of beams reinforced with macro and micro synthetic fibers. Mainly it focuses on the effect of fibers in relation to concrete grade and determining an optimized geometry that will enhance the bond between the fiber and the concrete matrix, which leads to an increase in the toughness properties of concrete.

1.2.Statement of the problem

In recent years, however, increasing efforts have been devoted toward the development of a new generation of macro synthetic fibers that impart significant toughness and ductility to concrete comparable to commonly used steel fibers. Accordingly, the application of macro and micro synthetic fibers in the concrete industry has extended beyond shrinkage and thermal cracking control to structural applications (Altoubat *et al*.,2010).

Some Building Code (ACI 318, 2008) is permitted structural use of synthetic fiber but, the structural design code adopted in design procedures for synthetic fiber-reinforced structural members and the equations to determine their effects on shear and mechanical behavior is not formulated yet.

The addition of discrete fibers to concrete improves both its mechanical behavior of concrete and post-cracking behavior (residual strength, toughness, and ductility). The improved material properties of fiber-reinforced concrete (FRC) tend to improve the flexural and shear behavior of FRC structures. This helps to reduce the problems associated with congestion of shear reinforcement particularly at critical sections such as beam-column junctions.

Many types of research carried out and most of the published works over the past three decades have focused on the shear behavior of steel fiber-reinforced concrete (SFRC). Unlike SFRC, there are only a few studies reporting results on mechanical performance and shear behavior of synthetic fibers reinforced concrete.

To facilitate the use of FRC in design, there is a need for simple and robust methods for characterizing the response of the material to stress. This study will provide detailed data regarding the effect of different volume fractions of both micro and macro synthetic fibers on the mechanical properties and shear behavior (toughness, ductility, and cracking behavior). In addition, it establishes the relationship between the concrete strength and effect of synthetic fibers in the concrete mixture.

1.3. Research questions

The study was to answer the following question:

I. What is the effect of variation in synthetic fiber content in improving concrete properties?

II. Does the effect of synthetic fibers on the concrete is affected by the change in concrete grade?

III. Which type of synthetic fiber (macro or micro) is more effective in improving the mechanical performance and shear strength of concrete?

IV. How the ductility of the concrete beam is enhanced with the addition of the synthetic fibers?

1.4. Objectives of the study

1.4.1. General objective

The primary objectives of this research were to investigate the mechanical performance and shear behavior of synthetic fiber reinforced concrete beam.

1.4.2. Specific objectives

The objective of this research was to investigate the following aspects of fiber-reinforced beams made of medium-high concrete capacity. Particular attention was devoted to the mechanical performance and shear behavior of micro and macro SNFRC for both C-25 and C- 40 concrete grade in a number of experimental tests.

The specific objectives of this research are:

- To determine the effect of variation in fiber content on mechanical and shear behavior of SNFRC.
- To describe the effect of concrete grade on the effectiveness of synthetic fibers in improving both the mechanical and shear behavior of concrete.
- To determine the effective synthetic fiber type (macro and micro) and in improving the concrete properties.
- To describe the effect of synthetic fibers on the post cracking behavior of the concrete.
- To determine the optimum fiber contents that shows a better result in a concrete mixture.

1.5.Significance of the study

This study is part of a comprehensive experimental program that was focused on the mechanical performance and the shear behavior of fiber reinforced concrete beam with concrete strengths ,25 and 40MPa and fiber volume fractions ,0.20,0.35,0.50, and 0.65% of micro and macro synthetic fibers.

The observations and results that will be presented in this paper establish the effectiveness of micro and macro synthetic fiber in increasing the shear strength, compressive strength, tensile strength, flexural strength and preventing a brittle failure of the concrete beam. In addition, the test results obtained from this study was used to help in formulating the shear behavior and flexural strength equations and also, establishes the relationship between the concrete strength and effect of synthetic fibers in a concrete mixture.

1.6.Scope and limitation of the study

In recent years, FRC becomes an attractive material for several applications including beams, slabs-on-ground, and pavement as such, the study on the effect of the fibers on the plain and reinforced concrete needs a more advanced experimental investigations and analysis.

This study was determining the mechanical performance and shear behavior of concrete with varying synthetic fibers (0.2%,0.35%,0.5% and 0.65%) by concrete volume for both macro and micro synthetic fibers after conducting experimental test on fresh concrete (slump test) and dry cast concrete (compressive, tensile strength, flexural strength and shear strength of SNFRC).

Since casting the beams with different lengths in the laboratory is time-consuming and a limited amount of fibers are available, the study was used a single beam type and only 0.35 and 0.65% of fiber volume fraction was used in determining the effect of fibers on concrete strength of 40 MPa. In addition, since the direct shear strength measuring machine is not available in Ethiopia, Bazant “shear fracture tests of concrete” was used to determine the shear behavior of SNFRC beam.

The study will be limited to investigate the mechanical performance and shear behavior of simply supported beam with the formerly mentioned variations of synthetic fiber content without considering other parameters like; shear span-depth ratios (a/d), flexural reinforcement ratio (ρ), and size of the beam under monotonic center-point loading.

1.7. Organization of the thesis

This thesis has five chapters. Chapter 2 starts with an introduction to conventional and fiber reinforced concrete. Application of fiber-reinforced, classification of synthetic fibers and its uses is discussed in the first part of this chapter. The second part of Chapter 2 is dedicated to reporting test results of SNFRC beams from previous investigations on the bond between fibers and concrete, workability, compressive, tensile, flexural, and shear strength of SNFRC, as well as its post crack behavior.

The experimental program, including the materials used, mould preparation and testing of SNFRC specimens, is discussed in Chapter 3. Tests adapted to obtain mechanical properties and shear behavior of synthetic fiber reinforced concrete specimens are also discussed in this chapter. The mechanical performance and shear behavior of the tested beam specimens is discussed in Chapter 4. Test results are reported and comparison is done in that chapter. The comparison includes the volume fiber content, fiber types and its relationship with the strength and failure mode of the test beams. Finally, conclusions from this research, along with major findings and design recommendations, are featured in Chapter 5.

CHAPTER TWO

RELATED LITERATURE REVIEW

2.1.Fiber reinforced concrete

Since ancient times, fibers have been used to reinforce brittle materials such as concrete. Sunbaked bricks were reinforced using a straw, while horsehair was used to reinforce mortar utilized for masonry units as well as plaster. It is believed that the oldest house constructed of straw reinforced sunbaked brick units was built around 1540 AD (ACI. 544.4R, 2002).

Fiber-reinforced concrete is concrete consisting of a binder, aggregates (fine and coarse), water with the inclusion of short, discrete and usually randomly distributed fibers, thus improving its properties in all directions.

The purpose of fibers in concrete is to improve the energy absorption capacity, tensile strength, cracking and deformation characteristics of concrete thereby controlling the fracture process by bridging the cracked plane (Zile and Zile, 2013).

This leads to a reduction in the crack width and deflection in members subjected to flexure. Since the fibers only become effectively active after the crack formation, the inclusion of fibers in concrete alters the post cracking behavior of normal concrete. Depending on the type of fiber, fiber volume, geometrical properties, the post cracking behavior can be classified as either strain-hardening or strain-softening (Naaman and Reinhardt, 2006; Wille *et al* .,2014).

The post cracking behavior is said to be strain hardening if the post crack strength increases beyond the first cracking strength (σt) of the composite. Materials exhibiting these characteristics are usually described as high-performance material composites and the post cracking region is characterized by multiple cracking. At stress σ_w, crack localization then begins and the crack width(w) increases with decreasing stress. Examples are strain-hardening cementitious composites (SHCC), high performance fiber reinforced concrete (HPFRC) and more recently, ultra-high performance fiber reinforced concrete (UHPFRC)(Barnett *et al.*,2010;Ferrier *et al.*, 2015;Li and Maalej, 1996;Maalej and Li, 1995;Naaman and Reinhardt, 2006;Yang *et al.*, 2009).

On the other hand, composites showing strain-softening behavior have their post cracking strength lower than the first cracking strength (σt) and the crack is usually localized.

The post cracking responses of fiber-reinforced cementitious composites do have much to do with the type of fibers used in its production. Some fibers are known to have a relatively high tensile capacity and when used in concrete translates to the improved tensile capacity of the concrete. The most important aspect of this enhanced tensile capacity is based on the interaction between the fiber and matrix under the action of load.

Despite all the significant research and developments in the field of FRC, structural applications using FRC are still limited. One of the factors inhibiting its use is the lack of appropriate standards and suitable certification(Oliveira, 2010). Also, available guidelines for the use of fiber-reinforced concrete do not take into account the creep deformation of this type of concrete(Zerbino and Barragn, 2012).

Typical FRC generally falls into this category. The macro synthetic FRC used in this research exhibits a strain-softening post cracking behavior. Figure 2-1 shows the typical tensile response of fiber-reinforced cementitious composite beyond the first crack strength. Plain concrete shows no resistance what so ever after the first crack while the conventional FRC shows an initial drop in stress but soon reflects increased energy absorption due to fibers bridging the cracked planes (Wittmann *et al*.2010).

A study of the post crack behavior of micro and macro synthetic FRC will be a major contribution to the future development of a harmonized design guidelines for the short and long term use and behavior of structural synthetic fibers in concrete.

2.1.1. Applications of FRC

It is used on account of the advantage of increased static and dynamic tensile strength and better fatigue strength. (Kaur, 2017).FRC is used for:

- Runway, Aircraft parking and Pavements

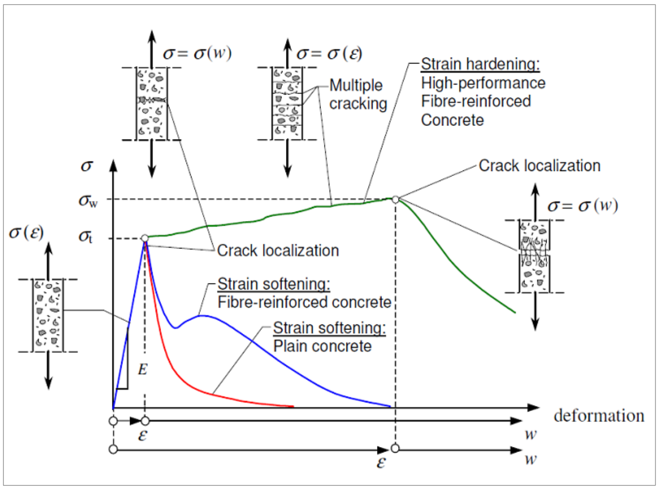


Figure 2-1 Classification of the tensile response of cement-based composites (Löfgren, 2005)

- Industrial flooring
- Tunnel and canal lining
- Dams and Hydraulic structures
- Composite decks
- Impact resisting structures

2.2. Types of synthetic fibers

Typical fibers that have been used over the past decades are steel, glass, nylon, asbestos, polyester, polyethylene, polyvinyl alcohol, rayon, wool, and polypropylene.

Those commonly used in concrete applications are steel, carbon and synthetic fibers(Yao, Li, and Wu, 2003). These fibers are available in different shapes and sizes and have a wide area of applications. Synthetic fibers are man-made fibers resulting from research and development in the petrochemical and textile industries. SNFRC utilizes fibers derived from organic polymers which are available in a variety of formulations.

(BS EN 14889-2, 2006) classifies polymer or synthetic fibers as straight or deformed pieces of extruded, orientated and cut material which is suitable to be homogeneously mixed into fresh concrete. A polymer is a material such as a polyolefin, which can be regarded as polypropylene, polyethylene, nylon, PVA, polyester, aramids or a blend of these materials.

Polymer fibers are classified according to their physical form into micro and macro fibers, see Table 2-1.

Polypropylene microfibers have been in use since the mid-1980s (Concrete Society UK TR 63, 2007) as a potential means to modify the properties of fresh concrete. Microfibers are used in small dosages (typically 0.9 kg/m3) typically as a controlling aid for plastic shrinkage cracking. Microfibers may further affect the bleeding rate of plastic concrete leading to an improved near-surface property of hardened concrete.

Table 2-1: Polymer fiber classification according to (BS EN 14889-2, 2006)

Classification	Type of Fiber	Length
Ia	Micro	< 0.3 mm in diameter, mono-filament
Ib	Micro	> 0.3 mm in diameter, fibrillated
II	Macro	> 0.3 mm diameter

Additionally, microfibers have been found to reduce spalling of concrete exposed to fire. They are usually used at low volumes (up to 0.2 %) while macro fibers are used at high volumes (up to 2.0 % or more).

The fiber used in this research falls into Class Ia and Class II. Macro synthetic fibers have been commercially available since the 2000's and are sometimes referred to as "structural synthetic fibers" (Concrete Society UK TR 63, 2007).

Macro fibers are larger than the microfibers and their diameters could range from 0.3 mm to 1.0 mm while their length could be between 15to 60 mm.They are said to be structural because they exhibit structurally effective properties: increased toughness and/or load carrying capacity after cracking (Oh *et al.*, 2005).

Macro synthetic fibers are gaining a significant level of usage in a number of applications particularly in pavements and shotcrete. The use of these structural synthetic fibers has been reported to provide a significant level of post crack control in the same way as that achieved by steel fabric and steel fibers (Oh *et al.*, 2005). According to (Zheng and Feldman, 1995),synthetic fibers, relatively also serve as a cost-effective replacement for the more expensive fibers such as glass, asbestos, and steel.

Fiber types that have been tried in Portland cement concrete based matrices are acrylic, aramid, carbon, nylon, polyester, polyethylene and polypropylene (ACI. 544.4R, 2002).

2.3. Synthetic fiber reinforced concrete

The SNFRC is a composite material made of cement, fine and coarse aggregates and discontinuous and continuous synthetic fibers. The mechanical properties of synthetic fiber reinforced concrete are influenced by the type of fiber; length-to-diameter ratio (aspect ratio); the amount of fiber; the strength of the matrix; the size, shape, and method of preparation of the specimen; and the size of the aggregate. For this reason, mixtures proposed for use in a design should be tested, preferably in specimens representing the end-user, to verify the property values assumed for design(ACI. 544.4R, 2002). Table 2-2 represents selected synthetic fiber types and their properties.

2.3.1. Advantages of SNFRC

The advantages of Synthetic Fiber Reinforced Concrete (ACI. 544.4R, 2002).

- Improve the shear strength of the concrete

- Improve the ultimate shear capacity of FRC beams
- Enhancement of ductility and energy absorption capacity
- Control shrinkage and thermal cracking in the concrete industry
- Maximize the flexural strength, direct tensile strength, and fatigue strength

Table 2-2: Selected synthetic fiber types and properties (ACI. 544.4R, 2002)

Fiber type	Equivalent diameter, in. x 10^{-3}	Specific gravity	Tensile strength, ksi	Elastic modulus, ksi	Ultimate elongation, percent	Ignition temperature, degrees F	Melt, oxidation, or decomposition temperature, degrees F	Water absorption per ASTM D 570, percent by weight
Acrylic	0.5-4.1	1.16-1.18	39-145	2000-2800	7.5-50.0	—	430-455	1.0-2.5
Aramid I	0.47	1.44	425	9000	4.4	high	900	4.3
Aramid II†	0.40	1.44	340	17,000	2.5	high	900	1.2
Carbon, PAN HM‡	0.30	1.6-1.7	360-440	55,100	0.5-0.7	high	752	nil
Carbon, PAN HT§	0.35	1.6-1.7	500-580	33,400	1.0-1.5	high	752	nil
Carbon, pitch GP**	0.39-0.51	1.6-1.7	70-115	4000-5000	2.0-2.4	high	752	3-7
Carbon, pitch HP††	0.35-0.70	1.80-2.15	220-450	22,000-70,000	0.5-1.1	high	932	nil
Nylon‡‡	0.90	1.14	140	750	20	—	392-430	2.8-5.0
Polyester	0.78	1.34-1.39	33-160	2500	12-150	1100	495	0.4
Polyethylene‡‡	1.0-40.0	0.92-0.96	11-85	725	3-80	—	273	nil
Polypropylene‡‡	—	0.90-0.91	20-100	500-700	15	1100	330	nil

*Not all fiber types are currently used for commercial production of FRC. †High modulus.

‡Polyacrylonitrile based, high modulus.

§Polyacrylonitrile based, high tensile strength.

**Isotropic pitch based, general-purpose.

††Mesophase pitch based, high performance.

‡‡Data listed is only for fibers commercially available for FRC.

Metric equivalents: 1 in. = 25.4 mm; 1 ksi = 6.895 MPa; (degrees F - 32)/1.8 = degree

2.4.Mechanical properties of SNFRC

2.4.1. Workability of SNFRC

With the addition of fibers, the entrapped air voids increase and hence the increased air content reduces the workability causing difficulty in compaction of mixes. The fibers may also interfere and cause finishing problems.

(J.Patel. Methul, 2013) used the fibrillated fiber length of 12mm and diameter of 32 microns and examined their effect on the mechanical properties of fresh and hardened high strength concrete. From the test result, it reported that the workability of polypropylene fiber concrete has been found to decrease with an increase in polypropylene fiber content replacement.

(Thirumurugan and Sivakumar, 2013) reported that the workability of concrete decreased with the addition of polypropylene fibers but it can be overcome by the addition of high range water reducing admixtures.

(Guerini *et al.*, 2018) investigated the workability of four different types of fibers; steel fiber of hooked end with 35mm and 65mm in length and crimped and embossed polypropylene with 40mm and 54mm in length in amounts of 0.5% and 1.0% by volume of concrete strength of 50 MPa and 45 MPa.

The slump reduction due to fiber addition was observed in both C45 and C50, indicating stiffer, less workable mixes. Figure 2-2 shows the slump-volume of fiber relationship for the concrete strength of 45 MPa and 50 MPa.

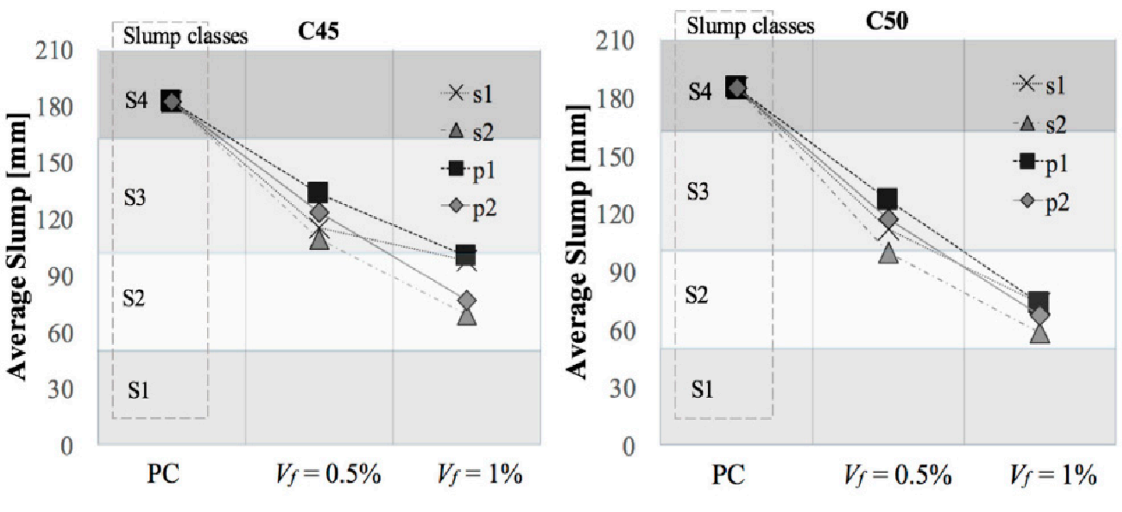


Figure 2-2 Influence of fibers on slump reduction in concrete C45 (left) and C50 (right) in case of plain concrete (PC) and fiber-reinforced concretes (Vf = 0.5% and Vf = 1%)(Guerini et al., 2018)

(Gencel *et al.*, 2011) used monofilament polypropylene fibers in self-compacting concrete with fly ash and studied the workability and mechanical properties. The materials used in this study showed no workability or segregation problems.

(Madhavi *et al.*, 2015), reported that the workability of concrete reduced with higher polypropylene fiber content. vebe time indicated that at 0.5% of fiber content workability is high while at 1% it is medium.

2.4.2. Compressive strength of SNFRC

The compressive strength of concrete is one of the most important properties of concrete. It is a qualitative measure of concrete. Failure of concrete under compression is a mixture of crushing and shear failure. The compressive strength varies as a function of both cement paste and fibers. A higher binder ratio gives higher compressive strength.

Since the main attributes and the reason for adding any reinforcing material in most cases is to improve the tensile properties, little focus has been put on the compressive strength of FRC. Because compressive strength tests typically measure the load until failure (first cracks) and since fibers only contribute to the structural integrity of concrete by bridging cracks after cracks begin to form, the effect of fibers on compression strength is not its main attribute.

Contradictory test results have been reported by different investigators regarding the effects of polypropylene fibers on the compressive strength.

(J.Patel. Methul, 2013) used fibrillated polypropylene fiber of 12mm and diameter 34 micron and low density of 0.9 Kg/m^3, in percentages of 0.5%, 1% and 1.5% in high strength concrete. Superplasticizer Conplast-Sp430 was used. They observed that the compressive strength of concrete increased with the addition of fibers.

(Southararajan *et al.*, 2013) carried out experimental investigations on M15, M20 and M25 grade fly ash concrete reinforced with 0%, 0.5% and 1% polypropylene fibers. Concluded that, the compressive strength also increased with an increase in fiber content up to 1% for all the three grades of concrete.

(K. Murahari, 2013) studied the effect of polypropylene fibers in fly ash concrete. The fiber volume fraction of 0.15%, 0.2%, 0.25%, and 0.3% was used in fly ash concrete with class C fly ash of specific gravity 1.96, obtained from NLC. Fly ash content was varied as 30%, 40%, and 50%. 12 mm (40%) and 20 mm (60%) coarse aggregate with a specific gravity of 2.7 were used. The cube specimens were tested for 28days and 56 days' strength.

The compressive strength gained maximum strength at an early age as observed for all fly ash and polypropylene fiber concrete. It is also observed that the compressive strength increased gradually from 0.15% to 0.3% fiber content.

(Mirzac, 1996) reported that the addition of low volumes (0.1%) of polypropylene fibers to a concrete mix has no significant effect on the compressive strength of conventional concrete.

(Hasan *et al.*,2011) performed tests to determine compressive strength on a total of 12 cubes of size 100×100×100 mm and splitting tensile strength for both plain concrete and polypropylene fiber reinforced concretes with four different percentages of macro synthetic fiber volume fractions, such as 0, 0.33, 0.42 and 0.51%.Test results showed that macro synthetic fiber enhanced the compressive strength insignificantly.

(Oh *et al.*, 2007) reported that there is no significant variation in the values of compressive strength associated with varying polypropylene fiber contents. Moreover, during the compression tests, the plain concrete failed catastrophically, while as reported by (Brandt, 2008) the macro plastic fiber reinforced concrete cylinders failed with many minor cracks on the surface. The plastic fibers still held the concrete together at the failure load. Figure 2-3 shows stress-strain curves of a compressive test on concrete cylinders conducted by (Hasan *et al.*, 2011).

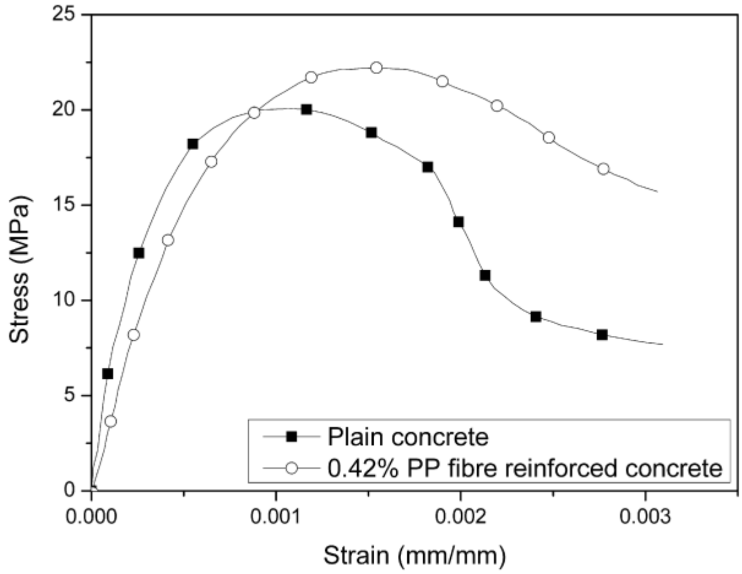


Figure 2-3 Average stress-strain curves for concrete with macro plastic fiber (Hasan et al., 2011)

The samples with fibers showed a more ductile mode of failure and a post-failure structural performance. This is attributed to the ability of the fibers to distribute stresses and slow down the crack propagation process.

(Khan *et al.*, 2015)investigated in their research a comparative experimental study on the mechanical performance of polypropylene fiber reinforced concrete (PFRC) under compression and split tensile loading. The M25 and M30 grades of concrete mixes and polypropylene mono-filament macro-fibers of length 35mm at volume fractions of 0.0%, 0.5%. 1.0%, 1.5%, 2.0%, 2.5% and 3.0% were used in the research. The cube specimens were tested at the curing age of 28 days. So on average to gain maximum compressive and tensile strength with mono-filament macro fiber the optimum dosage be limited 1% to 1.5%, after further increase these strength properties decrease. In addition to that, compressive strength concludes that with an increase in cement content the strength gains due to the percentage of fiber decreases.

2.4.3. Tensile strength of SNFRC

The tensile properties of SNFRC are difficult to experimentally assess. To the author's knowledge, there has been no agreement upon a standard test method to evaluate the direct tensile behavior of SNFRC. The problem arises primarily from the need for specimens that have a sufficiently-large cross-section such that a fiber distribution similar to that in real structural members is obtained.

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.

The splitting tensile strength of concrete can be increased by adding fibers to a concrete mix. During their research (Choi and Yuan, 2005) found that glass fiber reinforced concrete (GFRC) and polypropylene fiber reinforced concrete (PFRC) have a splitting tensile strength of 20 to 50% more than that of unreinforced concrete (Figure 2.4). They also concluded that the splitting tensile strength of these composites ranged between 9 and 13% of their compressive strengths (Choi and Yuan, 2005).

(Ahmed *et al.*, 2006) tested concrete cylinder specimens 150mm in diameter and 300mm in height with different amounts of polypropylene fiber. The tensile strength of concrete increases linearly only with the addition of fibers up to about 0.40% after which the tensile strength decreases with the addition of more fibers. The key to success in achieving strength seems to lie on two points i.e. fibers must be uniformly distributed in the mix and fiber proportion must be carefully selected. The tensile strength increases by about 65%~70% % up to 0.40% after which it decreases.

(Ramujee, 2013) used polypropylene fiber of 12mm and width crossing circular and specific gravity of 0.91g/cm^3, in percentages of 0%,0.5%,1% 1.5% and 2.0% in concrete. Reported that the tensile strength was increased proportionately with the increase in volume ratios of polypropylene fibers with reference to the controlled mix without fibers.

The important effect fibers have on concrete tensile strength is on the tensile fracture behavior. In normal concrete, the tensile load carrying abilities of the concrete will decrease a lot after crack widths of about 0.3 mm. The FRC will be able to carry considerable loading after cracking (Löfgren, 2005).

(Cifuentes *et al.*, 2013) tested concrete cylinder specimen 150mm in diameter and 300mm in height with polypropylene fibers of different length and thickness, and different mixture of concrete strength from normal to high strength concrete. In all the concrete mixes the compressive strength, the split tensile strength and the modulus of rupture were slightly improved by the presence of the fibers.

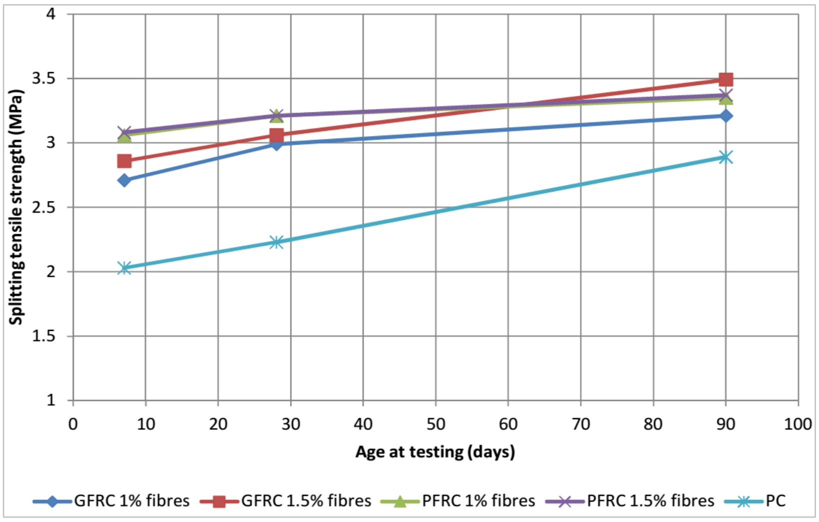


Figure 2-4 Comparison between splitting tensile strength of GFRC and PFRC with unreinforced concrete after (Choi and Yuan, 2005)

When polypropylene fibers are added to concrete they will not significantly affect the elastic response of the concrete and they only start giving the concrete structural support at the point of cracking. From there the fibers improve the tensile strength as well as the impact strength and toughness (Manolis *et al.*, 1997). This could be attributed to the reduced crack formation and development, providing post-crack strength(Topçu and Canbaz, 2007).

2.4.4. Flexural strength of SNFRC

(ACI Committee.544.R, 1999) commented that two strength values should be reported from a flexural test. These are the first-crack flexural strength and the peak post-cracking flexural strength, which can be calculated using the assumption of linear stress distribution. The first-crack flexural strength, if expressed in terms of the square root of the concrete compressive strength, is often referred to as the modulus of rupture, a quantity reported in the literature. Another important property that should be reported is the toughness, which is defined as the area underneath the load-deflection curve from a bending test.

It has been reported that for the flexural strength and modulus of rapture, polypropylene fibers do not have a significant effect. Adding a 0.1% volumetric ratio of fibrillated polypropylene fiber would slightly increase pre-cracking flexural strength. However, fiber content ranging from 0.2 to 0.3 by volume will decrease the pre-flexural strength (ACI Committee.544.3R, 1993).

Adding fibers with volume fractions less than 1.0% does not significantly affect the flexural strength beyond the first crack. By contrast, those volume fractions would greatly enhance the flexural post-cracking strength (Setkit, 2012).

The use of polypropylene fibers does not significantly improve the flexural strength of concrete since the load capacity of PPFRC is similar to conventional concrete at first crack. Three or four-point beam tests can be used to obtain the load-deflection curve from which the equivalent flexural strength, Re3, a value can be calculated.

The equivalent flexural strength is defined as the average load applied for the 450 mm span beam to deflect to 3 mm. This is expressed as a ratio of the load compared to the load at first crack (Soutsos, Le and Lampropoulos, 2012). Figure 2.5 illustrates the effect of fiber on the modulus of rupture. (Ramakrishnan, Gollapudi and Zellers, 1987) found that modulus of rupture for fibrillated concrete is slightly increased than plain concrete by using 0.1 to 0.3 volumetric ratio of polypropylene fiber.

The flexural strength of SNFRC increases as the temperature decreases as was found in a study that tested the flexural strength on to different dosages of fibers under a temperature below freeze point.

(Pigeon and Cantin, 1998) conducted a four-point flexural test on beam specimens with water: cement (w/c) ratios of 0.45 and 0.3 respectively. The research found that for both normal strength concrete (w/c of 0.45) and a higher performance one (w/c of 0.3) flexural strength of the concrete increased for temperatures under 0°C. Two different fiber dosages were used: 40 and 60kg/m³ respectively. Four-point beam tests done by (Soutsos, Le and Lampropoulos, 2012) showed that the use of a synthetic fiber, made from a mixture of polypropylene and polyethylene, at dosages ranging from 4.5 to 5.330kg/m3, only increased the flexural strength of the conventional concrete by 0.2 to 0.25 N/mm^2 from its original value of 4.2 MPa.

(Selvi and Thandavamoorthy, 2013), from their experimental investigations on hybrid fibers with crimped steel and polypropylene in the concrete matrix to study the improvements in strength and durability properties, reported that the addition of steel and polypropylene fibers to concrete exhibit better performance.

(K. Murahari, 2013) tested 500 x 100 x 100 mm specimens under three-point loading in accordance with ASTM C 078. It is observed that the flexural strength increased with content up to 0.3% and gained more strength at 28 days when compared to 56 days. (Gencel *et al.*, 2011) reported that the flexural strength increases with the addition of fiber content.

(V. Ramadevi and D.L. Vanketsh Babu, 2012) studied the flexural behavior of hybrid steel-polypropylene fiber reinforced concrete beams and observed that the use of steel-polypropylene hybrid fiber reinforced concrete improves the flexural performance of the beams during loading.

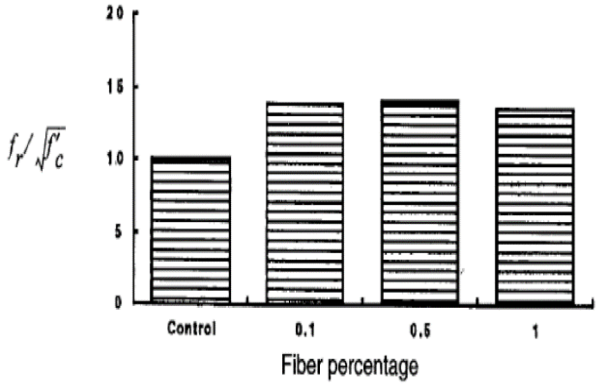


Figure 2-5 The effect of fiber content on the modulus of rupture (ACI Committee.544.R, 1999)

2.4.5. Flexural toughness of SNFRC

Since flexural loading is the most common and important loading state for FRC applications and the bending test is relatively easy to carry out and to the instrument, flexural toughness testing is most often used. Many different test methods have been developed for measuring the flexural toughness. Most of them use a static third point bending configuration, and the energy absorbed by the specimen is computed from the area under the load-deflection curve.

An important property of FRC is the increased toughness (energy absorption capacity) observed in tests(Yurtseven, 2004). Toughness can refer to results from compression, tension, and flexural tests. All toughness measurements require testing by a satisfactorily stiff hydraulic machine. In order to eliminate energy loss after the first peak and to obtain reliable post-crack curves, a satisfactorily stiff hydraulic machine is required (J.Patel. Methul, 2013; Löfgren, 2005).

(Cengiz and Turanli, 2004) performed panel tests to compare the performance of steel mesh reinforcement to that of steel fiber reinforcement, high-performance polypropylene fiber reinforcement and a hybrid mix of both steel- and polypropylene fibers. Their most important conclusions obtained were that polypropylene fibers greatly enhanced the flexural ductility, toughness, and load-carrying capacity of the concrete. They further found that a hybrid polypropylene- and steel fiber mix can be used alternatively to steel mesh in shotcrete applications to gain improvements in mechanical properties.

(Won *et al.*, 2009) found that the flexural test results of concrete containing crimped-type synthetic macro fiber showed that strain hardening behavior was evident after the first crack occurred. In addition, the sample with a synthetic macro fiber volume of 2% showed excellent toughness after the first crack without a load decrease.

An increase in flexural toughness was witnessed by (Mirzac, 1996) in their research by performing flexural strength tests on concrete specimens reinforced with polypropylene fibers. They found that for volume fractions of 0.1%, 0.2% and 0.3% of fibers the flexural toughness increased by 44%, 271%, and 386% respectively over that of plain unreinforced concrete for the same mix compositions.

(Soutsos, Le and Lampropoulos, 2012) tested 150mm×150mm×550mm beam specimen with synthetic fiber dosage of 4.6 kg/m^3 and 5.3 kg/m^3.The flexural toughness of concrete increased considerably when steel and synthetic fibers were used.

(Won *et al.*,2006) found that the structural synthetic fibers improved the flexural toughness of the concrete by 22 to 30% compared with steel fibers because the structural synthetic fibers fully utilized matrix anchoring without fracturing, while maintaining the maximum pullout resistance owing to mechanical deformation of fibers.

2.4.6. Fibers properties affecting the toughness of FRC

It is generally accepted that an increase in fiber dosage results in an increase in the post cracking performance parameters. The fiber material also affects the performance with steel fibers generally outperforming synthetic fibers at the same dosage (Buratti *et al*.,2011; Soutsos *et al*.,2012; Won, Lim and Park, 2006).

Figure 2-6 shows results from the research of (Soutsos *et al*.,2012)which shows the improvement in post-cracking three-point beam bending test performance when increasing synthetic fiber dosage from 4.6 $kg.m^{-3}$ to 5.3 $kg.m^{-3.}$

While the testing variables already affect the measurement of the load-deflection response of FRC, the material variables influence the intrinsic performance of FRC.

The material variables include:

a. Fiber: adddition rate (volume),type,geometry(profile),aspect ratio,orientation and distribution in concrete mix,etc.
b. Matrix:w/c ratio (matrix strength),maximum aggregate size ,cement,admixture,etc.
c. FRC: age of concrete,moisture content of FRC specimen, and so on.

Many investigators have studied the effects of these variables on the performance of FRC.In this section, some of the most important effects are discussed.

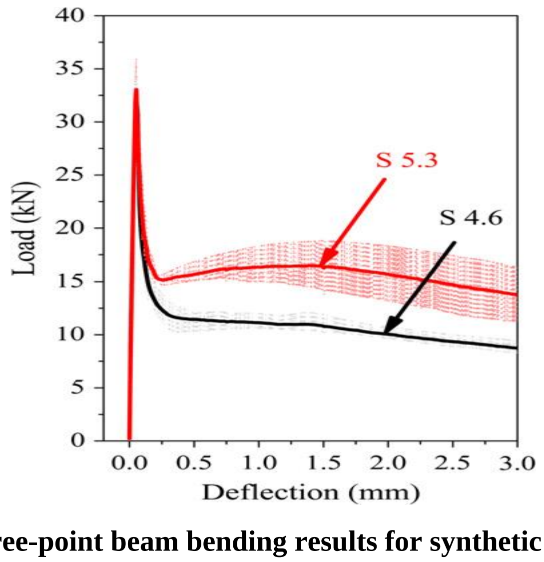


Figure 2-6 Typical three-point beam bending results for synthetic fibers (Soutsos, Le and Lampropoulos, 2012)

a. Fiber addition rate (fiber volume rate)

The fiber addition rate probably has the largest influence on the mechanical performance of FRC. Adding discontinuous fibers to the concrete matrix improves the post cracking response of the concrete and increases its toughness. It is well known (Balaguru *et al*.,1992;

(Gopalaratnam and Gettu, 1995; Johnston and Gray, 1986; Johnston and Skarendahl, 1992) that, with an increase of fiber addition rate, the toughness of FRC increases. Different fiber addition rates will lead to very different shapes of load-deflection curve and hence the calculate toughness values. Therefore, an acceptable method of evaluating toughness should be able to distinguish well among different fiber contents.

b. Fiber Type

Fibers significantly improved the ductility of the concrete matrix, that is its energy absorption capacity (toughness). Many different types of fibers have been used in practice, including steel fibers, glass fibers, synthetic fibers,asbestos fibers, natural fibers, etc. the mechanical properties and toughness of different types of FRC are thus very different. as summarized by (J.Patel. Methul, 2013; Bentur A, 1990), the application of FRC are as varied as the types of fibers that have been used.

Asbestos fibers have long been used in pipes and corrugated or flat roofing sheets. glass fibers are used primarily in precast panel (non-structural). steel fibers have been used in pavements, in shortcrete , in dams, and a variety of other structures. Increasinglly,fibrillated polypropylene fibers are being used to control plastic shrinkage cracking.

To compare the contributions of different fibers to the toughness of FRC and to evaluate new types of fibers, it is necessary to evaluate how well a particular test method characterizes and distinguishes the toughness performance of different kinds of FRC.

c. Water to cement ratio (Matrix strength)

The matrix strength of FRC is mainly dependent on its W/C ratio. In third point flexural toughness tests, it is usually being found that changes in W/C ratio change the first crack stress and the ultimate strength of FRC significantly, but have relatively little effect on the shape of the load-deflection curves (Johnston and Skarendahl, 1992). Therefore, W/C ratio can change significantly the absolute toughness values of FRC but has only a slight influence on its relative toughness.

The post crack behavior of FRC composites depends mainly on the content and properties of the fibers, while the pre-crack behavior depends primarily on the properties of the matrix.

If in two different FRC beams, the fiber contents are the same but the matrix strength is different, the load-deflection curve from the higher matrix strength (lower W/C ratio) beam will have a higher first crack load and hence a larger first crack toughness (energy absorbed up to the first crack), but the two beams will have similar post crack toughness. However,(Balaguru *et al.*,1992)found that an increase in matrix strength generally leads to a more abrupt in post-peak load.(Banthia and Trottier, 1994) also found that the matrix strength also has a significant influence on the toughness characteristics. At high matrix strength, there is usually a steeper and a sudden drop in the load-carrying capacity after the first crack. The influence of matrix strength, however, is fiber geometry dependent.

In any event, a good method of toughness evaluation should provide the complete characterization of FRC, not only in terms of absolute toughness values but also in terms of the relationship between pre-crack and post crack toughness.

d. Profile of fiber

For a particular fiber type, the profile (shape) of the fibers can be as important to the mechanical performance of FRC as the fiber volume content. Surveys of flexural strength data have been made by (Johnston and Gray, 1986 and Swamy, Mangat and Rao, C.V.S.K.,) and extensive experimental work has been carried out by(Lankard, 1972) and (Edgington, J.M, 1973). All of these authors agree that the major fiber-related factors affecting flexural strength are the fiber volume content and the aspect ratio (length/diameter ratio for straight fibers) of the fibers.

An increase in either of these parameters leads to higher flexural strengths. (Johnston and Gray, 1986) surveyed the data for the area under the complete load-deflection curve and also the area up to the maximum stress. Figure 2-7 was plotted using the information in Reference (Johnston and Gray, 1986) by (Hannant).

For deformed or hooked fibers the aspect ratio of the fibers cannot be simply expressed as the length /diameter ratio due to their complicated profile. In this case, the profile (shape) of the fibers may affect the mechanical performance of FRC to an even greater extent.

2.4.7. Shear Strength of SNFRC

Macro synthetic FRC increased the first diagonal cracking strength and the ultimate shear strength relative to the control RC beams. The increase in shear strength above the reference beams ranged between 14 and 30% for slender SNFRC beams, depending on the dosage of fibers and by more than 28% for short beams (Altoubat, Yazdanbakhsh and Rieder, 2010).

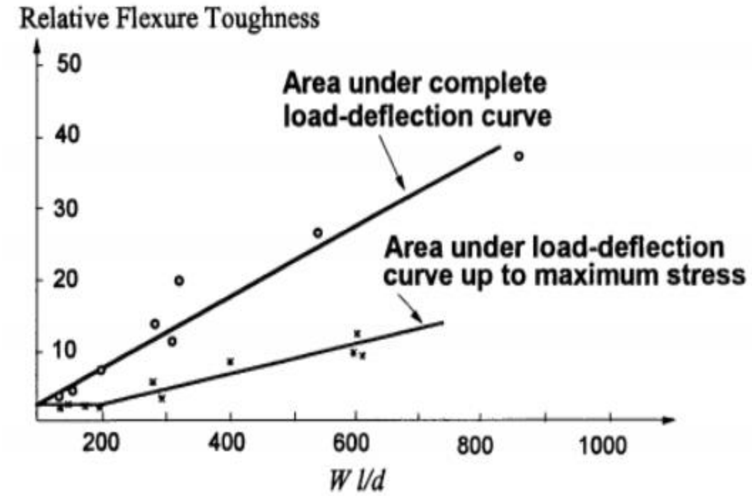


Figure 2-7 Influences of W l/d on flexural toughness (after Hannant)

Where l = fiber length

d = fiber diameter

$$W = \frac{\text{weight of fibers } \times 100}{\text{weight of concrete}} \qquad (2.1)$$

A total of 30 beams were cast and tested based on Japan Society of Civil Engineers (JSCE G-553) and ASTM C1609 for evaluating the effect of synthetic fibers on shear capacity and flexural behavior of concrete with 28 MPa compressive strength. Based on the shear and flexural test results, increasing fiber dosages enhance the shear strength and shear toughness as well as flexural strength and flexural toughness. Moreover, lower fiber dosages have more influence on compressive strength than higher ones (Mostafazadeh and Abolmaali, 2016).

(Majdzadeh, Soleimani and Banthia, 2006) investigated the influence of shear reinforcement on the shear capacity of reinforced concrete beams by using both steel and synthetic fibers at variable volume fraction. Fiber reinforcement enhanced the shear load capacity and shear deformation capacity of RC beams, but 1% fiber volume fraction was seen as optimal: no benefits were noted when the fiber volume fraction was increased beyond 1%.

(Ahmed *et al.*, 2006) found that the shear capacity of concrete increases when fibers are added. The test results concluded that there is a remarkable increase in load-carrying capacity up to the first crack appears.

2.4.8. Shear Failure Mechanism of FRC

Concrete is a brittle material. Its tensile strength is considerably lower than its compressive strength. Reinforced concrete fails suddenly in shear without any previous warning the first diagonal crack was associated with a sudden load reduction in the load-deflection curve. For control beams, the load did not increase beyond the first diagonal cracking load, and thus it marked their ultimate capacity.

The reference beam failed immediately after the formation of an inclined crack exhibiting the expected brittle shear failure. The beams reinforced with fibers, however, were able to resist further load after the occurrence of inclined shear cracking and the mode of failure for some of the beams was changed from a shear failure to a more ductile flexural failure (Greenough and Nehdi, 2009).

The addition of macro synthetic fibers increased the first diagonal crack load relative to the control beams. The failure mechanism starts with diagonal cracks, which can be wider than flexural cracks (Altoubat *et al*.,2010).

The first type of behavior was related to the control concrete beams that exhibited sudden shear failure as indicated by the abrupt drop in the load-deflection curve followed by a complete loss of the load-carrying capacity. The second type of behavior was related to the fiber concrete beams, which did not fail when the first diagonal shear crack was formed and the post-cracking behavior was dependent on the fiber dosage (Altoubat *et al*.,2010).

CHAPTER THREE

MATERIALS AND RESEARCH METHODOLOGY

3.1. Study Area

The research was conducted in Jimma Town, Oromia National Regional State South West Ethiopia which is located at 346km from Addis Ababa. The geographical location is 7° 13‟-8° 56N latitude and 35°49‟-38°38‟E latitude and longitude respectively. The altitude is 1780m above sea level; the climate is (weynadega) and the estimated area of 19506.24km^2. The experimental test was conducted in Jimma Institute of Technology Construction Materials University Laboratory, Jimma and Material Research and Testing Center, Addis Ababa.

3.2. Research Design

The aim of this research was to investigate the mechanical performance and shear behavior of synthetic fiber reinforced concrete. An experimental study was performed to examine this properties fiber reinforced concrete beam with a concrete strength of 25 and 40 MPa and fiber volume factions,0.2, 0.35, 0.50, and 0.65%. The non-fibrous concrete is used as a control to compare and select the fiber which was enhance both mechanical and shear behaviors.

In order to determine the effect of fibers on mechanical and shear behaviors SNFRC, different laboratory test was performed on fresh and hardened concrete; slump test, compressive strength test, split tensile strength test, flexural strength test and shear strength test was conducted.

3.3. Study variables

3.3.1. Dependent Variables

- Mechanical performance and Shear Behavior of SNFRC beam.

3.3.2. Independent Variables

- Percentage of synthetic fiber
- Concrete strength
- Type of synthetic fiber
- Specimen dimension

3.4. Population and sampling method

The sampling size was done based on the percentage of fibers and concrete strength used for conducting the laboratory tests to determine the mechanical and shear behavior of SNFRC. The total number of population was the number of cubes for compressive strength test, cylinder for split tensile strength test, beams for flexural and shear tests were prepared by considering 0.20,0.35,0.50 and 0.65% fiber by volume of concrete and two types of concrete strength (25 and 40 MPa).

Sampling model was done by using representative sampling in which the samples were prepared in the laboratory from the concrete batch contains the same material properties and under the same mixing temperature in addition to this, the curing period and moisture contents of the concrete sample have been under consideration. For fibers an additional safety was taken when weighing the amount of fibers and to prevent the materials from mix of dust and chemicals. Number of samples taken for the research and their dimension is presented in Table 3-1.

Table 3-1 Total number of required specimens

Test Conducted	Type of Mold	Dimension			Number of specimens[1]
		b/d,mm	h,mm	l,mm	
Compressive strength	Cube	150	150	150	42
Split tensile strength	Cylinder	-	100	200	28
Flexural Strength	Beam	150	150	500	28
Shear strength	Beam	100	100	270	42
Total samples					**140**

[1] Number of specimens for each test consists of:

- Wet cured all the way tested at the age of 28 days for both micro and macro fibers with fiber contents of 0.20,0.35,0.50 and 0.65% with each 3, for concrete strength of 25 MPa yields 3×4×2=24.
- 28 days cured for both micro and macro fibers with fiber contents of 0.35 and 0.65% with each 3, for concrete strength of 40 MPa yields 3×2×2=12.
- Wet cured all the way tested at the age of 28 days with non-fibrous (0% fiber) as control for both 25 and 40 MPa concrete strength gives 3×2=6.

- Samples were tested for compressive and shear strength with the size given in the table.
- for each trial mix two cylinders for tensile and beams for shear test with size given in the table which sum up to 2×4×2+2×2×2 +2×2=28.

3.5. Experimental program and strategy

Figure 3-1 shows the simple procedures for conducting the experimental test and collecting the results for analysis.

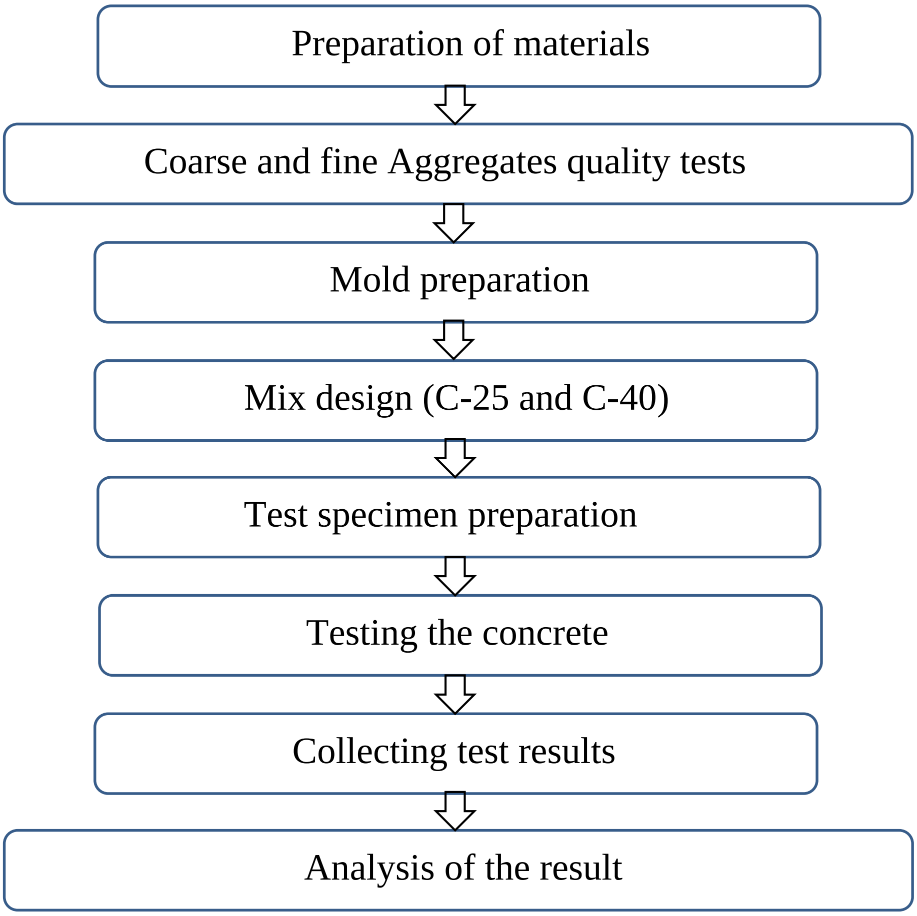


Figure 3-1 Flow chart of experimental program

3.6. Material properties

3.6.1. Cement

The binding material used in this research was Ordinary Portland Cement produced by Dangote Cement Factory,42.5R. The cement considered was stored in a dry place until it is used for concrete production. Its specific gravity was 3.15.

3.6.2. Fine aggregate

The fine aggregate used for the investigation was a natural sand which is purchased from Jimma sand suppliers, in Jimma city but, the main source of the material, Gambella, which is located about 426.7 km western part of Jimma.

Sieve analysis tests were carried out on representative samples and it was initially found that the sand was coarser than required to be used for concrete production, according to ASTM C33-03. It was, therefore, required to sieve finer sand separately with 4.75mm sieve size in order to meet the ASTM requirements. Accordingly, 75% passing sieve size 9.5mm and 25% passing 600 µm sieves the mean results are tabulated in Table A-6 in the Appendix A3.

The sand was also checked for silt content and it was found that it consists of a mean of 6.5% (6.9,5.1and 7.5) for sand passing 4.75mm. It was then decided to wash the sand until the silt content was lowered to an allowable limit of less or equal to 6%. After washing the sand, the silt content was reduced to an average value of 1.6% (1.37 and 1.83). The detail calculation and results are tabulated in Table A-8 in the Appendix A3.

In addition, moisture content, specific gravity, absorption, unit weight and fineness modulus test are have done to determine the physical properties of sand. Table 3-2 represents the mean results of the test. Test Procedures and the detail calculation of the results are given in Appendix A3.

3.6.3. Coarse aggregate

In concrete, an aggregate was used for its economy factor, to reduce any cracks and most importantly to provide strength to the structure. It also increases the volume of concrete, thus reduces the cost, provide dimensional stability influence hardness, abrasion resistance, elastic modulus and other properties of concrete to make it more durable, strong and cheaper.

Table 3-2: Fine aggregate properties

No.	Description	Test Result	Recommended Value
1	Type of Fine Aggregate	Natural Sand	Good Quality
2	Silt Content (%)	1.6	≤ 6%
3	Moisture Content (%)	0.25	
4	Bulk Specific Gravity	2.54	-
5	Absorption (%)	0.76	2.5-3.5
6	Unit weight (kg/m 3)	1625	
7	Fineness Modulus (%)	2.4	<3

Table 3-3 Coarse aggregate properties

No.	Description	Test result
1	Type of coarse aggregate	Crushed stone
2	Moisture content (%)	0.525
3	Specific gravity(%)	2.82
4	Water absorption(%)	1.05
5	Unit weight (kg/m^3)	1656

The coarse aggregate was obtained from the quarry in Jimma. The aggregates were supplied relatively clean, washed to keep quality and had an absorption capacity less than 1%. The supplied aggregates were not of the required grading and could not be used to produce concrete without blending. After the sieve analysis of the purchased aggregates, the results with the average size of 20 mm were selected to satisfy the ASTM Standard C33-03 requirement. The aggregates sieve analysis test results are shown in Tables A-2 in the Appendix A2. In addition, moisture content, specific gravity, absorption, unit weight and fineness modulus test are have done to determine the physical properties of sand. Table 3-3 represents the mean results of the test. The procedures, formulas, and the detail calculation of the results are given in Appendix A2.

3.6.4. Water

In conducting the study municipal water was used in mixing and curing of concrete. Mixing water was the quantity of water that comes in contact with cement, impacts slump of concrete and was determined from water to cement ratio as per ACI mix design Specification.

3.6.5. Synthetic polypropylene fiber

Two different types of fibers were used in this investigation:

The first one is virgin polypropylene fiber (micro synthetic fiber). They were supplied by Reliance Industries Limited, Mumbai, India with trade name Recron 3S. The intent of the fiber profile is to enhance the bond between the fiber and the matrix. According to the manufacturers, the fiber is designed to reduce the rebound loss by 50-70%, reduces cracks during plastic and hardening stage, reduces the water seepages and protects steel in concrete from corroding and walls from dampening of the floor, increases the abrasion resistance by over 40% thereby increasing life of roads, and reduce the matrix.

The second one is 100% macro synthetic fiber. They were supplied by Bajaj Reinforcements, Nagpur, India with the trade name of Fiber Tuff.

The intent is to enhance the energy absorption capacity and improve the post crack behavior of concrete. Figure 3-2 shows the virgin micro polypropylene and macro synthetic fiber with its crimped configuration while Table 3-4 gives the properties of both fibers as obtained from the suppliers.

Benefits of using this fiber are:

- Significantly improves shrinkage and temperature crack control,
- Safer and lighter to handle than steel
- Reduces permeability
- Unlike steel, doesn't stain concrete with rust marks
- Increases flexural strength
- Increases tensile strength
- Increases energy absorption
- Increases ductility
- Increases toughness
- Increases post crack load capacity

➢ **To the author knowledge, no study on this type of fiber has been reported in Ethiopia yet**.

Figure 3-2 Synthetic fibers: a) Micro virgin polypropylene synthetic fiber; b) Macro polypropylene synthetic fiber

Table 3-4: Properties of fibers used

Properties	Micro synthetic fiber	Macro synthetic fiber
Tensile Strength, MPa	550-640	550-640
Young's Modulus, GPa	3-5	6-10
Specific Gravity/cm^3	0.9-0.92	0.90-0.92
Melting Point, ℃	162-167	159-179
Surface Texture	Triangular	Continuously embossed
Length, mm	12	50
Diameter, mm	-	>0.30

3.7.Mould Preparation

In preparation to cast samples for the investigation of the mechanical and shear behavior of synthetic FRC, specific molds had to be prepared for the various tests. Different tests carried out at the micro and macro synthetic fibers levels: slump test, compressive strength, split tensile test, flexural strength, and shear tests.

Compressive strength was tested using 150 mm steel cube molds. Cylindrical steel molds with 100×200(d×h) were used to cast specimens for the split tests. It should be remarked that while the molds for the flexural investigation need for an adjustment to meet its intended purpose, the molds used for the test is prepared in the laboratory from wood with a size of 150×150×500 mm to meet requirement given for the test specified in (AASTM C 078, 2002).

For the shear test, the molds are prepared from wood to meet the requirement of size given in Z.P. Bazant shear fractures method with 100×100×270 mm (b×h×l). The inner surface of all molds was properly oiled with mold oil to easily demolding of the specimens.

3.8.Mix design and proportioning of SNFRC

3.8.1. Mix Design of SNFRC

Mix design is used for selecting suitable ingredients of concrete and determining their relative proportions with the objective of producing concrete of certain minimum strength and durability as economically as possible. The third calls for use of the minimum amount of cement (the costliest of the components) that will achieve adequate properties. The better the gradation of aggregates, i.e., the smaller the volume of voids, the less cement paste is needed for wetting the surface of the aggregate. As water is added, the plasticity and fluidity of the mix increases (i.e., its workability improves), but the strength decreases because of the larger volume of voids created by the free water. To reduce the free water while retaining the workability, cement must be added. Therefore, as for the cement paste, the water /cement ratio is the chief factor that controls the strength- of the concrete.

The mix-design procedure used for this investigation is American Concrete Institute Method of Mix Design (ACI–211.1). The method of mix design makes use of the slump test together with a set of tables that, for a variety of conditions (e.g. types of structures, dimensions of members, degree of exposure to weathering, etc.), permits one to estimate proportions that will result in the desired properties. This method is selected because, it is widely used in world concrete construction practices and is found to be easier to be adopted to our situation.

The design process involves nine stages, each of the which deals with a particular aspect of the design and ends with a required mix parameter. The detail procedures for the mix design is given in Appendix Figure 3-3 shows the flow chart for used during the in proportioning the ingredients of SNFRC.

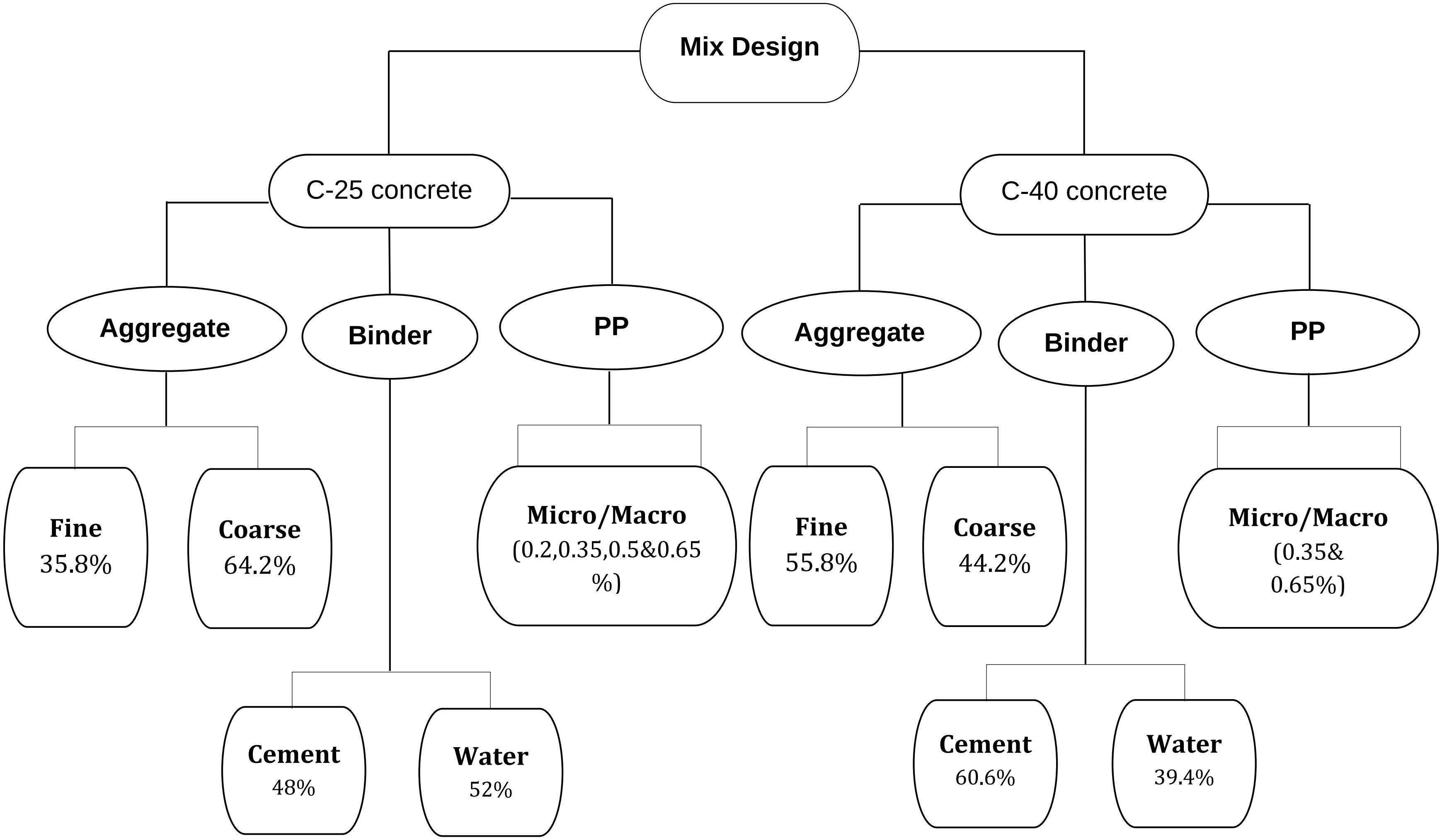


Figure 3-3 Mix design flow chart for SNFRC

3.8.2. Proportioning of SNFRC

a. materials in concrete

The amounts of cement, fine aggregate, and coarse aggregate were determined depending on the targeted compressive strength using different mixes done before in the laboratory. In this research, the ACI Standard 211.1-91 “Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete” is used to determine each quantity of the ingredients in the mixture.

Stepwise procedures followed for calculation are given in Appendix B. Table 3-5 represents the summary of the mix proportion used for 25 MPa concrete strength. The same followed for the mix design 40 MPa concrete strength, the summary of results is shown in Table 3-6.

Mass calculation for one mix is given as follows:

Total volume of One mix (V_T) = $3\times V_1 + 2\times V_2 + 2\times V_3 + 3\times V_4$ (3.1)

Where:

$V_1 = 3.375\times10^{-3}$ m^3(Compressive Cube mold,150×150×150mm)

$V_2 = 1.570\times10^{-3}$ m^3(Tensile cylindrical mold,100×200mm(d×h))

$V_3 = 11.25\times10^{-3}$ m^3(Flexural Beam,150×150×500mm(b×h×l))

$V_4 = 2.700\times10^{-3}$ m^3(Shear Beam,100×100×270mm(b×h×l))

Therefore, $V_T = 3\times3.375\times10^{-3}\ m^3+2\times1.570\times10^{-3}\ m^3+2\times11.25\times10^{-3}\ m^3+3\times2.700\times10^{-3}\ m^3$

$= \underline{45.43\times10^{-3}\ m^3}$

Hardened concrete, $V_T = 1.55\times45.435\times10^{-3}\ m^3$

$= \underline{70.41\times10^{-3}\ m^3}$

Mass of cement in one mix (Kg)= $\left(\frac{VT}{Ratio\ of\ proportions}\right) \times \text{Unit weight of cement}$ (3.2)

Unit Weight of cement = 1440 Kg/m^3

Table 3-5: Summary of mix proportions for C-25 concrete

Ingredients	**Quantity in (Kg/m^3)**	**Ratio**	**Calculation**	**Total mass in one mix (Kg)**
Cement	370	1	$\left(\frac{V_T}{1+1.91+2.98}\right)\times 1440$	17.21
Fine aggregate	708.80	1.91	Mass of cement × 1.91	32.88
Coarse aggregate	1103.89	2.98	Mass of cement × 2.98	51.30
Water	193.8	0.52	Mass of cement × 0.52	8.95

Table 3-6: Summary of mix proportions for C-40 concrete

Ingredients	Quantity in (Kg/m³)	Ratio	Calculation	Total mass in one mix (Kg)
Cement	462.5	1	$\left(\frac{V_T}{1+1.33+2.39}\right)\times 1440$	21.49
Fine aggregate	616.07	1.33	Mass of cement × 1.33	28.63
Coarse aggregate	1103.89	2.39	Mass of cement × 2.39	51.29
water	182.4	0.394	Mass of cement × 0.394	8.47

b. Fiber volume fraction

However, the required amount of each fiber type was determined depending on the specific gravity, which was provided by a producer. The amount of polypropylene synthetic fiber content 0.20%,0.35%,0.50% and 0.65% by a total volume of concrete was added calculated for $1m^3$ of both 25 MPa and 40 MPa concrete strength. From the producer the specific gravity of the fibers is 0.9-0.92 g/cm^3 so, in this research, the average is taken as 0.91 g/cm^3 is used to calculate amount of fiber in mixture by weight.

The general calculation of 0.20% fiber volume content for each mold in tests is given in the Table 3-7. Table 3-8 shows the summary of fiber content for all percentage of volume. The sample calculation is shown below:

Total volume (V_T) = $1m^3$ + Vpp (Volume of polypropylene) (3.3)

For 0.20% addition of PP fiber:

$Vpp = 0.20\%(V_T)$

$Vpp = 0.20\%(1m^3 + Vpp)$

$0.998Vpp = 0.20\%\times 1m^3$

$Vpp = 2.004\times 10^{-3}m^3$

$Vpp = 2004cm^3$

For 0.35% addition of PP fiber:

$Vpp = 0.35\%(V_T)$

$Vpp = 0.35\%(1m^3 + Vpp)$

$0.9965Vpp = 0.35\%\times 1m^3$

$Vpp = 2.007\times 10^{-3}m^3$

$Vpp = 2007cm^3$

For 0.50% addition of PP fiber:

$$Vpp = 0.50\%(V_T)$$

$$Vpp = 0.50\%(1m^3 + Vpp)$$

$$0.995Vpp = 0.50\% \times 1m^3$$

$$Vpp = 2.01\times10^{-3}m^3$$

$$Vpp = 2010cm^3$$

For 0.65% addition of PP fiber:

$$Vpp = 0.65\%(V_T)$$

$$Vpp = 0.65\%(1m^3 + Vpp)$$

$$0.9935Vpp = 0.65\% \times 1m^3$$

$$Vpp = 2.013\times10^{-3}m^3$$

$$Vpp = 2013cm^3$$

Table 3-7: General calculation of 0.20% fiber volume content in concrete

Test conducted	Volume of single mould (cm³)	Calculation	Mass of fiber in single specimen , g	Total mass in single mix(M_T) (g)
Compressive strength test	3375	0.002004×3375×0.91	6.15	18.46
Split tensile test	6286	0.002004×6286×0.91	11	22
Flexural strength test	11250	0.002004×11250×0.91	21	42
Shear strength test	2700	0.002004×2700×0.91	4.92	14.8
				97.26

Table 3-8: Summary of fiber content in the mix

Test conducted	volume of a single mold (cm³)	Mass of fiber in a single specimen(g)			
		0.20%	**0.35%**	**0.50%**	**0.65%**
Compressive strength test	3375	6.15×3	10.79×3	15.43×3	20.09×3
Split tensile test	6286	11×2	20×2	29×2	37.42×2
Flexural strength test	11250	21×2	36×2	51×2	67.0×2
Shear strength test	2700	4.92×3	9×3	12×3	16.07×3
Total mass in single mix(M_T),g		**97.26**	**171.37**	**242.29**	**317.32**

3.9.Mixing of SNFRC

The concrete is mixed at Jimma Institute of Technology, Construction Material Laboratory. As soon as the molds were prepared and ready for use, the mixing of the FRC proceeded. Materials based on the mix design already established were batched by weight. Mixing was done in a 50 liters Gustav Eirich Concrete Mixer.

It was ensured that the number of specimens needed for each investigation was cast from the same batch of mixture. For example, since three specimens were mostly tested for each loading level in the compressive strength and shear strength tests, in addition, two specimens for split tensile and Flexural strength tests, ten specimens were cast from each batch of the concrete mixture at the same volume of fiber to maintain consistency. The mixing procedure for the FRC is enumerated below:

- The mixing drum was properly rinsed with water and dried.
- The dry aggregates and the cement were added to the mixing drum in the order of sand, cement, and aggregate and were allowed to mix for about 3 minutes.
- The water, which already had been measured was added to the mix and allowed to mix for another 3 minutes until a uniform mix was visible.
- For mixes without fibers, the mixing procedure stopped at this point. However, for mixes with fibers, the fibers were then carefully sprinkled into the mix to prevent balling. This stage was allowed to go on for another 5 minutes until a good visible dispersion of fibers was observed.
- Finally, a slump test of the FRC mixture was conducted to study the effect of the fibers on the workability of the concrete.

The procedure outlined in the (AASTM C192, 2002)“Method of making and curing concrete test specimen in a laboratory” is followed.

3.10. Tests on SNFRC specimen

3.10.1. Workability of fresh concrete mix

Workability is a property of fresh concrete by which tile consistency of the mix be such that the concrete can be transported, placed and finished easily and without segregation. The water content of the mix, the amount of cement, particles shape and properties of aggregates mainly affect the workability of concrete. Adding fibers to concrete can pose serious workability issues if the concrete mix is not properly designed to accommodate the fibers.

The aim of this research is to attain slump height of 30-50 mm. The normal concrete mixture for this study was designed to allow for the inclusion of fiber at 0.20%,0.35%,0.50 and 0.65% by the total volume of concrete.

The procedure for the slump test was carried out in accordance with the (AASTM C 143, 2000) " Slump of Hydraulic-Cement Concrete". A slump test value of 54.5mm was obtained for the normal concrete before the introduction of the fibers. This procedure was done for each batch of the concrete mixture as earlier mentioned to ensure consistency.

After the fibers were added; a slump test was also conducted to observe the effect of fibers. The slump of the fiber concrete taken showed a value of 0-50 mm. This indicates a 100% reduction in the slump value of the normal concrete when more than 0.35% micro synthetic polypropylene fiber was added to the mix. Table 4-1 reports the slump height concrete for all fibers content corresponding to different concrete strength and type of fibers.

3.10.2. Compressive strength test

Generally, the term concrete strength is taken to refer to the uniaxial compressive strength as measured by compression tests of a standard test cylinder and/or cubes. The standard acceptance test for measuring the strength of concrete involves short time compression tests on 150-mm cubes or cylinders.

The standard acceptance test is carried out when the concrete is 28 days old. The standard strength test is the mean of the strengths of at least three cubes from the same sample tested at 28 days or an earlier age if specified.

The concrete mixture was designed for compressive strength of 25 and 40 MPa. To achieve the required concrete strength, the ingredients are proportioned depending up on the trial mixes done before in the laboratory so as the excel sheet were prepared for the design.

The provision for specimen size and procedure of test was done according to the requirement of (AASTM C39/C, 2001) using cube sizes of 150 mm. According to the specification given, the size of the fibers used, a cylinder 150 mm diameter and 300mm in high would have been required to ensure a fiber distribution similar to that in the beam specimens. However, because the main intention of the cylinder tests was to determine compressive strength which is not significantly affected by the presence of fibers, the use of a smaller cylinder size was believed to be adequate.

The samples were tested for compressive strength at a loading rate of 0.30 MPa/s using a UTEST Material Testing Machine which had a maximum capacity of 2000 kN.

Three cubes were molded for different fiber types and content whereas, the other three samples were used as control (non fibrous). After the mixture is done the specimens were covered with a plastic sheet and left in the laboratory for one day thereafter, they were demolded the next day and immersed in a water tank for curing until being tested. After all, cylinders were pulled out of the tank approximately one day prior to their test date.

Before each test, the testing machine bearing surfaces were wiped clean and any loose grit or other extraneous materials were also removed from the surface of the cube, which may be in contact with the platens. The cube specimen was centrally placed on the lower platen and it was checked to ensure that the load will be applied to two opposite faces of the cube.

The maximum load applied to the cube was recorded to obtain the failure stress. The mean results obtained and the failure stresses is calculated. The compressive strength, σ, from a cube test is computed using Eq. (3.4).

$$\sigma = \left(\frac{P}{A}\right) \quad (3.4)$$

where: σ = compressive stress, MPa;

P = Applied load, kN

A= Area of a specimen, m^2, in this case, A= 0.0225 m^2

Test results. Table 4-2 reports the concrete cube compressive strength result and the detail sample information is listed in Appendix C1. Figure 3-4 shows the digital series compression tester used to conduct the compressive strength and shaking table used during the compaction of concrete to evenly distribute the fibers and get sufficient compaction.

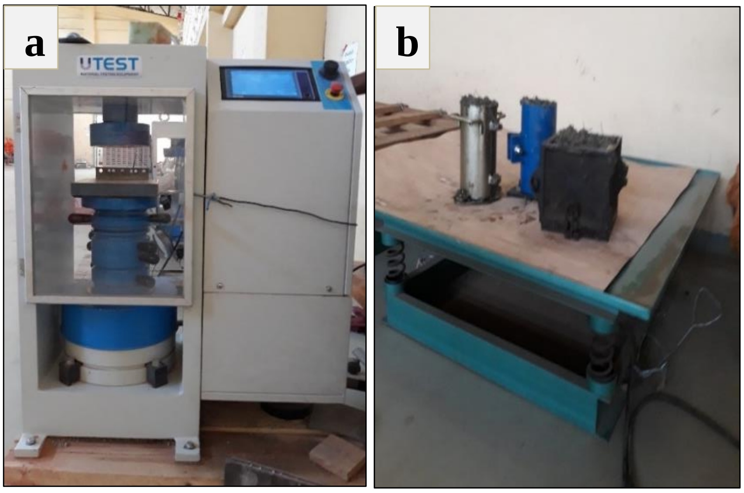


Figure 3-4 a)Concrete compressive testing machine; and b)shaking table (from the laboratory)

3.10.3. Split Tensile Strength

The tensile strength of concrete varies between 8% and 15% of its compressive strength. The actual value is strongly affected by the type of test carried out to determine the tensile strength, the type of aggregate, the compressive strength of the concrete, and the presence of a compressive stress transverse to the tensile stress (Raphael J.M., 1984).

All three-cylinder specimens from each mix were wet cured for 28 days and sampled following ASTM C 172-99. The test was conducted following (AASTM C 496, 1996)**"**Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens" as shown in Figure 3-5. A concrete compressive tester was used to apply the load at a loading rate of (689 to 1380 kPa/min) until failure of the specimen. The summary of mean results is given in Table 4-3 and

Figure 3-5 Split tensile test;a) test setup;b)first crack initiation;c) near to failure ;and d)at failure stage

Test results. Table 4-3 reports the concrete split tensile strength for cylinders corresponding to all the test beams and the detail specimen information is given in Appendix C2.

The splitting tensile strength from split cylinder test is computed according ASTM C 496 as follows:

$$\sigma_t = \left(\frac{2P}{\pi l d}\right) \qquad (3.5)$$

where: σ_t = splitting tensile strength, MPa

P = maximum applied load indicated by the testing machine, kN,

l&d = length and diameter of specimens, m

3.10.4. Flexural Strength Test

In conventional concrete, the flexural strength is often called the modulus of rupture (MOR), and it is usually investigated using either the three or four-point bending tests. When dealing with FRC, post-peak behavior is usually of interest.

In this research work, the requirement of (AASTM C 78, 2002) **"**Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)" in characterizing the residual flexural tensile strength of FRC beam specimens were adopted.

All specimens conformed to the dimension recommended by (AASTM C 78, 2002),150mm × 150mm × 500 mm(b×h×l).Each beam specimen was sampled prepared and cured following (AASTM C192/C, 2002).

Hence the toughness or load-deflection behavior is also of interest in this research the beam specimens were tested at the age of 28 days following (AASTM C 1018, 1997). Specimens were wiped clean of excess moisture, then marked to ensure correct placement of the beams on three points loading. After the samples were positioned in a third point bending test setup with a span of 450 mm and specimen supports at 150 mm testing commenced.

All specimens were tested in the UTM 70-C0820 machine. The beam midspan deflection was measured by a pair of linear potentiometers attached to a frame such that a net midspan deflection would be measured. The machine was then controlled in sequence using a load rate of 1.1 MPa /min up to the failure of the specimen is occur. Figure 3-6 shows the specimen setup for concrete under the flexural third point testing.

It should be noted that the load-deflection measurement used to determine the flexural toughness of the SNFRC was also measured from this test.

Figure 3-6 Flexural strength test under loading

Test results. Table 4-4 reports the concrete flexural strength for beams corresponding to all the test beams and the detail specimen information is given in Appendix D1.

The flexural strength from third point test is computed according to ASTM C 078 as follows:

$$f_b = \left(\frac{P \cdot L}{b \cdot h^2}\right) \qquad (3.6)$$

Where: f_b = flexural strength in MPa,

L = the span of the specimen in mm, in this case, L = 450 mm,

P = the failure load in N,

b = the width, mm

h = height of the specimen's in mm

3.10.5. Shear Strength Test

Hence the direct shear test machine is not available in Ethiopia, the test setup for the shear strength followed the method reported by (Bazant and P.A.feiffer, 1986)"Shear fracture tests of concrete" with some minor modifications to the size of the specimen under tests.

The test specimens were beams of constant rectangular cross-section and constant length-to-depth ratio 8:3. The geometry of the test specimen and shear force diagram used in this research consisted of the following arrangement (see Figure 3-7). The specimens of sizes were cast from the same batch of concrete and their thickness were the same.

A shear mold with a size of 100 mm×100mm × 270mm were prepared from the plywood and a pair of symmetric wooden notches, with depth d/6 (17mm) and thickness 17mm (the same for all specimens) was cut by saw and placed at the bottom and top center of the mold.

The purpose of these wooden notches is to form crack initiation in the specimen. Before the placement of the top notches in the mold, it should be fastened by nail to make easily remove the wood when before the test is going on. The detail of the wooden notches and block dimension is shown in Figure 3-8.

Once the mixing was completed, the concrete was placed into 100mm × 100mm × 270mm oiled plywood molds in three-layer, roughly compacted with a tamping rod. The specimen was removed from the plywood formworks after 1 day and was subsequently cured for 28 days until the moment of test, in curing tank, and the specimen was exposed to the environment approximately three hours before the start of the test. Figure 3-8 shows the shear strength specimen set up.

Symmetrically notched beam specimens of concrete and mortar, loaded near the notches by concentrated forces that produce a concentrated shear force zone, are tested to failure.

The shear loading was produced by a system of steel plates, which applied concentrated vertical load on the specimen. Three of loads were applied through rollers, and one through a hinge, which produced statically determinate support arrangement. The steel surface should be carefully managed so as to minimize friction on the rollers.

All specimens were tested in a universal testing machine (UTM 70-C0820) at a constant loading rate. For each specimen size, the displacement rate was selected so as to achieve the maximum load in about 5 minutes.

Test results. Table 4-6 reports the concrete shear strength for beams corresponding to both fiber type, different volume fraction and concrete strength and and the detail specimen information is given in Appendix D3.

The shear strength from Bazant test is computed using Equation (3.7).

$$\tau_{max} = \left(\frac{Pmax}{2Aeff}\right) \qquad (3.7)$$

Where: τ_{max}: ultimate shear strength, MPa

P_{max}: peak load, kN

A*eff:* effective area of a shear plane on either side, m^2

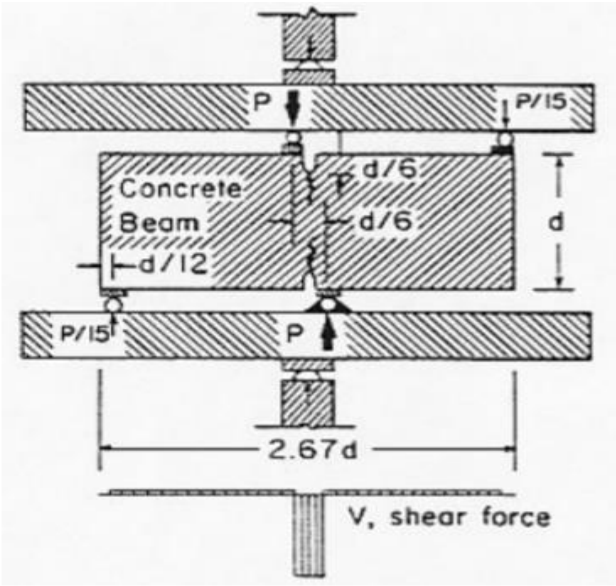


Figure 3-7 Geometry of test specimen and shear force diagram *(from Bazant and P.A.feiffer, 1986)*

Figure 3-8 Preparation of wooden notches and block dimension

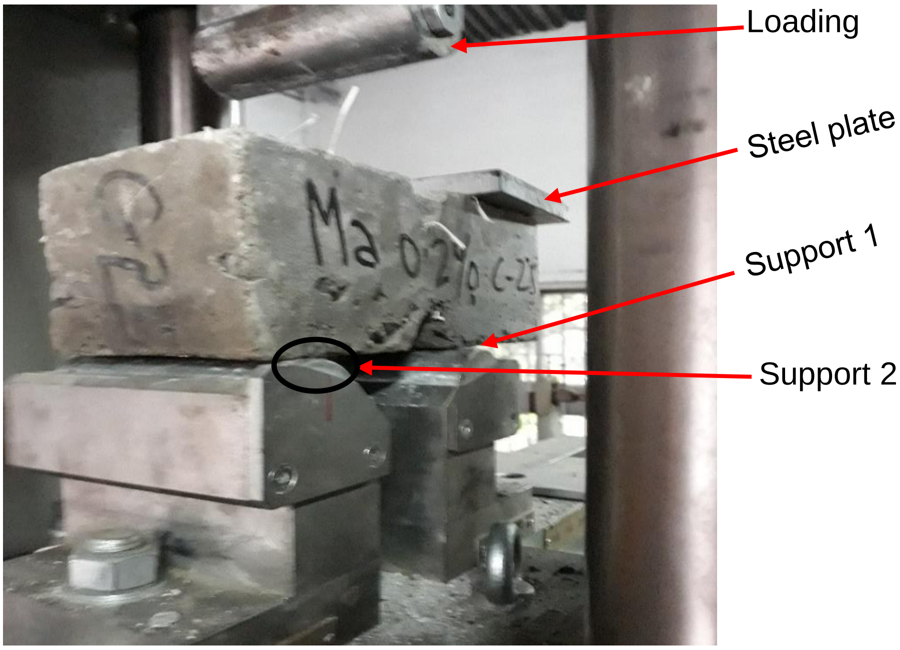


Figure 3-9 Shear strength test setup

CHAPTER FOUR

EXPERIMENTAL RESULTS AND DISCUSSIONS

General

This chapter contains two main parts. The first part focuses on fully understand the mechanical properties and behavior of the fiber-reinforced concrete, which are slump test, compressive strength, tensile strength, flexural strength test, toughness and shear behavior of SNFRC.

In the second part, each beam will be discussed separately to describe the behavior of the reinforced concrete beams by reviewing fresh and hardened concrete properties which are, workability test, compressive strength, tensile, shear strength, flexural and shear load versus deflection relationship. A comparison between the beam test results will be also made to analyze the effect of the studied parameters on beam behavior.

4.6. Mechanical properties of fiber reinforced concrete

4.6.1. Slump test

Before starting pouring of concrete, it's important to control whether the fresh concrete has the desired properties for the casting and finishing. It is essential that the concrete will be able to be mixed, handled, transported, and, most importantly, placed and consolidated with a minimal loss of homogeneity and minimal entrapped air, to check this a slump test is used.

The slump test is a common, convenient, and inexpensive test, but it may not be a good indicator of workability for FRC. However, once it has been established a particular FRC mixture has satisfactory handling and placing characteristics at a given slump, the slump test may be used as a quality control test to monitor the FRC consistency from batch to batch.

Figure 4-1 Steps in filling concrete cone and slump height measurement

Table 4-1: Slumps of different mixes

No.	Concrete Strength (Mpa)	Fiber volumetric content (%)	Fiber type	Slump (mm)
1	25	0	-	54.5
2	25	0.20	Micro	6.5
3	25	0.35	Micro	0
4	25	0.50	Micro	0
5	25	0.65	Micro	0
6	25	0.20	Macro	50
7	25	0.35	Macro	40
8	25	0.50	Macro	37.5
9	25	0.65	Macro	28
10	40	0	-	15
11	40	0.35	Micro	0
12	40	0.65	Micro	0
13	40	0.35	Macro	11.5
14	40	0.65	Macro	0

[i]Note:1mm=0.039 in,

Figure 4-1 the simple steps in filling standard cone and measuring the slump height of the concrete. Table 4-1 represents the slump values for the mixes before and after fibers were added.

4.6.2. Compressive strength of fiber reinforced concrete

To see the effect of fibers on the compressive strength of concrete, a total of forty-two concrete cubes of 150×150 × 150 mm were made in six sets. In four sets, different amounts of micro and macro synthetic fibers volume fraction, such as 0.2%,0.35%,0.5%, and 0.65% were added on both 25 MPa and 40 MPa concrete grade whereas, the rest two set was made without fibers as control cylinders.

The results are compared to one another and also with the control specimens to select the optimum fiber content. For each fiber volume fraction, at least three cylindrical specimens were tested, which was twenty-eight days after casting.

The system used to identify the specimens were labeled to indicate the type of test (compressive, split, flexural and shear), the percentage (0%,0.2%,0.35%,0.5% and 0.65%) and type (micro and macro), concrete strength (C-25 and C-40) and sample number (1,2, and 3). For example, the specimen labeled C-0.50Mi-25-S1 stands for a specimen under compression test with 0.50% of micro synthetic fiber with 25MPa concrete strength and sample number one. The compressive strength was determined using the Eq. (3.4).

The compressive test results are shown in Table 4-2. Figure 4-2 and Figure 4-3 shows a graphical representation of changes in average compressive strength of concrete relative to the different volume of micro and macro synthetic fiber.

Table 4-2: Compressive strength test results

Specimen ID.	Sample No.	Required Compressive strength (MPa)	Measured Compressive strength (MPa)	Average compressive Strength (MPa)	Variation of compressive strength (%)
C-0-25	1	25	35.88	**35.06**	---
	2	25	34.42		
	3	25	34.89		
C-0.20Mi-25	1	25	29.56	**30.86**	12↓
	2	25	32.37		
	3	25	30.64		
C-0.35Mi-25	1	25	33.11	**30.74**	12.32↓
	2	25	28.32		
	3	25	30.77		
C-0.50Mi-25	1	25	22.11	**26.66**	23.96↓
	2	25	29.89		
	3	25	27.97		
C-0.65Mi-25	1	25	18.59	**19.43**	44.6↓
	2	25	20.36		
	3	25	19.35		
C-0.20Ma-25	1	25	35.10	**36.42**	3.87↑
	2	25	37.73		
	3	25	36.42		
C-0.35Ma-25	1	25	34.99	**36.87**	5.16↑
	2	25	38.76		
	3	25	36.87		

C-0.50Ma-25	1	25	35.51	**36.93**	5.33↑
	2	25	38.54		
	3	25	36.73		
C-0.65Ma-25	1	25	37.69	**36.95**	5.39↑
	2	25	36.18		
	3	25	36.98		
C-0-40	1	40	39.81	**43.78**	---
	2	40	47.71		
	3	40	43.82		
C-0.35Mi-40	1	40	35.79	**42.83**	2.17↓
	2	40	49.88		
	3	40	42.83		
C-0.65Mi-40	1	40	11.81	**12.25***	72↓
	2	40	11.56		
	3	40	13.39		
C-0.35Ma-40	1	40	42.73	**44.13**	0.8↑
	2	40	45.56		
	3	40	44.09		
C-0.65Ma-40	1	40	45.47	**39.19**	10.48↓
	2	40	32.88		
	3	40	39.23		

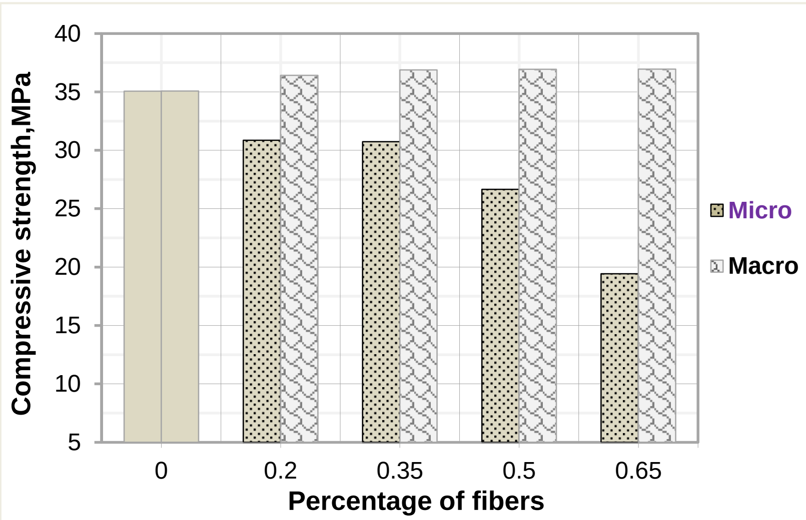


Figure 4-2 Variation of compressive strength for concrete with micro and macro synthetic fiber (C-25)

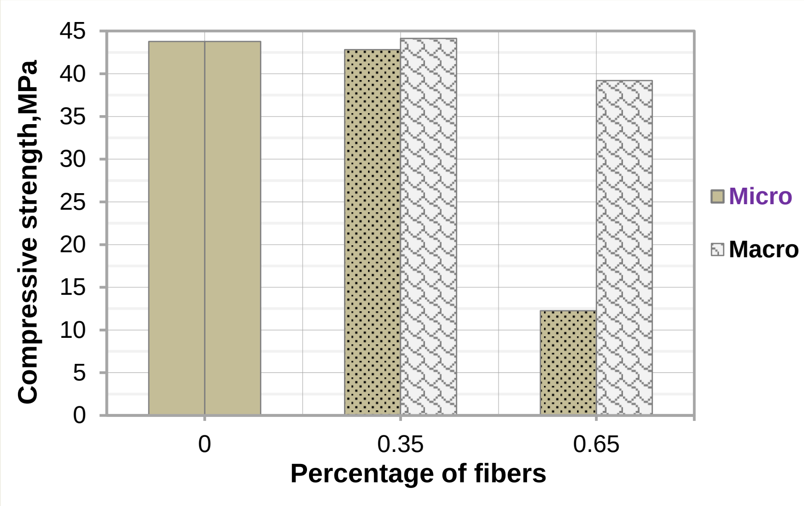


Figure 4-3 Variation of compressive strength for concrete with micro and macro synthetic fiber (C-40)

4.6.3. Splitting tensile strength of fiber reinforced concrete

The split-cylinder test is an indirect test method to obtain a tensile strength of a concrete. Splitting tensile strength is simpler to conduct than direct tensile strength. To check the effect of fibers on the tensile strength of concrete, a total of twenty-eight concrete cylinders of 100 mm in diameter and 200 mm high were made. There are fourteen mixes with a different volume fraction of fiber, in which at least two cylindrical specimens were tested.

The tensile splitting strength for each type of specimen was calculated from the maximum recorded failure load using Eq. (3.5).

Table 4-3 provides the average indirect tensile strength recorded during the test. Figure 4-4 and Figure 4-5 shows a graphical representation of changes in average tensile strength of concrete relative to the different volume of micro and macro synthetic fiber.

Table 4-3: Tensile strength test results

Specimen ID.	Sample No.	Tensile strength (MPa)	Average Tensile Strength (MPa)	Change in tensile strength (%)
S-0-25	1	4.46	**4.42**	---
	2	4.37		
S-0.20Mi-25	1	4.66	**4.58**	3.62↑
	2	4.50		
S-0.35Mi-25	1	3.60	**3.83**	13.34↓
	2	4.06		

S-0.50Mi-25	1	3.90	**3.82**	13.57↓
	2	3.74		
S-0.65Mi-25	1	3.86	**3.76**	14.93↓
	2	3.65		
S-0.20Ma-25	1	4.75	**4.68**	4.75↑
	2	4.62		
S-0.35Ma-25	1	4.83	**4.71**	5.88↑
	2	4.60		
S-0.50Ma-25	1	4.83	**4.73**	7.00↑
	2	4.62		
S-0.65Ma-25	1	4.48	**4.37**	1.13↓
	2	4.25		
S-0-40	1	5.40	**5.25**	---
	2	5.10		
S-0.35Mi-40	1	5.37	**4.94**	5.90↓
	2	4.50		
S-0.65Mi-40	1	3.04	**2.03**	61.33↓
	2	1.02		
S-0.35Ma-40	1	6.27	**5.80**	10.47↑
	2	5.34		
S-0.65Ma-40	1	6.06	**5.55**	5.71↑
	2	5.04		

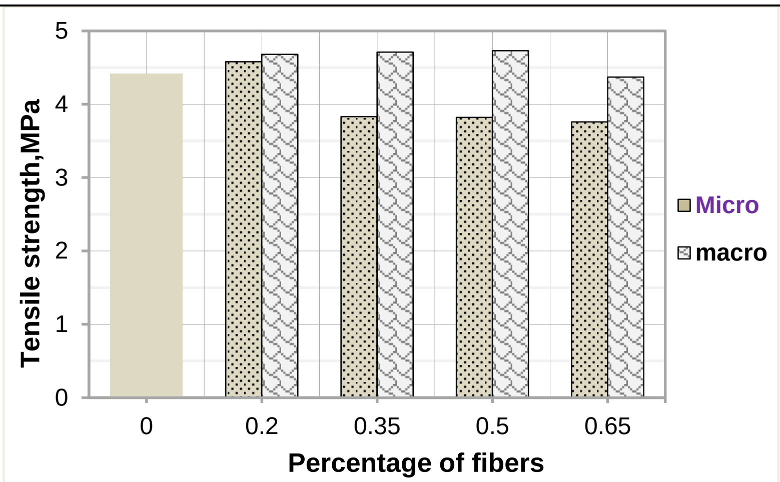


Figure 4-4 Variation of tensile strength for concrete with micro and macro synthetic fiber (C-25)

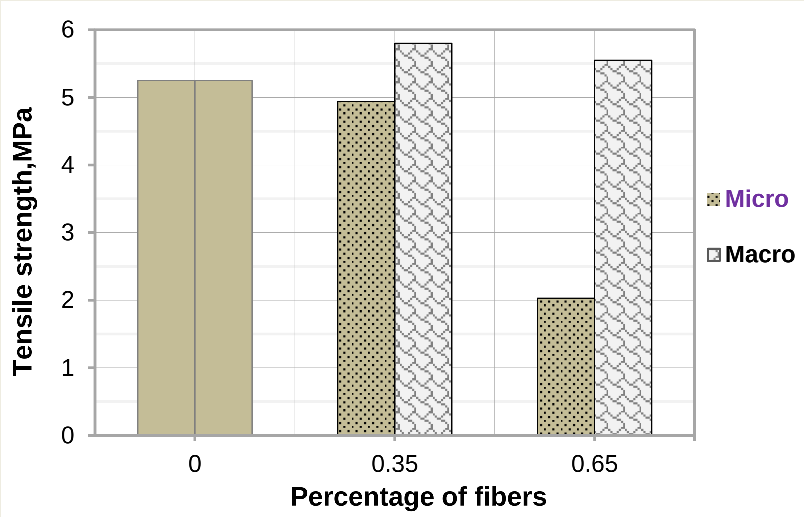


Figure 4-5 Variation of tensile strength for concrete with micro and macro synthetic fiber (C-40)

4.6.4. Flexural strength of fiber reinforced concrete

The flexural test is another indirect tensile test that measures the ability of a concrete beam to resist failure in bending. Two beam specimens are sampled for each type of fiber and concrete grade and a total of twenty-eight concrete beams of 150 ×150×500 mm were made. The test is conducted according to AASTM C 1018, 1997 "Standard Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam with Third-Point Loading)" and the results are compared with the control specimens and to one another to evaluate the behavior of the beams.

Table 4-4 reports the flexural strength for beam specimen corresponding to all fiber content test results. Figure 4-6 and Figure 4-7 shows a graphical representation variation in average flexural strength. The flexural strength was determined according to the equation (3.6).

Table 4-4: Flexural strength test results

Specimen ID.	Sample No.	Flexural strength (MPa)	Average Flexural Strength (MPa)	Variation in Flexural strength (%)
F-0-25	1	4.27	**4.33**	---
	2	4.40		
F-0.20Mi-25	1	4.37	**4.32**	0.23↓
	2	4.27		
F-0.35Mi-25	1	4.67	**4.67**	7.85↑
	2	4.67		

F-0.50Mi-25	1	4.40	**4.27**	1.38↓
	2	4.13		
F-0.65Mi-25	1	3.87	**3.82**	11.77↓
	2	3.77		
F-0.20Ma-25	1	4.16	**4.35**	0.46↑
	2	4.53		
F-0.35Ma-25	1	4.37	**4.45**	2.77↑
	2	4.53		
F-0.50Ma-25	1	4.33	**4.43**	2.3↑
	2	4.53		
F-0.65Ma-25	1	4.63	**4.65**	7.39↑
	2	4.67		
F-0-40	1	4.47	**4.57**	---
	2	4.67		
F-0.35Mi-40	1	3.17	**3.32**	27.3↓
	2	3.47		
F-0.65Mi-40	1	2.73	**2.43**	46.82↓
	2	2.12		
F-0.35Ma-40	1	3.13	**2.97**	35.1↓
	2	2.80		
F-0.65Ma-40	1	2.76	**2.79**	38.9↓
	2	2.81		

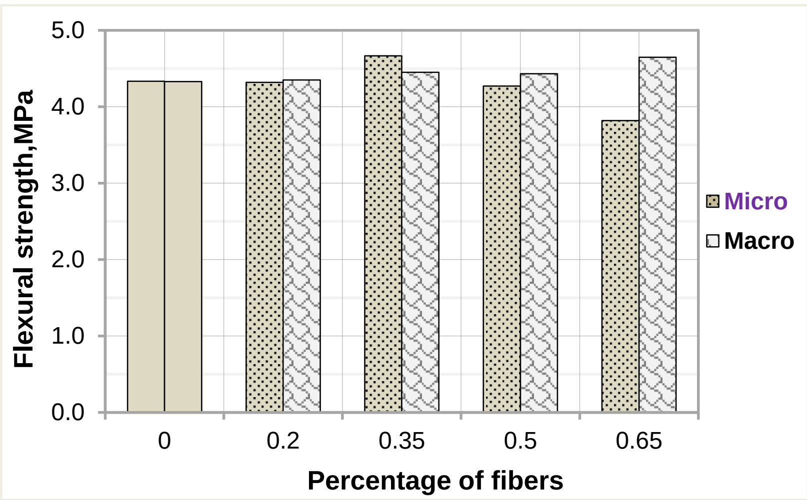


Figure 4-6 Variation of flexural strength for concrete with micro and macro synthetic fiber (C-25)

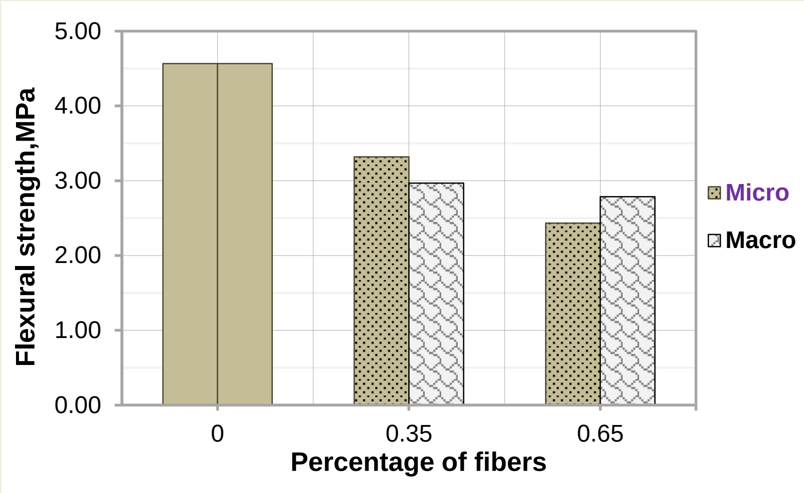


Figure 4-7 Variation of flexural strength for concrete with micro and macro synthetic fiber (C-40)

4.6.5. Flexural toughness of fiber reinforced concrete

Flexural toughness (Tb) is the term used to quantify the energy-absorbing capability of concrete; it is the area under the load-deflection curve of concrete, which is measured using toughness indices.

These indices are I_5, which is the ratio of the area under the load-deflection curve at 3 times the first-crack deflection to the area under the load-deflection curve at first crack, I_{10}, measured at 5.5 times the first-crack, and I_{20}, measured at 11.5 times the first-crack deflection. The test was stopped at a deflection equal to 5.5 times the deflection at the first crack occurrence.

Figure 4-8 shows the load versus deflection curves for plain and concrete with fibers. Figure 4-9 the areas used in the determination of flexural toughness indices, plot digitizer software is used to determine the areas. Figure 4-10 specimen for flexure before and after test for macro SNFRC. Table 4-5 presents the energy absorption capacity calculated from the SNFRC beam tests for micro and macro synthetic fiber volume fractions of 0.2,0.35,0.50, and 0.65 % and concrete compressive strengths of 25, and 40 MPa.

(AASTM C 1018, 1997) is the specification that was used to determine the fiber-reinforced concrete toughness. Similar to the flexural strength test, for both type of fiber and concrete strength, two beam specimens measuring 150 ×150×500mm were sampled according to (AATM C31, 2000).Since there were no LVDTs in the lab, the displacement control machine, universal testing machine UTM 70-C0820, was used in this test.

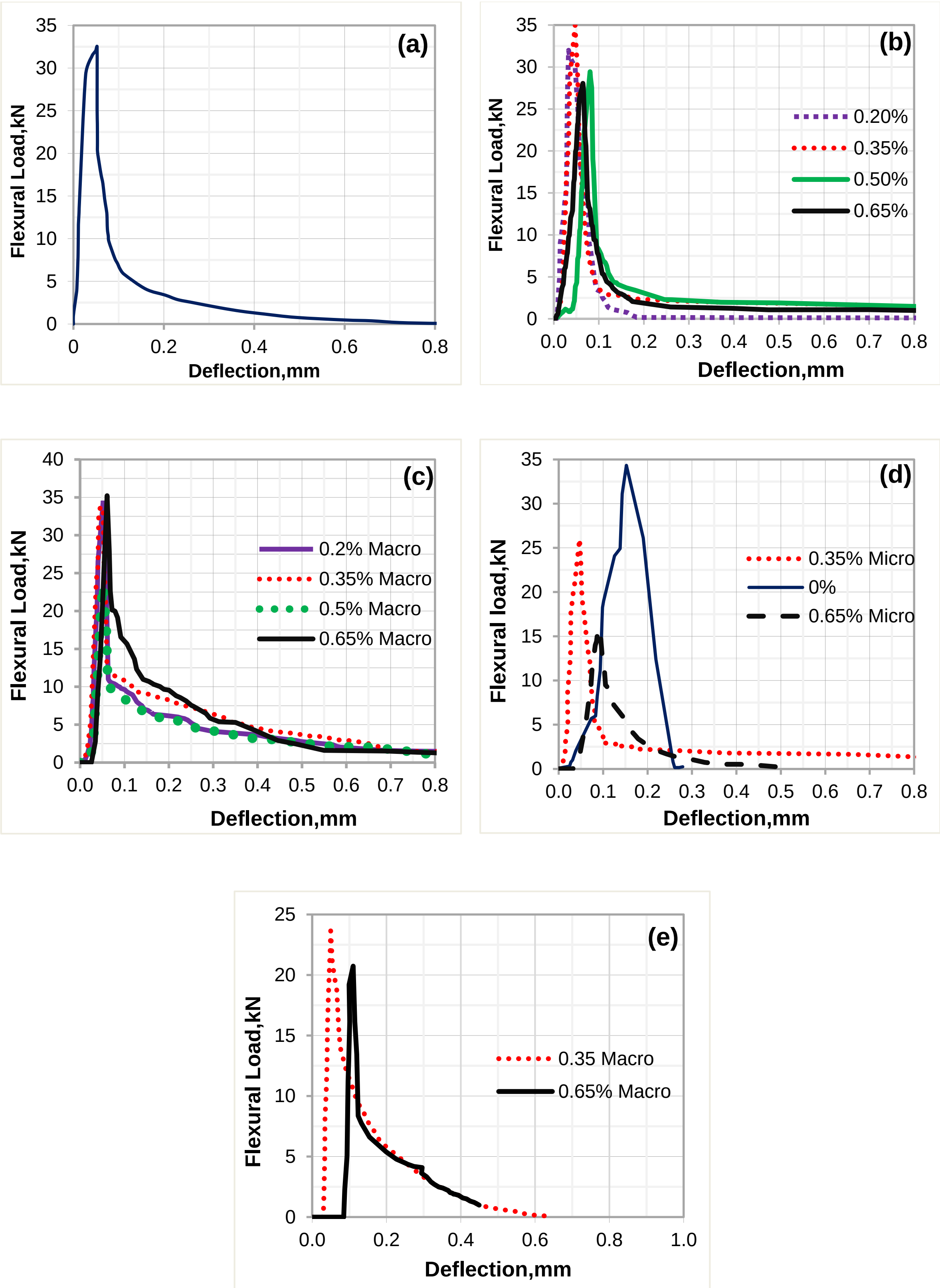


Figure 4-8 Flexural load-deflection curves of:*(a) plain concrete; (b) micro synthetic C-25; (C) macro synthetic C-25; (d) micro synthetic C-40; and (e) macro synthetic C-40.*

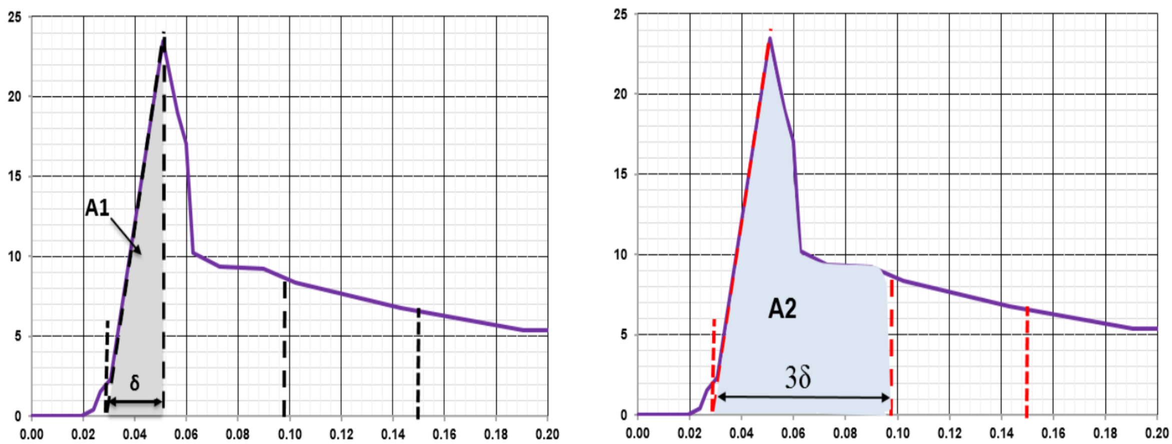
Table 4-5: Flexural toughness indices of fiber reinforced concrete

Specimen Id.	A1*	A2*	A3*	Toughness indices I_5	Toughness indices I_{10}	Residual strength factor $R_{5,10}$	Increase in Toughness I_{10} (%)
F-0-25	0.870	1.04	1.07	1.20	1.23	0.6	-
F-0.20 Mi-25	0.260	1.472	1.531	5.62	5.84	4.40	374.8
F-0.35 Mi-25	0.258	1.310	1.530	5.09	5.91	16.40	380.49
F-0.50 Mi-25	0.176	0.911	1.115	5.18	6.33	23.00	414.63
F-0.65 Mi-25	0.427	1.276	1.498	2.98	3.50	10.40	184.55
F-0.20 Ma-25	0.316	1.416	2.149	4.48	6.80	46.40	452.8
F-0.35 Ma-25	0.371	1.169	1.765	3.15	4.76	32.20	287
F-0.50 Ma-25	0.251	0.785	1.186	3.13	4.73	32.00	284.55
F-0.65 Ma-25	0.508	1.461	2.172	2.88	4.28	28.00	248
F-0-40	1.674	1.674	1.674	1.00	1.00	0	-
F-0.35 Mi-40	0.463	1.120	1.209	2.42	2.78	7.20	178
F-0.65 Mi-40	0.318	0.998	1.210	3.14	3.81	13.40	281
F-0.35 Ma-40	0.280	0.899	1.404	3.21	5.01	36.00	401
F-0.65 Ma-40	0.108	0.596	0.904	5.52	8.37	57.00	737

[ii]Note: A1*: Area under load-deflection curve up to the first crack; A2*: Area under load-deflection curve at 3 times cracking deflection; A3*: Area under the load-deflection curve at 5.5 times cracking deflection

Where:

$$\mathbf{I_5} = \left(\frac{A2}{A1}\right) \qquad \mathbf{I_{10}} = \left(\frac{A3}{A1}\right) \qquad \boldsymbol{R_{5,10}} = 20\times(I_{10}-I_5)$$



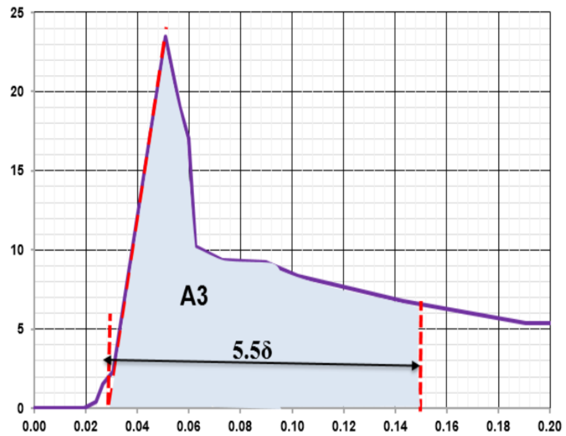


Figure 4-9 Areas used in the determination of flexural toughness index sample for F-0.5-Ma-25

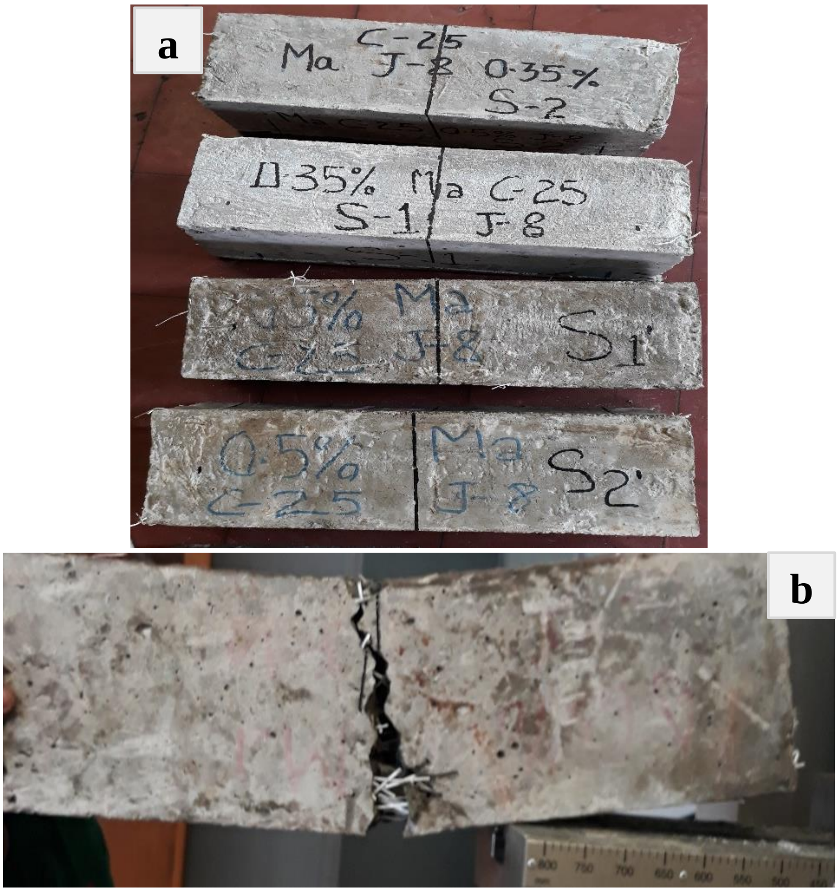


Figure 4-10 Failure stages of macro synthetic fiber concrete beam: *a) Specimen prepared for test; b) after failure*

4.1.6. Shear strength and toughness of fiber reinforced concrete

To verify the effect of fibers on shear strength of reinforced concrete beams, a total of forty-two concrete beams were made in six sets of beams each. In four sets, different amounts of fibers were added whereas the fifth and sixth set was made without fibers as control beams.

The results are compared with the control specimens and one to another to determine the effective fiber dosage also, the behavior of beams with different concrete strength.

Hence direct shear testing machine is not available in our country Ethiopia the “shear fracture tests of concrete” method adopted by (Batant and P.A.feiffer, 1986) is used. Procedures followed, specimen size and specimen setup used in this test method are briefly explained in chapter three of this thesis report.

The shear toughness is calculated from the area under shear load and deflection measured during the test, thereafter plot digitizer software is used to collect the values and draw the curves in Excel sheet.

The specimen details and results are summarized in Table 4-6. Figure 4-11 shows the graphical representation of average shear load-deflection curves for plain and SNFRC used to determine the shear toughness. Figure 4-12 represents the set-up of the specimen for shear test and failure stages for macro SNFRC. The shear strength is determined equation (3.7).

Table 4-6: Shear strength test results

Specimen ID.	Sample No.	Shear strength (MPa)	Average Shear Strength (MPa)	Variation in Shear strength,(%)
Sh-0-25	1	1.39	**1.46**	---
	2	1.50		
	3	1.50		
Sh-0.20Mi-25	1	1.58	**1.60**	9.6↑
	2	1.74		
	3	1.48		
Sh-0.35Mi-25	1	1.39	**1.53**	4.80↑
	2	1.25		
	3	1.95		
Sh-0.50Mi-25	1	1.95	**1.43**	2.05↓
	2	1.06		
	3	1.29		

Sh-0.65Mi-25	1	1.36	**1.71**	17.1↑
	2	2.12		
	3	1.64		
Sh-0.20Ma-25	1	1.44	**1.49**	2.05↑
	2	1.71		
	3	1.33		
Sh-0.35Ma-25	1	1.40	**1.52**	4.10↑
	2	1.59		
	3	1.56		
Sh-0.50Ma-25	1	1.55	**1.77**	21.23↑
	2	2.19		
	3	1.57		
Sh-0.65Ma-25	1	1.33	**1.39**	4.79↓
	2	1.25		
	3	1.59		
Sh-0-40	1	1.16	**1.08**	---
	2	1.10		
	3	0.98		
Sh-0.35Mi-40	1	1.15	**1.25**	15.74↑
	2	1.32		
	3	1.28		
Sh-0.65Mi-40	1	1.11	**0.86**	20.37↓
	2	0.68		
	3	0.80		
Sh-0.35Ma-40	1	1.02	**1.10**	1.85↑
	2	1.11		
	3	1.16		
Sh-0.65Ma-40	1	1.11	**0.96**	11.11↓
	2	0.82		
	3	0.94		

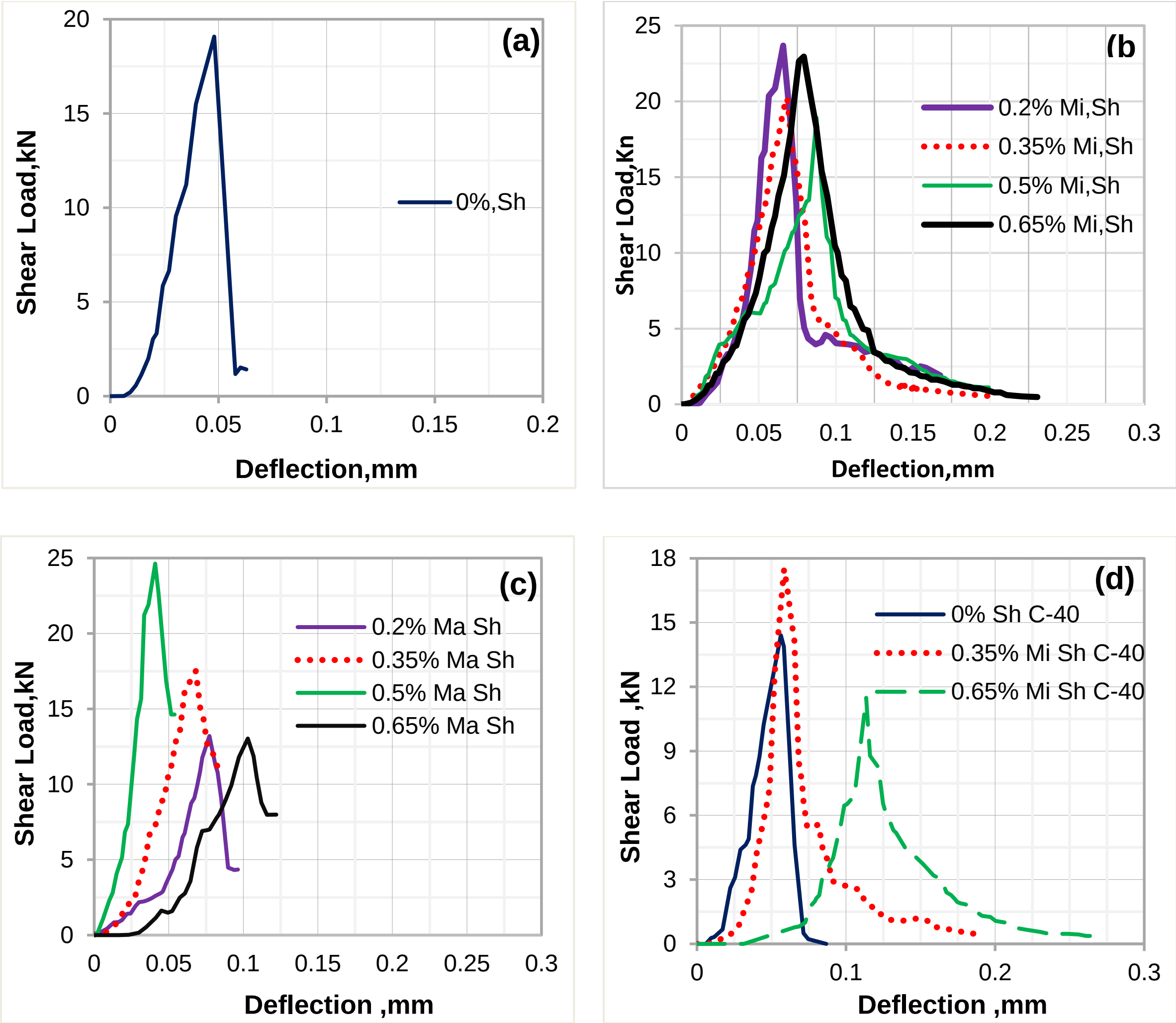


Figure 4-11 Shear load-deflection curves of:*(a) plain concrete; (b) micro synthetic C-25; (C) macro synthetic C-25; and (d) micro synthetic C-40.*

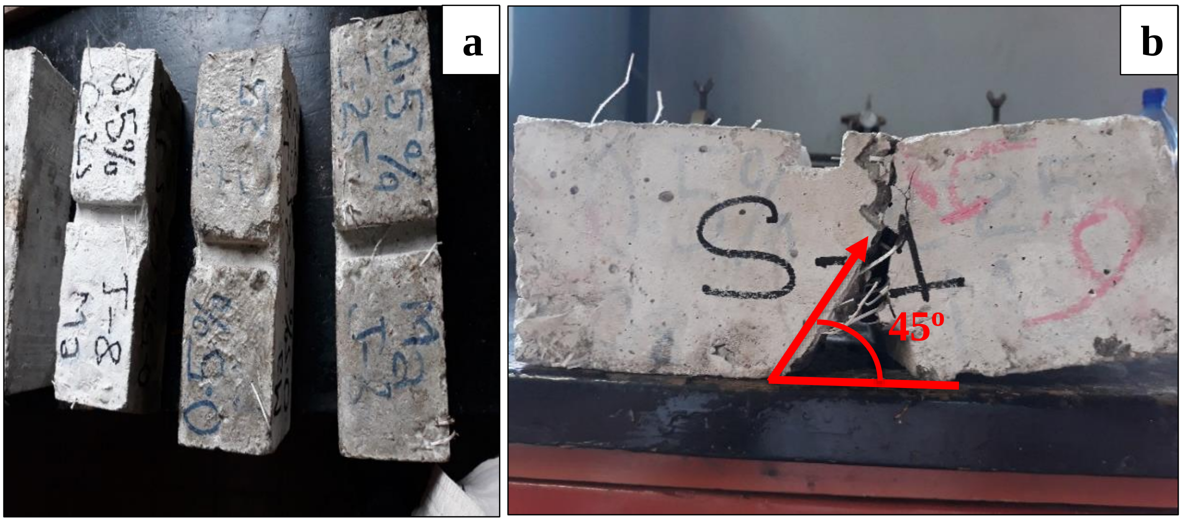


Figure 4-12 Shear strength test ;*a)Specimen prepared for test ; and b) Failure pattern (crack angle) of a macro synthetic beam under shear test*

4.2. Discussion and Comparison of SNFRC Behavior

4.2.1. Effect of fiber type, fiber volume fraction and concrete strength on the slump of SNFRC

a. Effect of fiber type and fiber volume

The workability of fresh concrete can be determined through a slump test. Table 4-7 shows slump test results and variation of a slump in plain concrete, micro and macro synthetic fiber reinforced concrete. The results indicate that the addition of micro and macro synthetic fibers decreases slump, thus decreasing the workability of fresh concrete.

Workability of concrete decreases with an increase in a volume fraction of both micro and macro synthetic fibers. For micro synthetic fibers, the reduction was 88.07% at lower fiber content (0.2%), and it decreases higher up to 100% for a higher volume of fiber such as 0.35%,0.5%, and 0.65%. This is due to the fact that the addition of fibers can form a network structure in the concrete matrix, thus restraining mixture from segregation and flow.

However, for macro synthetic fiber, the reduction was only 8.25% for 0.2% of fiber content and it ranges from 26.6% - 48.6% in other fiber content. This is due to high content and large surface area of the fibers, the fibers can wrap around the aggregate, hence decreasing the viscosity of the concrete mixture. In addition, all fiber types act like aggregates in the concrete mix and are required to have paste coating the individual strands. The more surface area to cover, the higher the paste demand within the mix. The more paste covering the fibers, the less available to act like a lubricant within the mixture and loss of slump will occur.

b. Effect of concrete strength

As the concrete strength increases the workability decreases this is due to the reduced water to cement ratio used in the mixture. From the slump result, it can be seen that as the concrete compressive strength increases to 40MPa the slump is reduced by 72.48% with respect to the concrete strength of 25MPa.

In addition to plain concrete, the reduction of the slump in macro synthetic FRC is about 78.9% in 40Mpa concrete strength while it is only 26.6% for 25MPa concrete strength.

c. Comparison of fiber type, fiber volume fraction and concrete strength

However, macro synthetic fibers can be used in the concrete with slump height recommended by ACI 211.1-91 for beams construction (25-100mm) in all fiber content.

.

Table 4-7: Summary and variation of slump test

Specimen Id.	Slump (mm)	Slump reduction relative to Control specimen(%)	Slump reduction in respective to fiber content (%)
0-25	54.5	-----	----
0.20Mi-25	6.5	88.07	87
0.35Mi-25	0	100	100
0.50Mi-25	0	100	100
0.65Mi-25	0	100	100
0.20Ma-25	50	8.25	----
0.35Ma-25	40	26.10	----
0.50Ma-25	37.5	31.20	----
0.65Ma-25	28	48.60	----
0-40	15	----	72.48
0.35Mi-40	0	100	0
0.65Mi-40	0	100	0
0.35Ma-40	11.5	23.33	71.25
0.65Ma-40	0	100	100

The fresh fiber reinforced concrete required much work when it was cast not to flow over the edges of the formwork, and the casting, therefore, took longer to carry out than the casting of the regular concrete. Higher workability can be achieved with the addition of HRWR admixtures.

(Gencel *et al.*, 2011) used monofilament polypropylene fibers in self-compacting concrete with fly ash and studied the workability and mechanical properties. The materials used in this study showed no workability or segregation problems.

4.2.2. Effect of fiber volume fraction and concrete strength on the compressive strengths of SNFRC

a. Effect of fiber type and fiber volume ratio

According to experimental results represented in Table 4-2, it is observed that compressive strength decreases as the fiber content in the concrete is increased in both 25MPa and 40 MPa micro Synthetic FRC.

The addition of micro synthetic fibers at low values i.e. 0.2% to 0.35% decreases the 28 days' compressive strength by about 12% but, when the volumes get higher to 0.50% the strength is decreased by 23.96%. The minimum compressive strength was 19.43MPa with 0.65% in which the strength is decreased by 44.6% relative to control concrete this occurs due to reduced effective compaction during the specimen preparation, strength decreases as the fiber content of concrete is increased in both 25MPa and 40 MPa micro Synthetic FRC.

Test results reveal that the addition of macro synthetic fiber in concrete enhanced the compressive strength of the specimens. It was improved at least by 3.87% for 0.20% fiber content and gradual improvement was found by 5.16% at 0.35% fiber content,5.33% and 5.39% for 0.5% and 0.65% fiber content respectively with respect to control specimens.

b. Effect of concrete strength

In addition, this study also examined the effects of the fiber volume fraction on different concrete strength of SNFRC. As compressive strength increases, with the increase in cement content the strength gains due to the percentage of fiber decreases. The strength reduction in 25 MPa concrete with 0.35% micro synthetic fiber is only 2.17% whereas, it is about 72% in 40 MPa concrete at the same volume of fibers.

Similar to that, the compressive strength of 40 MPa with 0.65% macro synthetic fibers decreases by 10.48% while it shows an increment of 5.39% in 25 MPa concrete at the same fiber content. The minimum compressive strength was 12.25MPa with 0.65% fiber content this occurs due to less water to cement ratio and reduced effective compaction.

(Owens, 2009) Another explanation could be that the fibers reduced the effective compaction thus resulting in a lower strength.

c. Comparison of fiber type, fiber volume fraction and concrete strength

As it is explained in the above section, the addition of micro synthetic fiber on concrete decreases the compressive strength in both concrete strengths whereas, macro synthetic fiber increases the compressive strength. The optimum dosage for macro synthetic fiber content was 0.65% giving a compressive strength of 36.93 with a 5.39% increase from the control specimen. In a comparison of the fiber content with concrete strength, addition of micro synthetic fiber on concrete reduces the strength in 40 MPa by 2.17% at 035% fiber content, compared to 25MPa concrete strength, which showed a rapid decrease in a compressive strength by 12.32% at the same fiber content.

There is no significant variation in the values of compressive strength associated with the addition of macro synthetic fibers on 40 MPa concrete. Still, the fibers are acting as anchors between the cement paste, fine and coarse aggregates which results in increased durability of concrete before failure. A comparison of cube compressive strength and the percentage of fibers is given in Figure 4-13.

(Saeed Ahmed et.,2006) carried out the compressive strength test to check the effect of polypropylene fibers on concrete and conclude that, the addition of polypropylene fibers at low values i.e. 0.18% to 0.40% actually increases the 28 days' compressive strength by about 5% but when the volumes get higher like 0.55% to 0.60% then the compressive strength decreases from original by 3 to 5%.

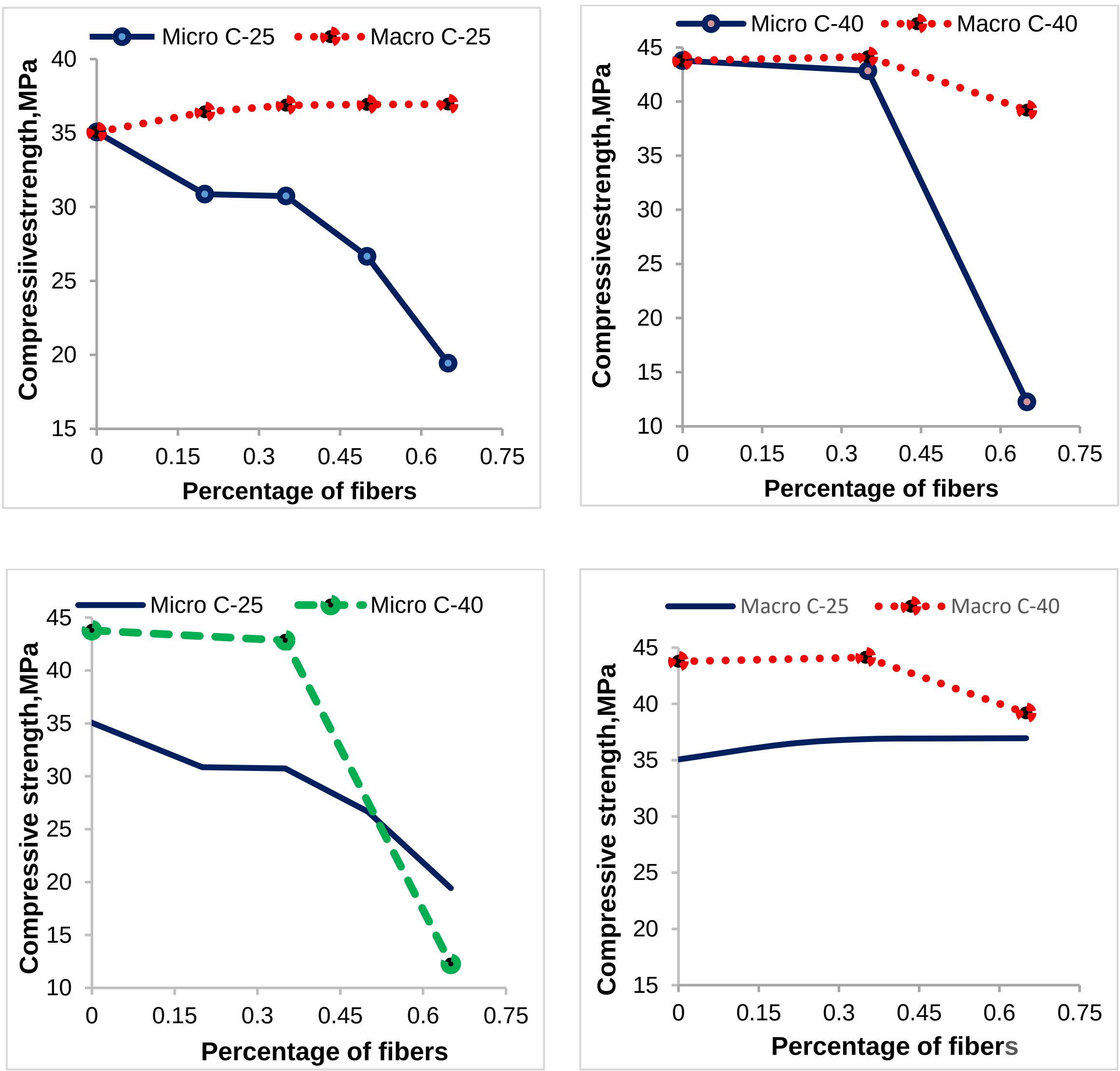


Figure 4-13 Comparison of cube compressive strength and percentage of fibers

4.2.3. Effect of fiber type, fiber volume fraction and concrete strength on the tensile strength of SNFRC

a. Effect of fiber type and fiber volume ratio

The tensile strength of concrete is only about 8-15 % of its compressive strength. From the split tensile strength test result, the addition micro synthetic fibers reduce the tensile strength of 25 MPa concrete strength whereas the macro synthetic fibers were improving it.

According to the result obtained from experimental test, the tensile strength decreases by about 13.34 % at 0.35% -0.5% and by 14.93% at 0.65% micro synthetic fiber content but, it increases by 3.62% at 0.2% fiber content.

As the summary of the tensile strength result given in Table 4-3, the addition of macro synthetic fibers improves the tensile strength by 4.75% at 0.2% fiber content,5.88% at 0.35% fiber content, 7.00% at 0.5% and decreases by 1.13% at 0.65% fiber content. The optimum dosage for fiber content was 0.5% giving tensile strength of 4.73 with a 7.00 % increase from the control specimen.

The tensile strength of concrete increases linearly only with the addition of fibers up to about 0.50% after which the strength decreases with the addition of more fibers. The fibers act as crack arresters in the concrete matrix prohibiting the propagation of cracks in plastic state and propagation of cracks in the hardened state.

b. Effect of concrete strength

As the concrete strength increases the effect fibers on tensile strength also increases. The fibers are acting as bridges between the concrete matrix to distribute the stresses uniformly thus making the whole matrix resist the tension.

The tensile strength of 40 MPa concrete containing micro synthetic fibers decrease tensile strength by 5.10% at 0.35% fiber content, and 61.33% at 0.65% fiber content. When the addition of macro synthetic fibers enhances the tensile strength by 10.47%,5.71% at 0.35% and 0.65% fiber content respectively.

The minimum tensile strength was 2.03 with a 61.33 % decrease from the control specimen at 0.65% micro synthetic fiber content this is due to insufficient compaction and variations in the actual air contents of the hardened concrete.

c. Comparison of fiber type, fiber volume fraction and concrete strength

Comparing the effect of micro and macro synthetic fibers, concrete with micro synthetic fibers decreases the tensile strength whereas, the addition of macro synthetic fiber gradually increases the strength up to 0.5% fiber content.

Tensile strength is enhanced when fiber volume increases, this is due to the bridging mechanism of polypropylene fibers and after certain ration, it reduced the bond strength between concrete ingredients so results in quick failure as compared to fewer volumes of fibers.

Figure 4-14 shows a graphical representation of a comparison of average indirect tensile strength for concrete with different fiber types, volume fractions and concrete strength.

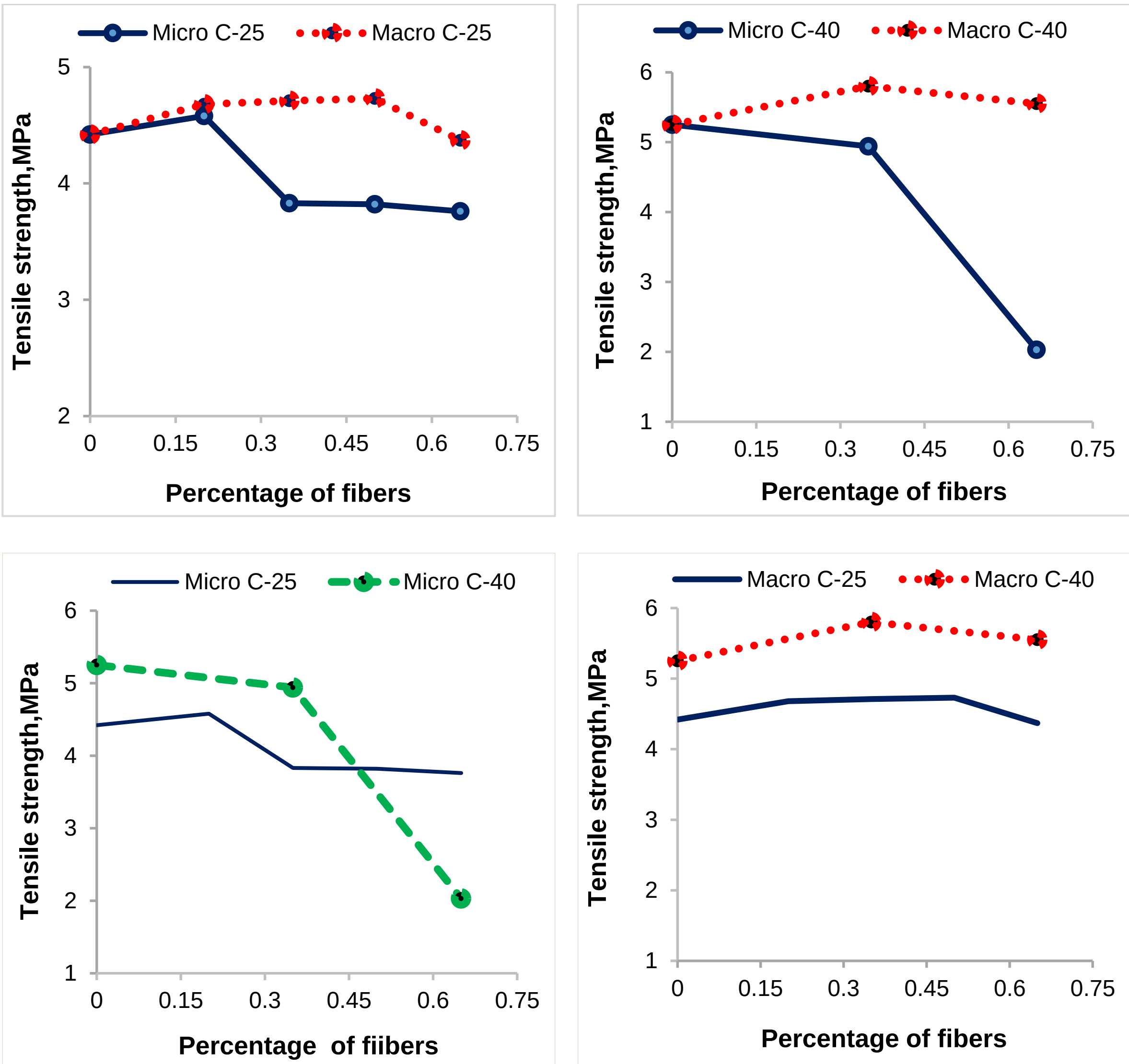


Figure 4-14 Comparison of tensile strength and percentage of fibers for different mixtures

For C-25(7.00↑) and C-40(10.47↑), mix concrete depicted a higher variation of tensile strength at 0.50% and 0.35% of macro synthetic fiber content for both concrete strengths respectively.

On the other hand, as the concrete strength increases a small fiber content can give a larger improvement. It was shown that plain concrete cylinders failed abruptly once the concrete cracked, whereas macro synthetic fiber reinforced concrete could retain its shape even after concrete cracked.

4.2.4. Effect of fiber type, fiber volume fraction and concrete strength on the flexural strength of SNFRC

a. Effect of fiber type and fiber volume ratio

The behavior of concrete in flexure seems to be identical with SNFRC to the tensile strength. According to the experimental data, the flexural strengths tend to decreases with the increases in the micro synthetic fiber volume fraction from 0.35% to 0.65%. Nevertheless, the fibers increase the flexural strength by 7.85% at 0.2% fiber content. The gradual decreasing in the flexural strength was caused by the bond failure of the synthetic fiber-concrete.

The data represented in Table 4-4 shows that the flexural strengths tend to increase with the increase in the macro synthetic fiber volume fraction from 0.25% to 0.65% but, each content enhanced it with a different trend. F-0.20Ma25, F-0.35Ma25, F-0.50Ma25, and F-0.65Ma25 have 0.46%,2.77%,2.3%,7.9% improvement of flexural tensile strength respectively, when compared with reference (F-0-25). The increases in flexural strength of synthetic fibers were lower, about 0.02 to 0.12 N/mm^2 for 0.2% to 0.5% fiber content.

b. Effect of concrete strength

The increase in concrete strength increases the amount of aggregates content in the concrete mix. This can be caused by lesser bridging action moreover the increased cement content ratio could not bond with fibers as polypropylene fibers are hydrophobic and resulted in even loss of flexural strength. Therefore, the flexural strength of 40 MPa containing 0.35% and 0.65% fiber content was smaller than the strength of 25 MPa with the same content.

c. Comparison of fiber type, fiber volume fraction and concrete strength

The flexural strengths are associated with both the fiber content and concrete strength. Variation of flexural strength with different synthetic types, volume and concrete strength is shown in Figure 4-7 and Figure 4-8.

It may be concluded that the incorporation of micro synthetic fibers did not significantly improve the flexural strength of SNFRC while the addition of macro synthetic fibers gradually rises the strength as the percentage of the fiber increases.

As discussed in the previous section, the flexural strengths in the SNFRC with a higher strength of 40 MPa rapidly decreased compared to the strengths of 25 MPa in both micro and macro SNFRC specimens.

This was similar to the result obtained by other researchers like Kumar et al studied the with M15, M20 and M25 grade concrete with 0%, 0.5 % and 1% fibers for flexure and shear behavior of deep beams and it is reported that there is marginal increase in flexural strength at first crack as fiber content increased from 0% to 1.0%. The main benefit of using macro synthetic fibers lies in improved ductility in the post-crack region and flexural toughness of concrete.

Brittle behavior is always associated with plain concrete. When the first crack is produced, the specimen cracks and collapses suddenly, with very small deformation and no prior warning. However, in SNFRC specimens, the failure progresses with bending, but without any sudden collapse as seen in plain concrete.

As it can be seen in Figure 4-15, the plain concrete showed a brittle failure. The flexural strength of plain concrete reached the maximum at a deflection of around 0.0523mm without any post-crack performance. However, macro synthetic fiber slightly increased the maximum flexural strength from 4.33 MPa to 4.60 MPa at the same deflection point as the plain concrete. This also confirmed by Figure 4-9 which shows the load-deflection curves of for different synthetic fiber reinforced concretes.

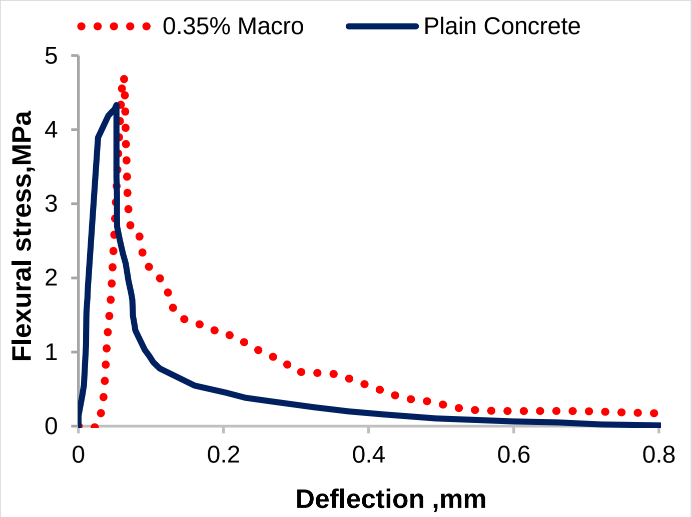


Figure 4-15 Flexural Stress –deflection curves of macro SNFRC

Table 4-8: Deflection at maximum flexural stress

Specimen ID.	Average Flexural Strength (MPa)	Deflection at maximum Stress (mm)	First crack strength (MPa)
F-0-25	4.33	0.052	
F-0.20 Mi-25	4.32	0.033	4.33
F-0.35 Mi-25	4.67	0.047	3.81
F-0.50 Mi-25	4.27	0.069	3.06
F-0.65 Mi-25	3.82	0.064	3.53
F-0.20 Ma-25	4.35	0.052	4.00
F-0.35 Ma-25	4.45	0.048	4.44
F-0.50 Ma-25	4.43	0.050	3.13
F-0.65 Ma-25	4.65	0.607	4.67
F-0-40	4.57	0.152	0
F-0.35 Mi-40	3.32	0.047	3.47
F-0.65 Mi-40	2.43	0.088	2.12
F-0.35 Ma-40	2.97	0.049	3.15
F-0.65 Ma-40	2.79	0.099	2.69

4.2.5. Effect of fiber type, fiber volume fraction and concrete strength on the flexural toughness of SNFRC

a. Effect of fiber type and fiber volume ratio

As it is discussed in the previous section, the flexural toughness parameters are derived from fiber reinforced concrete in terms of areas under the load-deflection curve obtained by testing a simply supported beam under third-point loading.

From load-deflection curves shown in Figure 4-9, it can be seen that the load versus deflection response of all beams are similar up to the load at which the first crack was formed in the control beams. The addition of synthetic fibers improved the flexural toughness or post cracking characteristics of concrete significantly. However, equal dosages of different fibers did not result in specimens with the same flexural toughness.

As presented in the Table 4-5, The value of toughness indices I_5 in both micro and macro SNFRC is decreasing as the percentage of fiber content increases. Nevertheless, the values of toughness indices I_{10} are constantly increasing with an increasing percentage of micro SNFRC and decreases in macro synthetic FRC.

With the addition of micro and macro synthetic fibers in both 25 MPa and 40 MPa concrete, the flexural indices (I_5 and I_{10}) increases by more than 130% relative to the control beam even at the lower fiber content.

In addition, the residual strength factor of concrete with micro synthetic fiber increases as the fiber volume content increases in both concrete grade but, in macro synthetic fibers, the strength factor decreases when fiber volume increases.

b. Effect of concrete strength

The energy absorption capacity increases with the increment in the content fraction of the fiber and the strength of concrete. At the same fiber content, when the concrete compressive strength increased, the energy absorption capacity of the concrete also increases.
On the other hand, with the addition of fiber in 40MPa concrete strength, the flexural toughness indices I_{10} of concrete increased by 8.9% at 0.65% micro synthetic fiber content, 1.9% at 0.35% macro synthetic fiber content,95.6% at 0.65 % macro synthetic fiber and decrease by 52.96% at 0.35 % micro synthetic fiber content relative to 25 MPa concrete strength of the same fiber content.

Similar to the flexural indices the residual strength factor of 40MPa also increased by 29.42% at 0.65% micro synthetic fiber content, 12.26% at 0.35% macro synthetic fiber content,103.8% at 0.65 % macro synthetic fiber and decrease by 56.12% at 0.35 % micro synthetic fiber content relative to 25 MPa concrete strength of the same fiber content.

c. Comparison of fiber type, fiber volume fraction and concrete strength

Depending on the toughness indices I_5 calculated from the load-deflection curves, micro synthetic fiber enhances the energy absorption capacity of SNFRC than the macro synthetic fiber of the same dosage. Despite the fact that the area under the load-deflection curve for micro synthetic fiber at the post-cracking phase on 3 and 5.5 times the deflection of this fiber was greater than the macro synthetic FRC, the residual strength was still lower than the macro SNFRC.

In addition, the residual strength of the optimum fiber content that enhance toughness, 0.20% in macro synthetic fiber is more than two times the optimum fiber content,0.50% in micro synthetic fibers. This indicates that the average load retained over a specific deflection after the first crack is higher.

This means, after the first crack macro synthetic fiber can resist more load without showing a significant deflection by bridging the crack and distributing the stress in the specimen, this can increase the energy absorption capacity of the specimen and also change the failure mechanism.

Figure 4-16 shows the comparison of flexural load versus deflection curves for the optimum percentage of micro and macro synthetic fibers that enhance the flexural toughness in 25 MPa concrete.

SNFRC beam with concrete strength of 40 MPa showed an increase in energy absorption capacity than 25 MPa concrete strength of the same fiber content. Therefore, the higher strength of the cementitious matrix is more effective in improving the energy absorption performance of the SNFRC.

An increase in flexural toughness was witnessed by (Alhozaimy, A. M. Soroushiad, and MirzaC, 1995) in their research by performing flexural strength tests on concrete specimens reinforced with polypropylene fibers. They found that for volume fractions of 0.1%, 0.2% and 0.3% fibers the flexural toughness is increased by 44%, 271%, and 386% respectively over that of plain concrete for the same mix compositions.

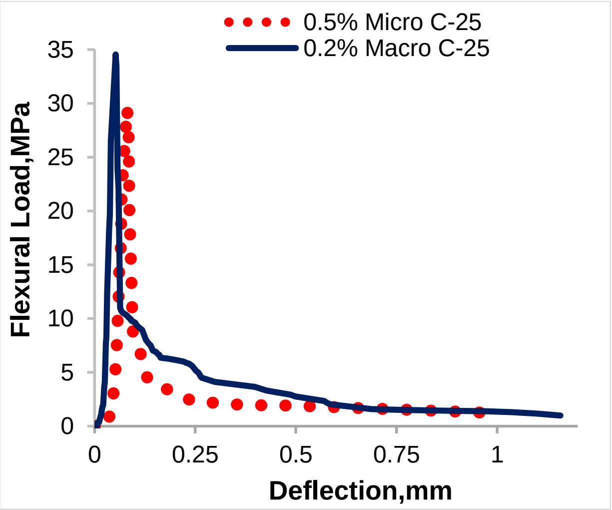


Figure 4-16 Comparison of the flexural load-deflection curve for optimum fiber dosage of C-25

4.2.6. Effect of fiber type, fiber volume fraction and concrete strength on the shear strength

a. Effect of fiber type and fiber volume ratio

From the shear strength test result, the concrete shear strength is gradually increases with the addition of micro and macro synthetic fibers.

The enhancement of shear strength above the control specimen ranges between 4.80 to 17.1% for 0.2 to 0.65% micro synthetic fiber content however, it is slightly falling in 2.05% at 0.2% fiber content which is expected variation in experimental work.

There is a remarkable upturn in the load-carrying capacity of the concrete. Sh-0.20Ma-25, Sh-0.35Ma-25, and Sh-0.50Ma-25, have 2.05%,4.10% ,21.23% improvement of shear strength respectively, when it is compared with reference specimen (Sh-025). However, there is a loss of shear strength in Sh-0.65Ma-25 by 4.79%.

The failure load is somewhat less than the control sample for minor ratios i.e. 0.20% to 0.35%, of fibers which indicates that no proper bridging action is developed in less percentage. But, when the percentage of fibers rises to 0.50% there is an improvement in failure load by a little percentage. The test results are given in Table 4-6.

The degree of enhancement was significant when macro synthetic fibers were added in a 0.50% volume fraction compared to the beams without fibers. The efficiency of fiber reinforcement seemed to have diminished when used in higher volume fractions which needs further study to exactly determine the optimum fiber dosage.

b. Effect of concrete strength

The shear strength of the concrete decreases with the increases in concrete strength and fiber content. With the addition of micro synthetic fibers, the shear strength of 40 MPa concrete drops by 18.3% and 49.7% at 0.35% and 0.65% micro synthetic fiber content relative to concrete strength of 25 MPa with the same fiber content.

Similarly, the shear strength of macro synthetic FRC decreases by 27.63% at 0.35% fiber content, and by 30.93% at 0.65% fiber content in relation to concrete strength of 25 MPa with the same fiber content.

c. Comparison of fiber type, fiber volume fraction and concrete strength

The addition fibers improve the shear strength of concrete significantly. Comparing the large increase in shear strength obtained with the addition of fibers in 0.65% volume fraction of micro synthetic fibers and 0.50% volume fraction of macro synthetic fibers, with the shear strength increase observed that the addition of macro synthetic gives a better improvement in shear strength than micro synthetic fiber.

The difference in strength between the optimum percentage of fiber clearly indicates that concrete with a macro synthetic fiber of 0.5% fiber content is better in improving the shear strength relative to concrete with a micro synthetic fiber of 0.65% fiber content.

On the other hand, in contrast to the concrete strength of 40 MPa, 25 MPa concrete strength increases linearly with the increase in the percentage of fiber especially for concrete with macro synthetic fibers. It may be concluded that the incorporation of fibers in higher concrete strength did not significantly improve the shear strength.

This was similar to the result obtained by other researchers like (Altoubat, Yazdanbakhsh, and Rieder, 2010) and (Hasan, Afroz and Mahmud, 2011). Macro synthetic fibers significantly rise the shear strength above the reference beams ranged between 14 and 30% depending on the dosage of fibers and it is linearly increases with the fibers dosage.

4.2.7. Effect of fiber type, fiber volume fraction and concrete strength on the Shear Toughness

a. Effect of fiber type and fiber volume ratio

The shear load-deflection curves measured during the bending tests are primarily used to study the effect of fibers on the post-cracking behavior of concrete.

According to the load-deflection curve shown in Figure 4-12, the peak load was reached at a corresponding deflection of less than or equal to 0.1mm for all the specimens. However, compared to the plain concrete, the ductility of the specimens after the peak load was significantly improved in both micro and macro synthetic fiber reinforced specimens.

With the addition of micro and macro synthetic fibers to the concrete, the deflection at which the peak load occurs also increases. In addition, the peak load is reached as the modulus of rupture is reached (load at first crack). After this point, the drop in load capacity occurs over a longer deflection interval than non-fibrous concrete.

From the shear load-deflection curve obtained during the test, at the same amount of deflection, plain concrete can resist more load than synthetic reinforced concrete. However, when synthetic fibers content rises the total area under the load-deflection curve (curve length) increases relative to plain concrete.

The shear strength of plain concrete reached the maximum (19.08 kN) at a deflection around 0.0480mm without any post-crack performance. At the same deflection point (0.048mm) macro synthetic fiber with 0.50% fiber content slightly decreases to 17.0 kN but, the total area under the load-deflection curve is much greater than the first (plain concrete). This shows that after the first crack has occurred, SNFRC specimen can resist the load over the large deflection before the failure thus enhance the energy absorption capacity of the beam.

This was the same result obtained by other researcher (Al-lami, 2015). Crimped-steel fiber significantly increased pre-cracking flexural strength and toughness. However, monofilament polypropylene fiber had a greater effect on the pre-cracking flexural strength.

b. Effect of concrete strength

Similar to the flexural toughness, the shear toughness of synthetic fiber reinforced concrete beams increases as the concrete strength increases. In 40 MPa concrete strength the peak load has occurred at larger deflection than that of 25 MPa concrete of the same fiber content.

The comparison of the load-deflection curve between plain and macro synthetic fiber reinforced concrete with 0.5 % fiber content is given in Figure 4-17.

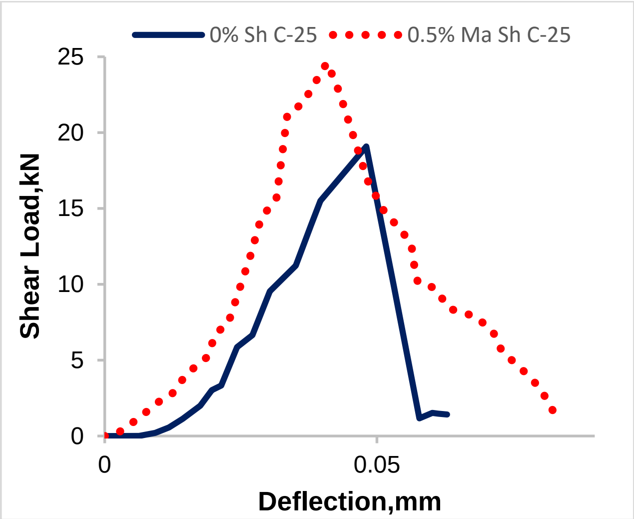


Figure 4-17 Comparison of the shear load-deflection curve for C-25 concrete strength

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusions

This paper has been concerned with the investigation of some mechanical performance and shear behavior of fiber-reinforced concrete beam by using micro and macro polypropylene synthetic fiber at different volume fraction and concrete cube strength. Using steel reinforcement and iron fixing of shear stirrups is a time consuming and hard work, to enhance the performance and failure behavior of concrete finding an alternative to this would be valuable for the building industry.

To determine the mechanical behavior, the experimental investigation was carried out on both fresh and hardened concrete. Slump tests were done to measure the workability of concrete in its fresh state.

In addition to slump test, compressive strength test was carried out to determine and evaluate the strength of concrete under the uniaxial compressive force, split tensile strength test is done to determine the influence of fibers on tensile strength of concrete, flexural tests were performed to analyze the direct residual flexural strength, which is recently required in the design of structural members using fiber reinforced concrete, shear tests were carried out to determine the shear strength of the concrete, with the changes in the fiber type, fiber volume fractions, and concrete strengths.

Moreover, this study also evaluated the energy absorption capacity of the SNFRC beams with the change in the fiber type, concrete strength, and fiber content ratio. Energy absorption was calculated using the load and deflection curve obtained from the flexural and shear tests of the SNFRC beam in accordance with (AASTM C 1018, 1997).

Lastly, a comparison was made in order to determine the optimum percentage and fiber type that can greatly enhance the behavior of synthetic FRC.

The following significant conclusions can be drawn from the result of the research program:

- Addition of micro synthetic fiber to the concrete and increase in concrete strength results in poor workability.
- Using macro synthetic fibers at all volume content can attain the slump recommended by ACI 211.1-91 for beams construction (25-100mm).

- The addition of 0.65% micro synthetic fibers decreases cube compressive strength of concrete up to 44.6% while the macro synthetic fibers enhance it by 5.39% at the same fiber content.
- The increased compressive strength by macro synthetic fiber percentage is due to fiber and aggregate bonding and not due to cement paste bonding. As the strength gains due to cement content increases, strength gains due to the percentage of fiber decreases.
- The tensile strength decreases by 14.95% when 0.65% of micro synthetic fiber used in the concrete. Conversely, macro synthetic fibers enhanced the strength by about 47.0% at 0.50% after which it decreases.
- There is about a 7.9% marginal increase in flexural strength by adding 0.35% micro synthetic fibers in concrete after which strength starts decreasing with further increment in fiber ratios it is linearly increasing up to 7.39% at 0.65% macro synthetic it needs additional investigation to exactly determine the optimum fiber dosage.
- For volume fractions of 0.2%, 0.35%,0.5% and 0.65% of micro and macro synthetic fibers the flexural toughness increased by more than 130% over that of plain unreinforced concrete for the same mix compositions.
- The energy absorption capacity increases with the increase in the fiber content and the strength of concrete. The higher strength of the cementitious matrix is more effective in improving the energy absorption performance of the SNFRC.
- The shear strength of concrete linearly increases as the volume of fibers increases. At 0.65% micro synthetic fiber content the strength increases by 17.1% and similarly it is increased by 21.23% at 0.5% macro synthetic fiber content
- The shear strength was also found no to be more effective in the higher strength concrete mixture compared to normal strength concrete.
- The post crack performance under shear load is enhanced with the addition of both micro and macro synthetic fiber. As the fiber content of concrete increases, the deflection at which failure load also increases this shows that the fiber can absorb the energy after the first crack has occurred.
- The shear toughness of the SNFRC is more effective in higher strength concrete thus, the concrete strength of 40 MPa concrete with 0.65% macro synthetic fiber shows a greatly enhance the properties.

From this study, it can be concluded that the addition of macro synthetic fiber with 0.50% and 0.35% fiber content in 25 MPa and 40MPa concrete strength respectively were chosen as the optimum fiber dosage and type to be used as the mix in the field of the construction industry. This decision is based on the better workability of the mix, better improvement in compressive strength, tensile strength, flexural toughness, and shear strength.

5.2.Recommendation for the further research

The tests done in this research gave some pointers towards the benefits of using synthetic fibers reinforcement in structural concrete beams. However, the results of this study are based on the limited number of test variables and use small scale testing. Therefore, to better identify the behavior of SNFRC, further experimental studies are recommended that include additional test numbers and variables, including the strength of concrete, the volume fraction and varied length of beams.

Further investigation is required on the combined effects of steel fibers with polypropylene fiber to enhance both fresh and hardened concrete characteristics. Also on mixing fibers of different shapes and sizes.

It will be beneficial to investigate the effect of synthetic fibers on the shear strength, post cracking behavior and develop formulas and equations to include this effect in the analysis and design of the fiber-reinforced concrete structure.

In addition, more studies are required on the modeling of synthetic fiber material with concrete material as a matrix in finite element analysis to better determine the response of each particle under different loading conditions and rates.

References

AASTM C 1018 (1997) *Standard Test Method for Flexural Toughness and First-Crack Strength of Fiber-Reinforced Concrete (Using Beam With Third-Point Loading)*. Harbor Drive,United States.: ASTM International.

AASTM C 143 (2000) *Standard Test Method for Slump of Hydraulic-Cement Concrete*. Harbor Drive,United States.: ASTM International.

AASTM C 192 (2002) *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*. Harbor Drive,United States.: ASTM International.

AASTM C 496 (1996) *Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens*. Harbor Drive,United States.: ASTM International.

AASTM C 78 (2002) *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*. Harbor Drive,United States.: ASTM International.

AASTM C 31 (2000) *Standard Practice for Making and Curing Concrete Test Specimens in the Field*. Harbor Drive,United States.: ASTM International.

ACI, 318 (2008) *Building Code Requirements for Structural Concrete and Commentary*. Farmington Hills, MI 48331 U.S.A.: American Concrete Institute.

ACI Committee.544.3R (1993) *Guide for Specifying, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete.*,Publication SP-American Concrete Institute.

ACI Committee.544.R (1999) *Design Considerations for Steel Fiber Reinforced Concrete*.

ACI. 544.4R (2002) *Report on Fiber Reinforced Concrete*. Farmington Hills, Michigan: American concrete Institute.

Ahmed, S. Imran A Bukhari. Javed Iqbal Siddiqui and Shahzad Ali Qureshi (2006) 'A Study on Properties of Polypropylene Fiber', *31st Conference on Our World In Concrete & Structures:*, pp. 16–17.

Alhozaimy, A. M. Soroushiad, P. and Mirza C, F. (1995) 'Mechanical Properties of Polypropylene Fiber Reinforced Concrete and the Effects of Pozzolanic Materials', *Cement & Concrete Composites.* Great Britain.

Al-lami, K. A. (2015) 'Experimental Investigation of Fiber Reinforced Concrete Beams.'

Altoubat, S.Yazdanbakhsh, A. and Rieder, K. (2010) 'Shear Behavior of Macro-Synthetic Fiber-Reinforced Concrete Beams without Stirrups', *ACI Materials Journal*,106(4), pp. 381–389.

Balaguru, P. Narahari, R. and Patel, M. (1992) 'Flexural toughness of steel fiber reinforced concrete', *ACI Materials Journal,* 89(6), pp. 541–546. doi: 10.14359/4019.

Barnett, S. J., Jean-Francois Lataste., Tony Parry, Steve G. Millard and Marios N. Soutsos. (2010) 'Assessment of fibre orientation in ultra high performance fibre reinforced concrete and its effect on flexural strength', *Materials and Structures/Materiaux et Constructions*, 43(7), pp. 1009–1023. doi: 10.1617/s11527-009-9562-3.

Bazant, Z. P. and P feiffer, P. A. (1986) 'Shear fracture tests of concrete', *Materiaux et Constructions*, 19(110).

Bentur A,M.S.(1990)'Fiber reinforced cementitious composites', *Elsevier Applied science*,UK.

Brandt, A. M. (2008) 'Fibre reinforced cement-based (FRC) composites after over 40 years of development in building and civil engineering', *Composite Structures*, 86(1-3), pp. 3–9. doi: 10.1016/j.compstruct.2008.03.006.

BS, E. (2006) *Fibres for concrete Part 2: Polymer fibres Definitions, specifications and conformity*. BSI.

Buratti, N., Mazzotti, C. and Savoia, M. (2011) 'Post-cracking behaviour of steel and macro-synthetic fibre-reinforced concretes', *Construction and Building Materials*. Elsevier Ltd, 25(5), pp. 2713–2722. doi: 10.1016/j.conbuildmat.2010.12.022.

Cengiz, O. and Turanli, L. (2004) 'Comparative evaluation of steel mesh, steel fibre and high-performance polypropylene fibre reinforced shotcrete in panel test', *Cement and Concrete Research*, 34(8), pp. 1357–1364. doi: 10.1016/j.cemconres.2003.12.024.

Choi, Y. and Yuan, R. L. (2005) 'Experimental relationship between splitting tensile strength and compressive strength of GFRC and PFRC', *Cement and Concrete Research*, 35(8), pp. 1587–1591. doi: 10.1016/j.cemconres.2004.09.010.

Cifuentes, H., Fidel García, Orlando Maeso and Fernando Medina. (2013) 'Influence of the properties of polypropylene fibres on the fracture behaviour of low-, normal- and high-strength FRC', *Construction and Building Materials*, 45, pp. 130–137.

Ferrier, E., L. Michel, B. Zuber and G. Chanvillard (2015) ‘Mechanical behaviour of ultra-high-performance short-fibre-reinforced concrete beams with internal fibre reinforced polymer bars’, *Composites Part B: Engineering*. Elsevier Ltd, 68, pp. 246–258. doi: 10.1016/j.compositesb.2014.08.001.

Gencel, O., C. Ozel, W. Brostow and G. Martı´nez-Barrera (2011) ‘Mechanical properties of self-compacting concrete reinforced with polypropylene fibres’,*Materials Research Innovations*, 15(3), pp. 216–225. doi: 10.1179/143307511X13018917925900.

Gopalaratnam, V. S. and Gettu, R. (1995) ‘On the characterization of flexural toughness in fiber reinforced concretes’, *Cement and Concrete Composites*, 17(3), pp. 239–254. doi: 10.1016/0958-9465(95)99506-O.

Greenough, T. and Nehdi, M. (2009) ‘Shear Behavior of Fiber-Reinforced Self-Consolidating Concrete Slender Beams’,105(5),pp.468-477.

Guerini, V. Antonio Conforti, Giovanni Plizzari and Shiho Kawashima (2018) ‘Influence of steel and macro-synthetic fibers on concrete properties’, *Fibers*, 6(3), pp. 1–14.

Hannant, D. J.*Fibre Cements and Fibre Concretes*. Chichester,New York,Brisbane,and Toronto: John Wiley and Sons.

Hasan, M. J., Afroz, M. and Mahmud, H. I. (2011) ‘An Experimental Investigation on Mechanical Behavior of Macro Synthetic Fiber,' *International Journal of Civil & Environmental Engineering*,11(3), pp.18-23.

J.M., R. (1984) ‘Tensile strength of Concrete’, *ACI Journal*.

J.Patel. Methul, K. S.(2013) ‘Civil Engineering Effect of Polypropylene Fibre’, *Effect of the Polypropylene Fibre on the High Strength Concrete*, 2(2), pp. 125–129.

Johnston, C. D. and Gray, R. . (1986) ‘Flexural Toughness and First-crack Strength of fiber Reinforced Concrete Using ASTM C 1018’, in Proceedings (ed.) *Third International Symposium on Developments in Fiber Reinforced Cement and Concrete*. RILEM, p. 5.1.

Johnston, C. D. and Skarendahl, Å. (1992) ‘Comparative flexural performance evaluation of steel fibre-reinforced concretes acoording to ASTM C1018 shows importance of fibre parameters’, *Materials and Structures*, 25(4), pp. 191–200. doi: 10.1007/BF02473063.

K. Murahari, R. mohan R. p (2013) ‘Effects of Polypropylene fibres on the strength properties of fly ash based concrete’, *International Journal of Engineering Science Invention*, 2(5), pp.13–19. doi: 26.6718/251319.

Kaur, P. (2017) ‘Different types of Fibres used in FRC’, *International Journal of Advanced Research in Computer Science*, 8(4), pp. 2015–2018.

Khan, S., Roohul Abad Khan, Amadur Rahman Khan, Misbahul Islam and Saman Nayal (2015) ‘Mechanical properties of Polypropylene Fibre reinforced concrete for M 25 & M 30 mixes : A Comparative study’, *International Journal of Scientific Engineering and Applied Science (IJSEAS)*,1(6),pp.327-340.

Lankard, D. R. (1972) ‘Flexural Strength Predictions,Construction Engineering Research Laboratory’,*Conference Proc. M-28*. Champaign, Illinois, pp. 101–124.

Li, V. C. and Maalej, M. (1996) ‘Toughening in cement based composites. Part II: Fiber reinforced cementitious composites’, *Cement and Concrete Composites*, 18(4 SPEC. ISS.), pp. 239–249. doi: 10.1016/0958-9465(95)00029-1.

Löfgren, I. (2005) 'Fibre-reinforced concrete for industrial construction - A fracture mechanics approach to material testing and structural analysis', *Doktorsavhandlingar vid Chalmers Tekniska Hogskola*,2378,pp.1-162.

Maalej, M. and Li, V. C. (1995) ‘Introduction of Strain-Hardening Engineered Cementitious Composites in Design of Reinforced Concrete Flexural Members for Improved Durability',*ACI Stuructural Journal*,92(2),pp.167-176.doi:10.14359/1150.

Madhavi, T. C. *et al.* (2015) ‘Behaviour of polypropylene fiber reinforced concrete’, *International Journal of Applied Engineering Research*, 10(9), pp. 22627–22638.

Majdzadeh, F.,Soleimani, S. M. and Banthia, N. (2006) ‘Shear strength of reinforced concrete beams with a fiber concrete matrix’, *Canadian Journal of Civil Engineering*, 33(6), pp. 726–734. doi: 10.1139/L05-118.

Manolis, G. D.,Gareis,P.J.,and Tsonos,A.D.(1997) 'Dynamic properties of polypropylene fiber reinforced concrete slabs',*Cement and Concrete Composites*,19(4),pp.341-349.

Mirzac, F. (1996) ‘Mechanical Properties of Polypropylene Fiber Reinforced Concrete and the Effects of Pozzolanic Materials’, *Cement and Concrete Composites* ,9465(96), pp. 85–92.

Mostafazadeh, M. and Abolmaali, A. (2016) ‘Shear Behavior of Synthetic Fiber Reinforced Concrete’, *Composites Applications in Infrastructures*, pp.83-89.

Naaman, A. E. and Reinhardt, H. W. (2006) ‘Proposed classification of HPFRC composites based on their tensile response’, *Materials and Structures/Materiaux et Constructions*, 39(289), pp. 547–555. doi: 10.1617/s11527-006-9103-2.

Oh, B. H. *et al.* (2005) 'Experimental and theoretical investigation on the postcracking inelastic behavior of synthetic fiber reinforced concrete beams',*Cement and Concrete Research*, 35(2), pp. 384–392. doi: 10.1016/j.cemconres.2004.07.019.

Oh, B. H., Kim, J. C. and Choi, Y. C. (2007) 'Fracture behavior of concrete members reinforced with structural synthetic fibers', *Engineering Fracture Mechanics*, 74(1-2), pp. 243–257. doi: 10.1016/j.engfracmech.2006.01.032.

Oliveira, F. L. de (2010) 'Design-oriented constitutive model for steel fiber reinforced concrete', *PhD thesis, Universitat Politècnica de Catalunya*, (March), p. 200.

Owens, G. (2009) *Fulton's concrete technology*. South Africa: Cement and Concrete.

Pigeon, M. and Cantin, R. (1998) 'Flexural properties of steel fiber-reinforced concretes at low temperatures',*Cement and Concrete Composites*,20(5),pp.365-375.

Ramakrishnan, V., Gollapudi, S. and Zellers, R. (1987) 'Performance characteristics and fatigue strength of polypropylene fibre reinforced concrete', *Special publication*, 105, pp. 159–178.

Ramujee, K. (2013) 'Strength Properties of Polypropylene Fiber Reinforced Concrete', *International Journal of Innovative Research in Science, Engineering and Technology* 2(8), pp. 3409–3413.

Rosidawani, Iswandi Imran, Saptahari Sugiri and Ivindra Pane (2015) 'Behaviour of macro fiber Reinforced concrete Columns under concentric axial compression,'*Procedia Engineering 125*,pp.987-994.

Selvi, M. T. and Thandavamoorthy, T. S. (2013) 'Studies on the Properties of Steel and Polypropylene Fibre Reinforced Concrete without any Admixture', *International Journal of Engineering and Innovative Technology (IJEIT)*, 3(1), pp. 411–416.

Sounthararajan, V. M., Anshul Jain, Abhishek Kumar Singh, S. Thirumurgan. and Dr. A. Siva Kumar. (2013) 'Evaluation of composite polypropylene fibre reinforced concrete', *International Journal of Engineering and Technology*, 5(2), pp. 1817–1828.

Soutsos, M. N., Le, T. T. and Lampropoulos, A. P. (2012) 'Flexural performance of fibre reinforced concrete made with steel and synthetic fibres', *Construction and Building Materials*, 36, pp. 704–710. doi: 10.1016/j.conbuildmat.2012.06.042.

Swamy, R. N., Mangat, P. S. and Rao ,C.V.S.K. (no date) ‘The mechanics of Fibre Reinforcement of Cement Matrices,Fibre-Reinforced Concrete’, *ACI Publication*, (S.P.44), pp. 1–28.

Jean-Francois Trottier and Nemkumar Banthia ' Toughness characterization of steel fiber reinforced concrete' (1994) *Journal of Materials*, 6(2), pp. 264–289.

Thirumurugan, S. and Sivakumar, A. (2013) ‘Compressive strength index of crimped polypropylene fibres in high strength cementitious matrix’, *World Applied Sciences Journal*, 24(6), pp. 698–702. doi: 10.5829/idosi.wasj.2013.24.06.714.

Topçu, I. B. and Canbaz, M. (2007) ‘Effect of different fibers on the mechanical properties of concrete containing fly ash’, *Construction and Building Materials*, 21(7), pp. 1486–1491. doi: 10.1016/j.conbuildmat.2006.06.026.

V.Ramadevi and Babu, D. L. V. (2012) ‘Flexural behavior of hybrid (steel and polypropylene) fibre reinforced concrete beams’, *European Journal of Scientific Research*, 70(1), pp. 81–87.

Wafa, F. F. (1990) ‘Properties and Applications of Fiber Reinforced Concrete’, *JKAU: Eng. Sci*, 2(September), pp. 49–63. doi: 10.4197/Eng.2-1.4.

Wille, K., El-Tawil, S. and Naaman, A. E. (2014) ‘Properties of strain hardening ultra high performance fiber reinforced concrete (UHP-FRC) under direct tensile loading’, *Cement and Concrete Composites*.Elsevier Ltd,48(7)pp.53-66.

Won, J., Lim, D. and Park, C. (2006) ‘Bond behaviour and flexural performance of structural synthetic fibre-reinforced concrete’, *Magazine of Concrete Research*,58(6), pp. 401–410.

Won, J. P. *et al.* (2009) ‘Performance of synthetic macrofibres in reinforced concrete for tunnel linings’, *Magazine of Concrete Research*, 61(3), pp. 165–172.

Yang, S. L. *et al.* (2009) ‘Influence of aggregate and curing regime on the mechanical properties of ultra-high performance fibre reinforced concrete (UHPFRC)’, *Construction and Building Materials*.Elsevier Ltd,23(6),pp.2291-2298.

Yao, W., Li, J. and Wu, K. (2003) ‘Mechanical properties of hybrid fiber-reinforced concrete at low fiber volume fraction’, *Cement and Concrete Research*, 33(1), pp. 27–30. doi: 10.1016/S0008-8846(02)00913-4.

Yin, S. *et al.* (2015) ‘Use of macro plastic fibres in concrete: A review’, *Construction and Building Materials.Elsevier Ltd,*93,pp.180-188 doi: 10.1016/j.conbuildmat.2015.05.105

Yurtseven, A. E. (2004) 'Determination of Mechanical Properties of Hybrid Fiber Reinforced Concrete',*Thesis submitted to the graduate school of natural and applied sciences of middle east technical university.*

Zerbino, R. L. and Barragn, B. E. (2012) ‘Long-term behavior of cracked steel fiber-reinforced concrete beams under sustained loading’, *ACI Materials Journal,* 109(2), pp. 215–224. doi: 10.14359/51683708.

Zheng, Z. and Feldman, D. (1995) *Synthetic Fiber-Reinforced Concrete*. Great Britain: Elsiever Science Ltd.

Zile, E. and Zile, O. (2013) ‘Effect of the fiber geometry on the pullout response of mechanically deformed steel fibers’, *Cement and Concrete Research*, 44, pp. 18–24. doi: 10.1016/j.cemconres.2012.10.014.

Appendix

Appendix A - Synthetic fiber reinforced concrete material properties

A1. Physical and chemical properties of synthetic fiber

Table A-1: Physical and chemical properties of synthetic fiber

Fiber Type	Specific Gravity (g/cm^3)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Flash Point (° F)	Melting point (° F)	Ignition Temperature (° F)	Length (mm)	Surface Texture
Polypropylene	0.90-0.92	550-640	3-5	>329	162-167	>450	12	Triangular
Polypropylene fiber tuff	0.90-0.92	550-640	6-10	>329	159-179	>450	50	continuously embossed

A2. Coarse Aggregate Physical Properties

2.1 Sieve Analysis

This test method is used primarily to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance of the particle size distribution with applicable specification requirements and to provide necessary data for control of the production of various aggregate products and mixtures containing aggregates. This test method is conducted according to AASTM C 136.

Apparatus: Sieve Apparatus or sieve set. The apparatus consists of eight different types of sieves i.e. 37.5mm,28mm,19mm,12.5mm,9.5mm and 4.75mm, electric shaker and weighing balance.

Procedure

I. Dry the sample to Constant mass at a temperature of 110 ± 5°F (230 6 9°F)

II. Select sieves with suitable openings.

III. Limit the quantity of material on a given sieve by weighing ten kilograms of aggregate.

IV. Continue sieving for a sufficient period or ten minutes by mechanical sieve shaker.

V. Determine the mass of each size increment on a scale or balance conforming to the requirements specified.

VI. Calculate percentages passing;

VII. Total percentages retained, or percentages in various size fractions to the nearest 0.1 % on the basis of the total mass of the initial dry sample.

A sample calculation is given in the Table A-2 particle size distributions of coarse aggregate.

Table A-2: Particle size distributions of coarse aggregate

Location	*Jimma Institute of Technology*	*Sample No.*	*002/2019*
Source	*Jimma city*	*Mat. Type*	*Coarse aggregate*
Date of Sampling	*May 18, 2019*	*Job Ref.*	*MSc thesis*
Date Of Testing	*May 20, 2019*	*Mat. for*	*Concrete production*

Sieve size (mm)	Mass of samples		Avg. mass retained (g)	Percent retained	Cumulative retained (%)	Weight passing (g)	% Passing
	m_1,g	m_2,g					
37.5	0	0	0	0	0	10,000	100
25	903	898.6	900.8	9	9	9099.2	90.99
19	5001	4992	4996.5	50	59	4102.7	41.03
12.5	2337	2322.4	2329.7	23.3	82.3	1773.0	17.73
9.5	1329	1335.6	1332.3	13.3	95.6	440.7	4.41
4.75	436.6	439.8	437.7	4.4	100	3	0.03
Pan	4	2	3	0	100	0	0
Total			**10000**				

2.2 Moisture Content

This test method is used primarily to determine the moisture content of the coarse aggregates.

Procedure:

I. Weigh a sample of 2 kg aggregate (A) retaining on 4.75 sieve size
II. Oven-dry the sample for about 24 hours
III. Remove the sample from the oven and place them on a desiccator
IV. Weigh the aggregate after oven-dry (B)
V. Calculate the moisture content of the aggregate

$$\%\,Moisture\ content = \left(\frac{A-B}{B}\right) \times 100 \qquad \text{(A2-1)}$$

$$Average\ = \left(\frac{1+2}{2}\right) \qquad \text{(A2-2)}$$

Table A-3: Moisture content of coarse aggregate

No.	Description	Sample Number	
		1	**2**
1	A(g)	2000	2000
2	B(g)	1989	1990
3	Moisture Content (%)	0.55	0.5
	Average(%)	**0.525**	

2.3 Specific gravity and absorption test

This test is done according to the ASTM C 127-88 method, which covers the determination of specific gravity and absorption of coarse aggregate. The specific gravity may be expressed as bulk specific gravity, bulk specific gravity (SSD) (saturated-surface-dry), or apparent specific gravity. The bulk specific gravity (SSD) and absorption are based on aggregate after 24 hours soaking in water.

Bulk specific gravity is the characteristic generally used for calculation of the volume occupied by the aggregate in various mixtures containing aggregate. Apparent specific gravity pertains to the relative density of the solid material making up the constituent particles, not including the pore space within the particles which is accessible to water.

Procedure

I. Dry the test sample to the constant weight of 2000g at a temperature of 110 ± 5 °F (230 ± 9°F), Fool in the air at room temperature for 1 to 3 hours for test samples of 37.5mm (11⁄2-in.) nominal maximum size and above 4.75mm sieve size.
II. Soaking the sample in water for 24 hours
III. Remove the test sample from the water and roll it until all films of water are removed.
IV. Weigh the test sample in the saturated surface dry condition.
V. After weighing, immediately place the saturated surface-dry test sample in the sample container and determine its weight in water at 236 1.7°F (73.4 6 3°F).
VI. Dry the test sample to constant weight at a temperature of 110 ± 5°F (230 6 9°F), Fool in the air at room temperature 1 to 3 h, and weigh.

Results obtained from the tests are:

A. Bulk specific gravity
B. Bulk specific gravity (Saturated-Surface-Dry)
C. Apparent specific gravity
D. Coarse aggregate absorption

$$\text{Bulk Specific Gravity} \quad Gsb = \left(\frac{A}{B-C}\right) \quad \text{(A2-3)}$$

$$\text{Bulk SSD Specific Gravity} = \left(\frac{B}{B-C}\right) \quad \text{(A2-4)}$$

$$\text{Apparent Specific Gravity (Gsa)} = \left(\frac{A}{A-C}\right) \quad \text{(A2-5)}$$

$$\text{Absorption}, \% = \left(\frac{B-A}{A}\right) \times 100 \quad \text{(A2-6)}$$

where: *A* = weight of oven-dry test sample in air, g.

B = weight of SSD test sample in air, g.

C= weight of saturated test sample in water, g.

The specific gravity and water absorption of coarse aggregate are given in Table A-4.

2.4 Unit weight of coarse aggregate

The objective of this test method is to determine the unit weight of coarse aggregates by following the procedure given on AASTM C 29/C 29M. The unit weight effectively measures the volume that the graded aggregate will occupy in concrete.

Table A-4: Coarse aggregate specific gravity and water absorption

Location	*Jimma Institute of Technology*	*Sample No.*	*002/2019*
Source	*Jimma city*	*Mat. Type*	*coarse aggregate*
Date of Sampling	*May 18, 2019*	*Job Ref.*	*MSc. Thesis*
Date Of Testing	*May 20, 2019*	*Mat. for*	*concrete production*

	Test No.	**1**	**2**	**3**	**Avg.**
A	Mass of oven-dry sample in air, g	1990	1993	1987	1990.3
B	Mass of SSD Sample in air, g	2011	2012	2010	2011
C	Mass of Saturated test sample in water, g	1297	1299	1296	1297.3
G_{SSD}	Bulk specific gravity (saturated surface dry basis(SSD)	2.817	2.822	2.815	2.818
G_{sb}	Bulk specific gravity(OD)	2.787	2.795	2.784	2.789
G_{sa}	Apparent specific gravity	2.872	2.872	2.876	2.873
	Absorption,%	1.055	0.953	1.158	1.055

Table A-5: Unit weight of coarse aggregate

	Test No.	**1**	**2**	**3**
A	Mass of container, Kg	1.683	1.683	1.683
B	Mass of container + sample ,Kg	18.242	18.230	18.251
G	Mass of sample (g) = **B-A**	16559	16547	16556
V	Volume of container,m^3	0.01	0.01	0.01
M	Unit weight (Kg/m^3)	1656	1654.7	1656.8
	Average unit weight = **(1+2+3) / 3**	**1656**		

The unit weight is simply measured by filling a container of known volume and weighing it. Finally, calculate the unit weight of the coarse aggregate by the given formula. The unit weight of coarse aggregate is given in Table A-5.

$$Unit\ weight(M) = \left(\frac{G}{V}\right) \qquad \text{(A2-7)}$$

Where:

M = unit weight of aggregate, (kg/m^3)

G = mass of sample (kg)

V = is Volume of cylindrical Metal (m^3)

A3. Fine Aggregate Physical Properties

3.1 Sieve Analysis of fine aggregate

The objective of this test was to determine the fineness modulus.

This test method is conducted according to ASTM C 136-9a. The procedures of the test are;

I. Prepare 2kg fine aggregate select sieves with suitable openings and sieve by 9.5mm sieve size to remove oversize

II. Pour the sample in the top sieve on a mechanical shaker and continue sieving for a sufficient period or ten minutes.

III. Determine the mass of the sample retained on each sieve and determine the percentage retained and passing.

IV. Calculate fineness modulus.

Fineness modulus is defined as the sum of the cumulative percentage of sand retained in the designated sieves divided by 100. Table A-6 shows the sieve analysis of fine aggregate.

Table A-6: particle size distribution of fine aggregate

Test sieve size (mm)	Weight retained,(g)	Percent retained	Cumulative retained, (%)	Weight passing,(g)	Percent passing
9.5	0	0	0	0	100
4.75	26.5	1.3	1.3	1973.5	98.68
2.36	85.0	4.3	5.6	1888.5	94.43
1.18	258.5	12.9	18.5	1630.0	81.50
0.6	504.0	25.2	43.7	1126.0	56.30
0.3	616.0	30.8	74.5	510.0	25.50
0.15	382.0	19.1	93.6	128.0	6.40
Pan	128.0	6.4	100.0	0.0	0.00
Total	**2000g**				

$$\mathrm{F.M} = \frac{\Sigma \text{cummulative coarser}(\%)}{100} \qquad \text{(A3-1)}$$

Computation:

$$\mathrm{F.M} = \frac{0 + 1.3 + 5.6 + 18.5 + 43.7 + 74.5 + 93.6}{100}$$

$$= \left(\frac{237.2}{100}\right)$$

$$= \mathbf{2.4}$$

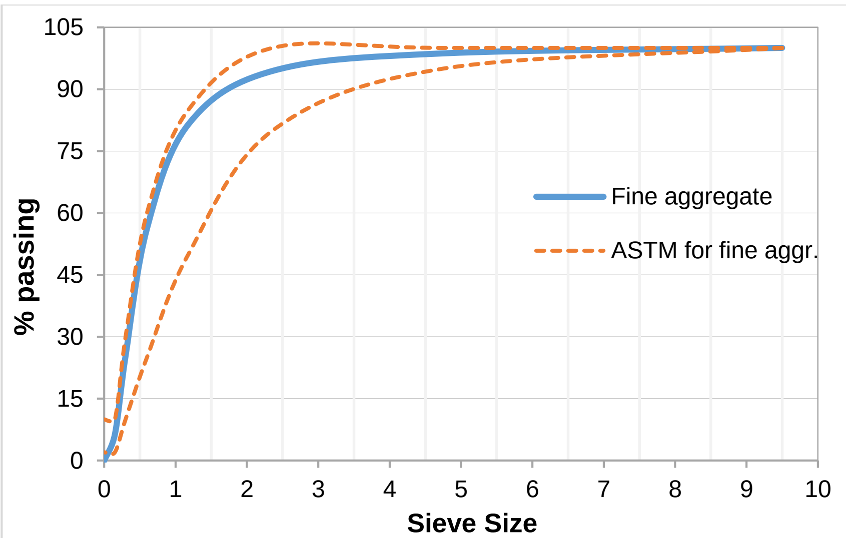


Figure A-1: Percentage passing versus sieve size for fine aggregate

Table A-7: Moisture content of fine aggregate

No.	Description	Sample Number	
		1	2
1	A(g)	500	500
2	B(g)	498.5	499
3	Moisture content (%)	0.3	0.2
	Average(%)	**0.25**	

3.2 Moisture content of fine aggregate

The objective of this test is to determine the moisture content of fine aggregate.to determine the moisture content; first prepare 500g sample passing 9.5mm sieve size to remove oversize (A), then dry the sample in the oven for 24 hours. Finally, remove the sample from the oven, measure it (B) and to calculate the moisture content of sand. Table A-7 shows the moisture content of fine aggregate.

$$\%\,Moisture\ content = \left(\frac{A-B}{B}\right) \times 100 \qquad \text{(A3-2)}$$

3.3 Silt content of fine aggregate

Silt content is a fine material that is less than 150 microns. An excessive quantity of silt, not only reduces the bonding of cement and fine aggregates but also affects the strength and durability of work. To determine the silt content measure 1000 g (A) of sample passing 9.5mm sieve size, then wash by 0.075 sieve size and put it in the oven for 24 hours. Finally, weigh the sample from the oven (B) and we calculate the silt content. Table A-8 shown below provides the silt content of fine aggregate.

$$\%\,Silt\ content = \left(\frac{A-B}{B}\right) \times 100 \qquad \text{(A3-3)}$$

Table A-8: Silt content of fine aggregate

No.	Description	Sample Number	
		1	2
1	A(g)	1000	1000
2	B(g)	986.5	982
3	Silt content (%)	1.37	1.83
	Average(%)	**1.6**	

3.4 Specific gravity and absorption capacity of fine aggregate

This test is done according to ASTM C 128-97 to determine the bulk and apparent specific gravity, and absorption of fine aggregate. The procedures are:

I. Prepare 500g sand passing 9.5mm sieve size.
II. Partially fill the pycnometer with water. Immediately introduce into the pycnometer 500 ±10 g fine and fill with additional water to approximately 90 % of capacity.
III. Manually roll, invert, and agitate the pycnometer to eliminate all air bubbles.
IV. Determine the total weight of the pycnometer, specimen, and water.
V. Remove the fine aggregate from the pycnometer dry to constant weight at a temperature of 110 ± 5°F (230 6 9°F) cool in the air at room temperature for 1 ± 1/2 h, and weigh.
VI. Determine the weight of the pycnometer filled to its calibration capacity with water.

Results are calculated by the following formula:

$$\text{Bulk Specific Gravity} \quad Gsb = \left(\frac{A}{B+500-C}\right) \qquad (A3\text{-}4)$$

$$\text{Bulk SSD Specific Gravity} = \left(\frac{500}{B+500-C}\right) \qquad (A3\text{-}5)$$

$$\text{Apparent Specific Gravity} = \left(\frac{A}{A+B-C}\right) \qquad (A3\text{-}6)$$

$$\text{Absorption, \%} = \left(\frac{500-A}{A}\right) \qquad (A3\text{-}7)$$

where:

A = weight of oven-dry test sample in air, g,

B = mass of flask filled with water, g,

C = mass of pycnometer with specimen and water, g,

W= mass of flask empty, g

S=Specimen weight,500g

Location	*Jimma Institute of Technology*	***Sample No.***	*002/2019*
Source	*Gambella*	***Mat. Type***	*Fine aggregate*
Date of Sampling	*May 22, 2019*	***Job Ref.***	*Master's Thesis*
Date Of Testing	*May 24, 2019*	***Mat. for***	*Concrete production*

Table A-9: specific gravity and absorption capacity of fine aggregate

	Test No.	1	2	Avg.
A	Mass of oven-dry sample, g	495.5	497	496.3
S	Mass of SSD sample in air, g	500	500	500
B	Mass of pycnometer + water, g	1554	1554	1554
C	Mass of pycnometer + water + sample	1856.5	1857	1856.8
G_{SSD}	Bulk specific gravity (saturated surface dry basis(SSD)	2.532	2.538	2.535
G_{sb}	Bulk specific gravity	2.509	2.523	2.506
G_{sa}	Apparent specific gravity	2.567	2.562	2.565
	Absorption,%	0.908	0.604	0.756

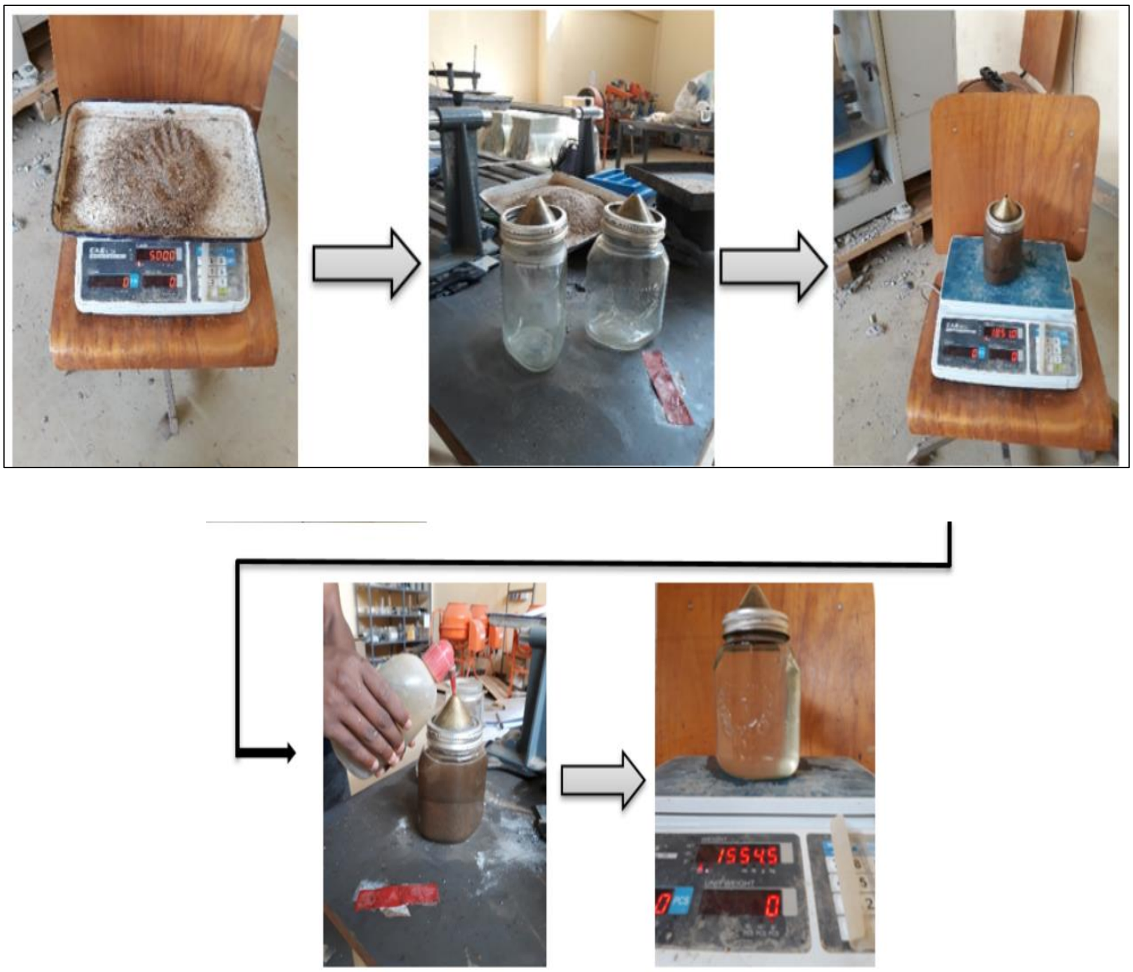


Figure A-2: specific gravity determination of fine aggregate

3.4 Unit weight of fine aggregate

The main objective of this test determination of bulk density ("unit weight") of aggregate in a compacted or loose condition, and calculated voids between particles in fine, coarse, or mixed aggregates based on the same determination. The test is conducted according to AASTM C 29/C 29M (standard test method for unit weight and voids in aggregate).

Procedure:

I. Fill the measure one-third full and level the surface with the fingers.
II. Rod the layer of aggregate with 25 strokes of the tamping rod.
III. Fill the measure two-thirds full and again level and rod as above.
IV. Finally, fill the measure to overflowing and rod again in the manner previously mentioned and level the surface and determine the mass of the measure plus its contents, and the mass of the measure alone.
V. Calculate the unit weight following the formula given below;

$$Unit\ weight = \left(\frac{G}{V}\right) \quad \text{(A3-8)}$$

Where: M= unit weight of aggregate, (kg/m^3) G = mass of sample (kg)
V= volume of a cylindrical metal (m^3)

Table A-10: Unit weight of fine aggregate

	Test No.	1	2	3
A	Mass of container, Kg	1.05	1.05	1.05
B	Mass of container + sample ,Kg	9.154	9.157	9.214
G	Mass of sample (g) = **B-A**	8.104	8.107	8.164
V	Volume of container,m^3	0.005	0.005	0.005
M	Unit weight (Kg/m^3)	1620.8	1621.4	1632.8
	Average unit weight = **(1+2+3) / 3**	**1625**		

Figure A-3: Unit weight determination of fine aggregate

Appendix B - Mix design synthetic fiber reinforced concrete

It is the process of selecting suitable ingredients of concrete and determining their relative proportions with the object of producing concrete of certain minimum strength and durability as economically as possible.

The mix design is done according to the ACI Standard 211.1-91 is a "Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete". The procedure is as follows:

Step 1. choice of the slump -- If the slump is not specified, a value appropriate for the work Fan be selected from Table 6.3.1 (Table A1.5.3.1). The slump ranges shown apply when vibration is used to consolidate the concrete. Table B-1 provides recommended slumps for various types of construction (SI).

Step 2. choice of a maximum size of aggregate -- Hence, concretes with the larger-sized aggregates require less mortar per unit volume of concrete. Generally, the nominal maximum size of aggregate should be the largest that is economically available and consistent with dimensions of the structure.

Step 3. Estimation of mixing water and air content -- The quantity of water per unit volume of concrete required to produce a given slump is dependent on: the nominal maximum size, particle shape, and grading of the aggregates; the concrete temperature; the amount of entrained air; and use of chemical admixtures. Table B-2 provides estimates of required mixing water for concrete made with various maximum sizes of aggregate, with and without air entrainment.

Table B-1: Recommended slumps for various types of construction (SI)

Types of construction	Slump, mm	
	Maximum *	Minimum
Reinforced foundation walls and footings	75	25
Plain footings, caissons, and substructure walls	75	25
Beams and reinforced walls	100	25
Building columns	100	25
Pavements and slabs	75	25
Mass concrete	75	25

* Maybe increased 25mm for methods of consolidation other than vibration

Table B-2: Approximate mixing water and air content requirements for different slumps and nominal maximum sizes of aggregates (SI),(AFI 211.1-91 TABLE A1.5.3.3.)

Slump, mm	Water, Kg/m³ of concrete for indicated nominal maximum sizes of aggregate 9.5*	12.5*	19*	25*	37.5*	50†*	75†‡	150†‡
Non-air-entrained concrete								
25 to 50	207	199	190	179	166	154	130	113
75 to 100	228	216	205	193	181	169	145	124
150 to 175	243	228	216	202	190	178	160	—
Approximate amount of entrapped air in non-air-entrained concrete, percent	3	2.5	2	1.5	1	0.5	0.3	0.2
Air-entrained concrete								
25 to 50	181	175	168	160	150	142	122	107
75 to 100	202	193	184	175	165	157	133	119
150 to 175	216	205	197	184	174	166	154	—
Recommended average§otal air content, percent for level of exposure:								
Mild exposure	4.5	4.0	3.5	3.0	2.5	2.0	1.5**††	1.0**††
Moderate exposure	6.0	5.5	5.0	4.5	4.5	4.0	3.5**††	3.0**††
Extreme exposure‡‡	7.5	7.0	6.0	6.0	5.5	5.0	4.5**††	4.0**††

Table B-3: Relationship between water-cement ratio and compressive strength of concrete (ACI 211.1-91 TABLE A1.5.3.4(a))

Compressive strength at 28 days, MPa	Water-cement ratio, by mass: Non-Air-Entrained concrete	Air –Entrained concrete
40	0.42	—
35	0.47	0.39
30	0.54	0.45
25	0.61	0.52
20	0.69	0.60
15	0.79	0.70

***Step 4. Selection of water-cement or water cementitious materials ratio* --** The required water/cement ratio is determined by strength, durability and finishes ability. Table B-3 provides a relationship between the water-cement ratio and the average compressive strength of concrete.

***Step 5. Calculation of cement content* --**The amount of cement per unit volume of concrete is fixed by the determinations made in Steps 3 and 4 above.

$$Weight\ of\ cement = \left(\frac{weight\ of\ water}{\frac{w}{c}}\right) \qquad \text{(B-1)}$$

Table B-4: Volume of Foarse aggregate per unit of volume of concrete (SI), (ACI 211.1-91 TABLE A1.5.3.6)

Nominal maximum size of aggregate, mm	Volume of dry-rodded coarse aggregate* per unit volume of concrete for different fineness moduli† of fine aggregate			
	2.40	2.60	2.80	3.00
9.5	0.50	0.48	0.46	0.44
12.5	0.59	0.57	0.55	0.53
19	0.66	0.64	0.62	0.60
25	0.71	0.69	0.67	0.65
37.5	0.75	0.73	0.71	0.69
50	0.78	0.76	0.74	0.72
75	0.82	0.80	0.78	0.76
150	0.87	0.85	0.83	0.81

*Volumes are based on aggregates in dry-rodded condition as described in ASTM C 29.

***Step 6. Estimation of coarse aggregate content* --** Appropriate values for this aggregate volume are given in Table B-4.

***Step 7. Estimation of fine aggregate content* --** At the completion of Step 6, all ingredients of the concrete have been estimated except the fine aggregate. Its quantity can be determined by difference if the "absolute volume" displaced by the known ingredients-, (i.e., water, air, cement, and coarse aggregate), is subtracted from the unit volume of concrete to obtain the required volume of fine aggregate.

***Step 8. Adjustments for aggregate moisture* –** The aggregates will be moist and their dry weights should be increased by the percentage of water they contain, both absorbed and surface.

Step 9. Trial batch adjustments

B1. Final design Proportion

Table B-1: final mix design proportion for C-25 concrete

Ingredients	Quantity in ,kg/m^3					Ratio	One bag cement, kg
Synthetic Fiber, concrete volume	0%	0.2%	0.35%	0.5%	0.65%	__	__
Cement	370	370	370	370	370	1	50
Fine aggregate	708.80	708.80	708.80	708.80	708.80	1.91	95.78
Coarse aggregate	1103.89	1103.89	1103.89	1103.89	1103.89	2.98	149.17
Synthetic Fiber	0	2.17	3.8	5.45	7.1	__	__
water	193.8	193.8	193.8	193.8	193.8	0.52	26.18
Chemical	__	__	__	__	__	NM	NM

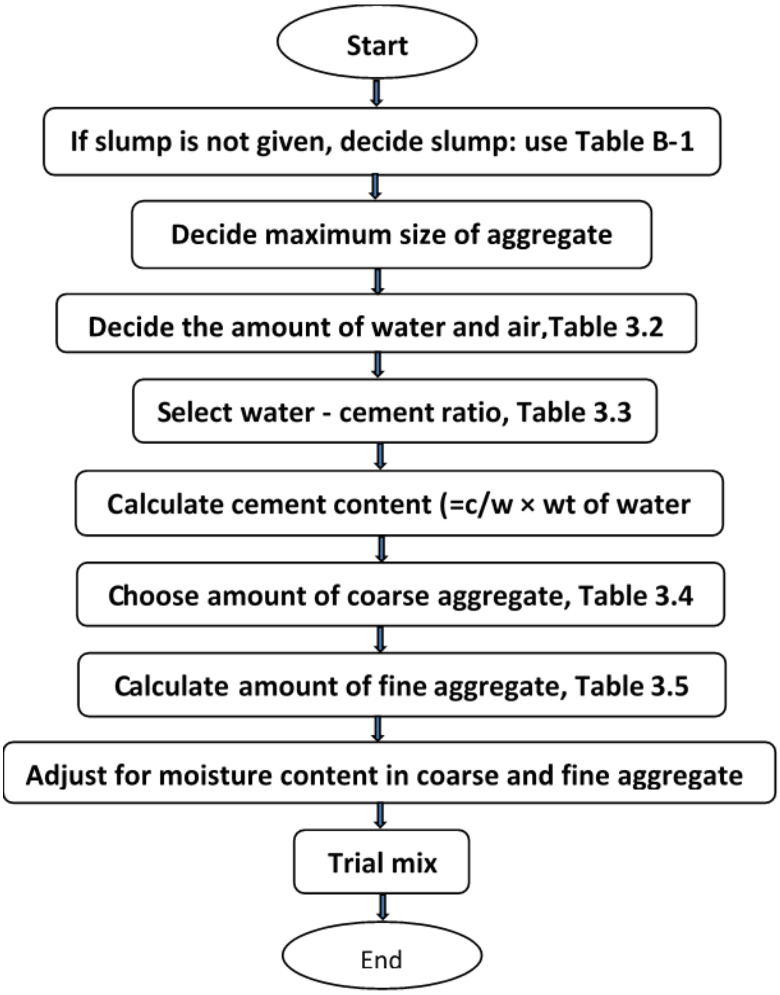


Figure B–1. Mix design flow Chart

Appendix C- Laboratory test results for compressive and tensile strength tests

C1. Results of compressive strength tests

Test series	Dimensions,m			Weight	Volume	Unit weight	Peak load	Compressive strength
	h	d	b	kg	$10^{-3}m^3$	kg/m^3	kN	MPa
C-0-25-S1	0.15	0.15	0.15	8.21	3.375	2433.8	807.3	35.88
C-0-25-S2	0.15	0.15	0.15	8.35	3.375	2474.4	774.5	34.42
C-0-25-S3	0.15	0.15	0.15	8.28	3.375	2453.3	785.0	34.89
C-0.20Mi-25	**Average**			**8.28**		**2453.8**	**788.9**	**35.06**
C-0.20Mi-25-S1	0.15	0.15	0.15	8.217	3.375	2434.7	665.1	29.56
C-0.20Mi-25-S2	0.15	0.15	0.15	8.198	3.375	2429.0	728.3	32.37
C-0.20Mi-25-S3	0.15	0.15	0.15	8.201	3.375	2429.9	689.3	30.64
	Average			**8.21**		**2431.2**	**694.3**	**30.86**
C-0.35Mi-25-S1	0.15	0.15	0.15	8.25	3.375	2445.0	745.0	33.11
C-0.35Mi-25-S2	0.15	0.15	0.15	8.43	3.375	2498.4	637.3	28.32
C-0.35Mi-25-S3	0.15	0.15	0.15	8.19	3.375	2427.3	692.3	30.77
	Average			**8.29**		**2456.9**	**691.5**	**30.74**
C-0.50Mi-25-S1	0.15	0.15	0.15	7.43	3.375	2201.2	497.5	22.11
C-0.50Mi-25-S2	0.15	0.15	0.15	8.14	3.375	2412.9	672.6	29.89
C-0.50Mi-25-S3	0.15	0.15	0.15	7.92	3.375	2347.0	629.3	27.97
	Average			**7.83**		**2320.4**	**599.8**	**26.66**
C-0.65Mi-25-S1	0.15	0.15	0.15	7.55	3.375	2236.4	418.3	18.59
C-0.65Mi-25-S2	0.15	0.15	0.15	7.62	3.375	2257.8	458.1	20.36
C-0.65Mi-25-S3	0.15	0.15	0.15	7.53	3.375	2231.1	435.4	19.35
	Average			**7.57**		**2241.8**	**437.3**	**19.43**
C-0.20Ma-25-S1	0.15	0.15	0.15	8.31	3.375	2461.0	79.7	35.10
C-0.20Ma-25-S2	0.15	0.15	0.15	8.21	3.375	2431.1	848.9	37.74
C-0.20Ma-25-S3	0.15	0.15	0.15	8.14	3.375	2412.7	819.5	36.42
	Average			**8.22**		**2435.0**	**819.4**	**36.42**

C-0.35Ma-25-S1	0.15	0.15	0.15	8.29	3.375	2455.1	787.3	34.99
C-0.35Ma-25-S2	0.15	0.15	0.15	8.58	3.375	2541.0	872.1	38.76
C-0.35Ma-25-S3	0.15	0.15	0.15	8.37	3.375	2480.0	829.6	36.87
	Average			**8.41**		**2492.0**	**829.7**	**36.87**
C-0.50Ma-25-S1	0.15	0.15	0.15	8.32	3.375	2464.6	798.9	35.51
C-0.50Ma-25-S2	0.15	0.15	0.15	8.47	3.375	2509.9	867.1	38.54
C-0.50Ma-25-S3	0.15	0.15	0.15	8.39	3.375	2486.5	826.5	36.73
	Average			**8.39**		**2487.0**	**830.8**	**36.93**
C-0.65Ma-25-S1	0.15	0.15	0.15	8.72	3.375	2582.5	848.0	37.69
C-0.65Ma-25-S2	0.15	0.15	0.15	8.70	3.375	2576.9	814.0	36.18
C-0.65Ma-25-S3	0.15	0.15	0.15	8.71	3.375	2579.3	832.0	36.98
	Average			**8.71**		**2579.6**	**831.3**	**36.95**
C-0-40-S1	0.15	0.15	0.15	8.87	3.375	2582.5	895.7	39.81
C-0-40-S2	0.15	0.15	0.15	8.55	3.375	2576.9	1073	47.71
C-0-40-S3	0.15	0.15	0.15	8.63	3.375	2579.3	986.0	43.82
	Average			**8.68**		**2572.3**	**985.0**	**43.78**
C-0.35Mi-40-S1	0.15	0.15	0.15	8.24	3.375	2442.1	805.4	35.79
C-0.35Mi-40-S2	0.15	0.15	0.15	8.54	3.375	2528.9	1122	49.88
C-0.35Mi-40-S3	0.15	0.15	0.15	8.35	3.375	2474.7	963.6	42.83
	Average			**8.38**		**2481.9**	**963.7**	**42.83**
C-0.65Mi-40-S1	0.15	0.15	0.15	7.49	3.375	2219.6	265.8	11.81
C-0.65Mi-40-S2	0.15	0.15	0.15	7.01	3.375	2078.2	260.0	11.56
C-0.65Mi-40-S3	0.15	0.15	0.15	7.58	3.375	2246.5	301.2	13.39
	Average			**7.36**		**2181.4**	**275.7**	**12.25**
C-0.35Ma-40-S1	0.15	0.15	0.15	8.69	3.375	2575.7	961.3	42.73
C-0.35Ma-40-S2	0.15	0.15	0.15	8.79	3.375	2603.0	1025	45.56
C-0.35Ma-40-S3	0.15	0.15	0.15	8.73	3.375	2587.0	992.1	44.09
	Average			**8.74**		**2588.5**	**992.8**	**44.13**

C-0.65Ma-40-S1	0.15	0.15	0.15	8.64	3.375	2559.4	1023	45.47
C-0.65Ma-40-S2	0.15	0.15	0.15	8.53	3.375	2528.3	739.9	32.88
C-0.65Ma-40-S3	0.15	0.15	0.15	8.61	3.375	2551.7	882.6	39.23
	Average			**8.59**		**2453.8**	**881.8**	**39.19**

C2. Results of splitting tensile strength test

Test series	**Dimension (m)**		**Weight**	**Volume**	**Unit weight**	**Peak load**	**Tensile strength**
	h	**dia**	**kg**	**$10^{-3}m^3$**	**kg/m^3**	**kN**	**MPa**
S-0-25-S1	0.2	0.1	3.836	6.283	610.54	140.2	4.46
S-0-25-S2	0.2	0.1	3.773	6.283	600.51	137.4	4.37
	Average		**3.80**		**605.5**	**138.8**	**4.42**
S-0.20 Mi-25-S1	0.2	0.1	3.76	6.283	597.6	146.4	4.66
S-0.20 Mi-25-S2	0.2	0.1	3.81	6.283	605.7	141.3	4.50
	Average		**3.78**		**601.7**	**143.9**	**4.58**
S-0.35Mi-25-S1	0.2	0.1	3.71	6.283	589.9	113.2	3.60
S-0.35Mi-25-S2	0.2	0.1	3.84	6.283	611.2	127.6	4.06
	Average		**3.77**		**600.5**	**120.4**	**3.83**
S-0.50Mi-25-S1	0.2	0.1	3.71	6.283	590.0	122.4	3.90
S-0.50Mi-25-S2	0.2	0.1	3.68	6.283	585.5	117.5	3.74
	Average		**3.69**		**587.8**	**120.0**	**3.82**
S-0.65Mi-25-S1	0.2	0.1	3.83	6.283	609.9	121.3	3.86
S-0.65Mi-25-S2	0.2	0.1	3.88	6.283	617.0	114.8	3.65
	Average		**3.85**		**613.5**	**118.1**	**3.76**
S-0.20Ma-25-S1	0.2	0.1	3.78	6.283	601.5	149.1	4.75
S-0.20Ma-25-S2	0.2	0.1	3.80	6.283	605.2	145.2	4.62
	Average		3.79	6.283	603.4	147.2	4.68
S-0.35Ma-25-S1	0.2		0.1	3.90	6.283	620.4	151.8
S-0.35Ma-25-S2	0.2		0.1	3.92	6.283	624.1	144.4

	Average		**3.91**		**622.2**	**148.1**	**4.71**
S-0.50Ma-25-S1	0.2	0.1	3.71	6.283	590.0	151.7	4.83
S-0.50Ma-25-S2	0.2	0.1	3.68	6.283	585.5	145.2	4.62
	Average		**3.69**		**587.8**	**148.5**	**4.73**
S-0.65Ma-25-S1	0.2	0.1	3.77	6.283	599.4	140.8	4.48
S-0.65Ma-25-S2	0.2	0.1	3.78	6.283	601.6	133.6	4.25
	Average		**3.77**		**600.5**	**137.2**	**4.37**
S-0-40-S1	0.2	0.1	3.98	6.283	633.1	169.7	5.40
S-0-40-S2	0.2	0.1	3.86	6.283	615.0	160.2	5.10
	Average		**3.92**		**624.1**	**164.9**	**5.25**
S-0.35Mi-40-S1	0.2	0.1	3.76	6.283	597.6	168.8	5.37
S-0.35Mi-40-S2	0.2	0.1	3.64	6.283	578.7	141.5	4.50
	Average		**3.70**		**588.2**	**155.2**	**4.94**
S-0.65Mi-40-S1	0.2	0.1	3.57	6.283	567.4	95.6	3.04
S-0.65Mi-40-S2	0.2	0.1	3.04	6.283	483.2	32.1	1.02
	Average		**3.30**		**525.3**	**63.9**	**2.03**
S-0.35Ma-40-S1	0.2	0.1	3.96	6.283	630.9	196.9	6.27
S-0.35Ma-40-S2	0.2	0.1	3.90	6.283	619.9	167.7	5.34
	Average		**3.93**		**625.4**	**182.3**	**5.80**
S-0.65Ma-40-S1	0.2	0.1	3.80	6.283	605.3	190.3	6.06
S-0.65Ma-40-S2	0.2	0.1	3.82	6.283	607.4	158.5	5.04
	Average		**3.81**		**606.3**	**174.4**	**5.55**

Appendix D - Laboratory test results of shear and Flexural strength test

D1. Results of Flexural strength test

Age of specimens: 28 days

Specimen type: Molded

Moisture condition: Test is conducted within 30 minutes after the specimen is removed from curing tank

Test series	Dimensions,m			Weight	Volume	Unit weight	Peak load	Flexural strength
	L	**d**	**b**	**kg**	**$10^{-3}m^3$**	**kg/m^3**	**kN**	**MPa**
F-0-25-S1	0.45	0.15	0.15	29.5	11.25	2622.2	32	4.27
F-0-25-S2	0.45	0.15	0.15	29.5	11.25	2622.2	33	4.40
	Average			**29.5**		**2622.2**	**32.5**	4.33
F-0.20Mi-25-S1	0.45	0.15	0.15	27	11.25	2400.0	32.8	4.37
F-0.20Mi-25-S2	0.45	0.15	0.15	26	11.25	2311.1	32	4.27
	Average			**26.5**		**2355.6**	**32.4**	**4.32**
F-0.35Mi-25-S1	0.45	0.15	0.15	26.5	11.25	2355.6	35	4.67
F-0.35Mi-25-S2	0.45	0.15	0.15	27.5	11.25	2444.4	35	4.67
	Average			**29.5**		**2400.0**	**35**	**4.67**
F-0.50Mi-25-S1	0.45	0.15	0.15	26	11.25	2311.1	33	4.40
F-0.50Mi-25-S2	0.45	0.15	0.15	26.5	11.25	2355.6	31	4.13
	Average			**26.25**		**2333.3**	**32**	**4.27**
F-0.65Mi-25-S1	0.45	0.15	0.15	26.5	11.25	2355.6	29	3.87
F-0.65Mi-25-S2	0.45	0.15	0.15	27.5	11.25	2444.4	28.3	3.77
	Average			**27**		**2400.0**	**28.65**	**3.82**
F-0.20Ma-25-S1	0.45	0.15	0.15	27	11.25	2400.0	31.2	4.16
F-0.20Ma-25-S2	0.45	0.15	0.15	28	11.25	2488.9	34	4.53
	Average			**27.5**		**2444.4**	**32.6**	**4.35**
F-0.35Ma-25-S1	0.45	0.16	0.16	31	12	2583.3	37.3	4.37
F-0.35Ma-25-S2	0.45	0.15	0.15	29.5	11.25	2622.2	34	4.53
	Average			**30.25**		**2602.8**	**35.7**	**4.45**

F-0.50Ma-25-S1	0.45	0.15	0.15	27	11.25	2400.0	32.5	4.33
F-0.50Ma-25-S2	0.45	0.15	0.15	28.5	11.25	2533.3	34	4.53
	Average			**27.75**		**2377.8**	**33.3**	**4.43**
F-0.65Ma-25-S1	0.45	0.15	0.15	29	11.25	2577.8	34.7	4.63
F-0.65Ma-25-S2	0.45	0.15	0.15	28	11.25	2488.9	35	4.67
	Average			**28.5**		**2533.3**	**34.9**	**4.65**
F-0-40-S1	0.45	0.15	0.15	27	11.25	2400.0	33.5	4.47
F-0-40-S2	0.45	0.15	0.15	27	11.25	2400.0	35	4.67
	Average			**27**		**2400.0**	**34.3**	**4.57**
F-0.35Mi-40-S1	0.45	0.15	0.15	28	11.25	2488.9	23.8	3.17
F-0.35Mi-40-S2	0.45	0.15	0.15	26.5	11.25	2355.6	26	3.47
	Average			**27.25**		**2422.2**	**24.9**	**3.32**
F-0.65Mi-40-S1	0.45	0.15	0.15	26	11.25	2311.1	20.5	2.73
F-0.65Mi-40-S2	0.45	0.15	0.15	25	11.25	2222.2	15.9	2.12
	Average			**25.5**		**2266.7**	**18.2**	**2.43**
F-0.35Ma-40-S1	0.45	0.15	0.15	27	11.25	2400.0	23.5	3.15
F-0.35Ma-40-S2	0.45	0.15	0.15	28.5	11.25	2533.3	21	2.80
	Average			**27.75**		**2466.7**	**22.25**	**2.97**
F-0.65Ma-40-S1	0.45	0.15	0.15	27	11.25	2400.0	20.73	2.76
F-0.65Ma-40-S2	0.45	0.15	0.15	27	11.25	2400.0	21.10	2.81
	Average			**27**		**2400.0**	**20.91**	**2.79**

D2. Results of flexural toughness test

Specimen Id.	A1*	A2*`	A3*	Toughness indices		Residual strength factor $R_{5,10}$	First crack load kN	First crack strength (MPa)
				I_5	I_{10}			
F-0.20Mi-25	0.260	1.472	1.531	5.62	5.84	4.50	32.5	4.33
F-0.35Mi-25	0.258	1.310	1.530	5.09	5.91	16.43	28.54	3.81
F-0.50Mi-25	0.176	0.911	1.115	5.18	6.33	23.18	22.95	3.06
F-0.65Mi-25	0.427	1.276	1.498	2.98	3.50	10.40	26.5	3.53
F-0.20Ma-25	0.316	1.416	2.149	4.48	6.80	46.39	30	4.00
F-0.35Ma-25	0.371	1.169	1.765	3.15	4.76	32.13	33.29	4.44
F-0.50Ma-25	0.251	0.785	1.186	3.13	4.73	31.95	23.45	3.13
F-0.65Ma-25	0.508	1.461	2.172	2.88	4.28	27.99	35	4.67
F-0-40	1.674	1.674	1.674	1.00	1.00	0	34.33	4.58
F-0.35Mi-40	0.463	1.120	1.209	2.42	2.78	7.21	26	3.47
F-0.65Mi-40	0.318	0.998	1.210	3.14	3.81	13.46	15.9	2.12
F-0.35Ma-40	0.280	0.899	1.404	3.21	5.01	36.07	23.64	3.15
F-0.65Ma-40	0.108	0.596	0.904	5.52	8.37	57.04	19.2	2.69

D3.Results of shear strength test

Test series	Dimensions,m			Weight	Volume	Unit weight	Peak load	Shear strength
	L	d	b	kg	$10^{-3}m^3$	kg/m^3	kN	MPa
Sh-0-25-S1	0.27	0.1	0.1	6.5	2.7	2407.4	18.3	1.39
SH-0-25-S2	0.27	0.1	0.1	6.5	2.7	2407.4	19.9	1.50
SH-0-25-S3	0.27	0.1	0.1	6	2.7	2222.2	19.8	1.50
	Average			**6.3**		**2345.7**	**19.3**	1.46
Sh-0.20Mi-25-S1	0.27	0.1	0.1	6.5	2.7	2407.4	20.8	1.58
Sh-0.20Mi-25-S2	0.27	0.1	0.1	6.5	2.7	2407.4	23	1.74
Sh-0.20Mi-25-S3	0.27	0.1	0.1	6	2.7	2222.2	19.5	1.48
	Average			**6.3**		**2345.7**	**21.1**	**1.60**

Sh-0.35Mi-25-S1	0.27	0.1	0.1	6	2.7	2222.2	18.4	1.39
Sh-0.35Mi-25-S2	0.27	0.1	0.1	6	2.7	2222.2	16.5	1.25
Sh-0.35Mi-25-S3	0.27	0.1	0.1	6.5	2.7	2407.4	25.8	1.95
	Average			**6.2**		**2284.0**	**20.2**	**1.53**
Sh-0.50Mi-25-S1	0.27	0.1	0.1	6.5	2.7	2407.4	25.8	1.95
Sh-0.50Mi-25-S2	0.27	0.1	0.1	5.5	2.7	2037.0	14	1.06
Sh-0.50Mi-25-S3	0.27	0.1	0.1	6	2.7	2222.2	17	1.29
	Average			**6**		**2222.2**	**18.9**	**1.43**
Sh-0.65Mi-25-S1	0.27	0.1	0.1	6.5	2.7	2407.4	18	1.36
Sh-0.65Mi-25-S2	0.27	0.1	0.1	6.5	2.7	2407.4	28	2.12
Sh-0.65Mi-25-S3	0.27	0.1	0.1	6.5	2.7	2407.4	21.6	1.64
	Average			**6.5**		**2407.4**	**22.5**	**1.71**
Sh-0.20Ma-25-S1	0.27	0.1	0.1	6.5	2.7	2407.4	19	1.44
Sh-0.20Ma-25-S2	0.27	0.1	0.1	6.5	2.7	2407.4	22.6	1.71
Sh-0.20Ma-25-S3	0.27	0.1	0.1	6	2.7	2222.2	17.5	1.33
	Average			**6.3**		**2345.7**	**19.7**	**1.49**
Sh-0.35Ma-25-S1	0.27	0.1	0.1	7	2.7	2592.6	18.5	1.40
Sh-0.35Ma-25-S2	0.27	0.1	0.1	7.5	2.7	2777.8	21	1.59
Sh-0.35Ma-25-S3	0.27	0.1	0.1	7	2.7	2592.6	20.6	1.56
	Average			**7.2**		**2654.3**	**20**	**1.52**
Sh-0.50Ma-25-S1	0.27	0.1	0.1	6.5	2.7	2407.4	20.4	1.55
Sh-0.50Ma-25-S2	0.27	0.1	0.1	7	2.7	2592.6	28.8	2.19
Sh-0.50Ma-25-S3	0.27	0.1	0.1	7	2.7	2592.6	20.7	1.57
	Average			**6.8**		**2530.9**	**23.3**	**1.77**
Sh-0.65Ma-25-S1	0.27	0.1	0.1	7	2.7	2592.6	17.5	1.33
Sh-0.65Ma-25-S2	0.27	0.1	0.1	7	2.7	2592.6	16.5	1.25
Sh-0.65Ma-25-S3	0.27	0.1	0.1	6.5	2.7	2407.4	21	1.59
	Average			**6.8**		**2530.9**	**18.3**	**1.39**

Sh-0-40-S1	0.27	0.1	0.1	7	2.7	2592.6	15.3	1.16
Sh-0-40-S2	0.27	0.1	0.1	7	2.7	2592.6	14.5	1.10
Sh-0-40-S3	0.27	0.1	0.1	7	2.7	2592.6	12.9	0.98
	Average			**7**		**2592.6**	**14.2**	**1.08**
Sh-0.35Mi-40-S1	0.27	0.1	0.1	6.5	2.7	2407.4	15.2	1.15
Sh-0.35Mi-40-S2	0.27	0.1	0.1	6	2.7	2222.2	17.5	1.32
Sh-0.35Mi-40-S3	0.27	0.1	0.1	6.5	2.7	2407.4	16.9	1.28
	Average			**6.3**		**2345.7**	**16.5**	**1.25**
Sh-0.65Mi-40-S1	0.27	0.1	0.1	6	2.7	2222.2	15	1.11
Sh-0.65Mi-40-S2	0.27	0.1	0.1	6.5	2.7	2407.4	9	0.68
Sh-0.65Mi-40-S3	0.27	0.1	0.1	6.5	2.7	2407.4	11	0.80
	Average			**6.3**		**2345.7**	**11.4**	**0.86**
Sh-0.35Ma-40-S1	0.27	0.1	0.1	6.5	2.7	2407.4	13.5	1.02
Sh-0.35Ma-40-S2	0.27	0.1	0.1	7	2.7	2592.6	14.6	1.11
Sh-0.35Ma-40-S3	0.27	0.1	0.1	7.5	2.7	2777.8	15.3	1.16
	Average			**7**		**2592.6**	**12.2**	**1.10**
Sh-0.65Ma-40-S1	0.27	0.1	0.1	7	2.7	2592.6	14.5	1.11
Sh-0.65Ma-40-S2	0.27	0.1	0.1	7	2.7	2592.6	10.8	0.82
Sh-0.65Ma-40-S3	0.27	0.1	0.1	7	2.7	2592.6	12.4	0.94
	Average			**7**		**2592.6**	**12.6**	**0.96**

Appendix E: Sample photos taken during laboratory test

Appendix F - Sample out puts from universal testing machine

BENDING TEST ON CONCRETE SPECIMENS

Client : Ameyu A. (FRC)

Test Organis. : Controls srl

Test location :Materials Research and Testing center, Addis Ababa

SPECIMEN DESCRIPTION:

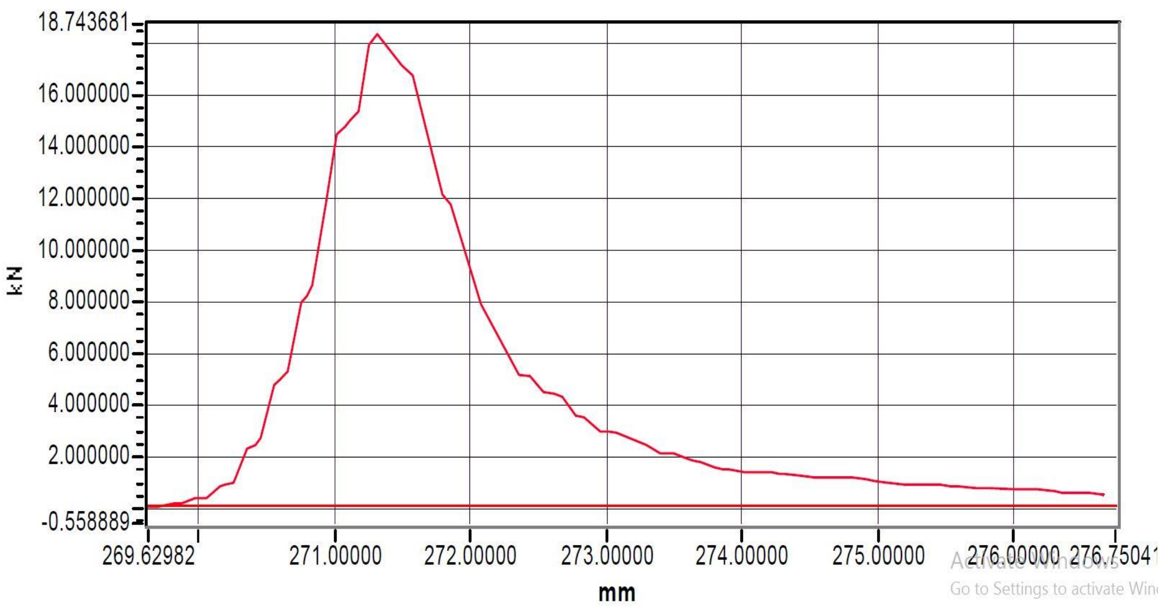
Test date : July 04,2019 Date / time received: July 04,2019

Label : Sh-0.35% C-25 Mi S-2 Span between roller (mm): 152

Max.Aggregate size : 20mm

Machined: : Yes

Upper bearer diam.(mm) : 10.0



Notes: Bazant Method

Name: Behailu Belta Position: Material Engineer

Signature:

CERTIFICATE IDENTIFICATION:

Cert 001:AAA1 Certificate date: July 14,2019

BENDING TEST ON CONCRETE SPECIMENS

Client : Ameyu A. (FRC)

Test Organis. : Controls srl

Test location :Materials Research and Testing center, Addis Ababa

SPECIMEN DESCRIPTION:

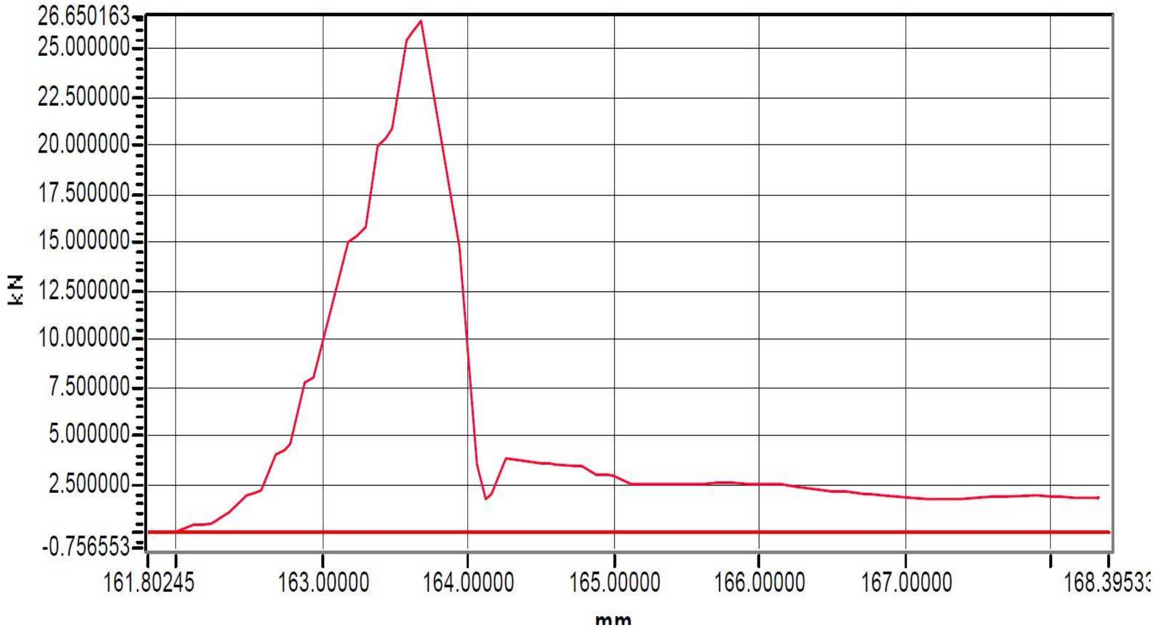
Test date : July 04,2019 Date / time received: July 04,2019

Label : F-0.20% C-25 Ma S-2 Span between roller (mm): 450

Max.Aggregate size : 20mm

Machined: : Yes

Upper bearer diam.(mm) : 10.0



Notes: Standard test method for flexural strength of concrete ASTM C 78

Name: Behailu Belta Position: Material Engineer

Signature:

CERTIFICATE IDENTIFICATION:

Cert 001:AAA3 Certificate date: July 14,2019