# EFFECT OF NYLON FIBER ASPECT RATIO ON THE MECHANICAL PROPERTIES OF FIBER REINFORCED CONCRETE

By

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## CANDIDATE'S DECLARATION

It is hereby declared that this project or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Signature

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The project titled "**Effect of Nylon Fiber Aspect Ratio on The Mechanical Properties of Fiber Reinforced Concrete**" submitted by Student-Nazmul Ummahat, Roll No.: 040804324, Session: 2008, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Engineering in Structural engineering on 25th March,2019.

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**DEDICATION**

***To my Teachers***

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# List of Abbreviations of Technical Symbols and Terms

RCC – Reinforced Cement Concrete

OPC – Ordinary Portland cement

PCC- Portland Composite cement

FRC- Fiber Reinforced Concrete

NFRC- Nylon Fiber Reinforced Concrete

PFRC- Polypropylene Fiber Reinforced Concrete

GFRC-Glass Fiber Reinforced Concrete

SFRC-Steel Fiber Reinforced Concrete

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# Abstract

Nylon fiber reinforced concrete is to mitigate the cracking trend of concrete due to the temperature and relative humidity of environment. Being a synthetic material nylon offers high tensile strength and good chemical resistance to the composite. Due to the benefits, the use of FRC has steadily increased during the last two decades. In Bangladesh nylon fiber is locally available and also cheaper than the other fibers like steel fibers and glass fibers. The properties of fiber volume, aspect ratio and orientation of the nylon fiber are responsible for efficient transfer of stress between matrix and the fiber. In this study the effect of the aspect ratio and the volumetric ratio of the nylon fiber on the mechanical properties of concrete has been explored.

Three different fiber lengths (19mm, 25mm and 50mm) of same diameter (1/14 mm) were used to analyze the influence of aspect ratio on the properties of concrete composite. The principal mechanical properties of concrete mixes were tested in the laboratory to identify the effects of the selected length of fiber. The results of compressive strength test, splitting tensile strength test and flexural strength test indicated improvement of the mix over non fibrous concrete. Aspect ratio 266 (19 mm length and 1/14 mm diameter) exhibits the maximum compressive strength (89%) over the non-fiber-concrete mix. Accordingly, the tensile strength showed higher value for low aspect ratio. Moreover flexural strength test indicates that increase in the fiber length results in the significant increment in the flexural capacity. The higher the aspect ratio the higher ductility can be achieved, which may affect the design of a structural member.

Nylon fiber cannot replace the reinforcing structural steel but the results showed that the fiber can be a worthy strength provider with a certain aspect ratio and volume percentage. As this material is available in the local market of Bangladesh and also the use of it in the concrete will act ecologically, this study is exploring the different aspects of nylon fiber reinforced concrete.

# 1 INTRODUCTION

## 1.1 General

Concrete is one of the most versatile, durable, and cost effective building materials known to the world. In Bangladesh it is the leading construction material and the maximum developing projects are built by reinforced cement concrete. Adequate sources of ingredients, sufficient standard manufacturing establishments and economical employment cost encourage us to use this type of construction works in this country. Comparatively concrete is more environment friendly for our climate than other construction materials.The Padma Multipurpose Bridge, Rooppur Nuclear Power Plant, Karnaphuli Tunnel, Matarbari Power Plant, Rampal Power Station, Payra Power Plant, Dhaka Metro Rail Project, Payra Deep Sea Port, and Bangabandhu Satellite-1 are the recent mega projects in our country and in which the huge amount of RCC works are involved. To ensure the sustainability of these developments the limitations of the concrete need to be minimized.

Concrete is a composite construction material composed primarily of aggregate, cement and water. Plain concrete possesses a very low tensile strength, limited ductility and little resistance to cracking. It has been recognized that the addition of small, closely spaced and uniformly dispersed fibers to concrete would act as crack arrester and would substantially improve its static and dynamic properties. This type of concrete is known as “Fiber Reinforced Concrete”. The use of FRC has steadily increased during the last two decades in the world in different countries and its current field of application includes: airport and highway pavements, earthquake-resistant and explosive-resistant structures, mine and tunnel linings, bridge deck overlays etc. constructions.

Among all the fibers the nylon fiber is generic and identifies a family of polymers. These fibers are imparted by the base polymer type. Nylon is heat stable, hydrophilic, relatively inert and resistant to a wide variety of materials. It is obvious that the behavior of Nylon Fiber Reinforced Concrete depends on the orientations, distributions, aspect ratios and geometrical shapes. As this type of composite material may contribute to our vast developing concrete construction projects, the research works about nylon fiber was undertaken.

### 1.2 Objective

The objectives of this study are:

(i) To determine the influence of the aspect ratio of nylon fiber on the compressive strength, split tensile strength and flexural strength of concrete.

(ii) To determine the effect of different dosages of nylon fiber for the same water cement ratio on the mechanical property of concrete composite.

(iii) To determine the effect of nylon fiber length on the energy absorption capacity of the concrete mix.

### 1.3 Scope of work

Fiber reinforced concrete is the composite material containing fibers in the cement matrix in an orderly manner or randomly distributed manner. Its properties would obviously, depend upon the efficient transfer of stress between matrix and the fibers, which is largely dependent on the type of fiber, fiber geometry, fiber content, orientation and distribution of the fibers, mixing and compaction techniques of concrete, and size and shape of the aggregate. This study is mainly explored on the effect of the length to diameter ratio on the strength properties and crack controlling of composite concrete. The nylon fiber diameter of 1/14 mm and three different lengths (19 mm, 25 mm and 50 mm) were used to determine the influence of the aspect ratio of nylon fiber on the compressive, tensile strength, flexural strength and toughness of concrete. So many researcher works have been done on the nylon in the different countries of the world and reported that nylon fiber has significant influences on the fresh and hardened concrete mixes. In Bangladesh, nylon is a locally available material and also the environmental condition of this country is suitable for using nylon. On the other hand as the volume of fiber has an influence to the composite this research was also completed the combination of the aspect ratio to percent volume of fiber during the mixes of the composite concrete.

## 1.4 Methodology

The work was related to define the effect of nylon fiber length on the concrete properties. To reach the aim all the related previous research works have been evaluated and collected for the information about the test processes and outcomes. The required materials were estimated and collected first then their physical properties were examined. As the nylon fibers were collected in the form of rope it was needed to cut as per the listed length of the test and made straight before use. The experiments had been done according to the ASTM Standards. To do so a set of specimens was prepared for the casting and data has been collected for the results.

After the completion of the tests, the results were collected to calculate the flexural strengths, splitting tensile strengths and compressive strengths. Accordingly the resulted data also had been used to establish the relationship with the different lengths and the percent volumes of the fiber. Finally conclusions and recommendations have been drawn based on the analysis results. The choice is bounded to assess and analyze the compressive, splitting tensile and flexural strengths on cylinders and beam specimens only.

## 1.5 Layout of the project

The layout of the project of the effect of aspect ratio on the mechanical properties of concrete has been designed as follows:

**Chapter 1** describes the background of the study, the major objectives and scope of the research and methodology of the work.

**Chapter 2** is mainly based on the literature review related to the present study. It provides a brief description of mechanism of fiber reinforced concrete, Characteristics of fiber reinforced systems, Fresh concrete properties of FRC, Mechanical properties of hardened fiber reinforced concrete, Structural behavior of fiber reinforced concrete, different types of fiber and their properties. Composition of Portland Composite Cement (PCC) is properties of the different cementitious materials and properties of fine (sand) and coarse aggregate (stone).

**Chapter 3** provides experimental program & methodology for the present study, physical and mechanical properties of different materials like stone aggregate, and sand. This chapter also provides the information about the making procedure and different properties of nylon fiber. Then, it provides information about concrete mixing, casting, and curing. Finally, it provides a description of fresh (workability) and hardened concrete properties i.e. Compressive strength, Tensile strength, Flexural strength in 28 days.

**Chapter 4** provides the results of fresh concrete properties. In the fresh concrete properties, the effects of fiber lengths and fiber percentages on workability of concrete are observed. In the hardened concrete properties, the effects of fiber percentages (0%, 0.25%, 0.37% & 0.5%) and fiber lengths (19 mm, 25 mm, and 50 mm) on compressive strength test, tensile strength and flexural strength are assessed. And finally it also presents some relationships of strength with different lengths as well as plain and fiber reinforced concrete.

**Chapter 5** presents the limitations and conclusion of the study, and also suggestions for future work.

# 2 LITERATURE REVIEW

## 2.1 General

Reinforced Concrete Construction in Bangladesh is playing a very important role in the development of infrastructure as the economy is growing over the years. Residential buildings, Educational Institutes, Hospitals, High rise shopping complexes, Stadiums, Industries, Internal roads, hydraulic structures, fly overs, bridges etc. all are constructed using RCC due to the exposure condition and hot and humid climate in this country. From the availability point of view the ingredients of the concrete mix are available locally in our country. As well as the low labor cost involves in the concrete construction, which offers the most economical construction process in Bangladesh.

Concrete is a mixture of cement blended with water and various sizes of aggregates. So it has two components; aggregate and paste. Aggregates generally are of two sizes; fine and coarse. Fine aggregates are those with particle sizes smaller than about 5mm, commonly known as sand, which can be natural or manufactured. Coarse aggregates are those with particle sizes greater than about 5mm. Gravel crushed stone and blast furnace slag are the most commonly used coarse aggregates. Paste is composed of cement, fly ash, water and sometimes entrained air. The benefits of concrete to society are enormous, being used to build our schools, hospitals, apartment blocks, bridges, tunnels, dams, sewerage systems, pavements, runways, roads and more. It is vitally important to develop products and systems that can be used to construct more durable, energy-efficient eco-buildings, and concrete can be used to do this. The advantages of concrete are as follows-

### 2.1.1 Strength and Durability

Concrete structures can withstand natural disasters such as earthquakes and hurricanes that’s why it is used in the majority of buildings, bridges, tunnels and dams. Roman buildings over 1,500 years old such as the coliseum are living examples of the strength and durability of concrete. In our country the most of the low and high rise buildings were constructed using concrete like our Parliament house, Nagar bhaban, Dhaka University, Dhaka Medical College, Bangladesh University of Engineering and Technology etc.

### 2.1.2 Low Maintenance

Concrete, being inert and compact does not lose its key properties over time. Compared to the other construction material concrete requires less maintenance. That’s why in the developing country like Bangladesh concrete is better than the other materials

### 2.1.3 Affordability

Compared to other comparable building materials e.g. steel, concrete is less costly to produce and remains extremely affordable. Being a riverine country we have some sources of aggregates, which makes the concrete construction less costly over others. In addition enough manpower with fewer labor cost provide more affordability.

### 2.1.4 Excellent Thermal Mass

Concrete walls and floors slow the passage of heat moving through and reduce temperature swings. This reduces energy needs from heating or air-conditioning, offering year-round energy savings over the life-time of the building. The hot and humid country like Bangladesh concrete buildings are working like green buildings.

### 2.1.5 Fire-resistance

Being naturally fire-resistant concrete forms a highly effective barrier to fire spread. It does not require any fire coating like steel structures except for highly corrosive environment. Although it can be severely damaged by exposure to high temperatures, it can maintain its structural integrity for a considerable period- long after steel buildings would have suffered irreparable damage.

### 2.1.6 Any Configuration

Concrete can be cast in any desired shapes like arches and columns, complex hyperbolic shell, dams, piers, abutments and complicated sculptures. As well as pipe for the drainage, sewerage system and water supply projects are mostly made of precast concrete.

### 2.1.7 On site fabrication

Cost can be kept down for the onsite concrete casting by using local material to a large extent. Under a proper supervision a good quality concrete can be produced at site. Though at present we have a lots of ready mix concrete plants, low rises structures still use the onsite fabrication in Bangladesh.

## 2.2 Limitations of concrete

### 2.2.1 Low Tensile Strength

Concrete is a brittle material with very low tensile strength. Plain concrete generally should not be loaded in tension and reinforcing steel must be used to carry tensile loads. The result of inadvertent tensile loading can cause cracking.

### 2.2.2 Low Ductility

The low ductility of concrete means lack of impact strength and toughness compared to metals.

### 2.2.3 Low Strength to Weight Ratio

Even in compression concrete has a relatively low strength to weight ratio and a high load capacity requires comparatively large masses of concrete.

### 2.2.4 Volume Instability

The volume instability must be considered in design and construction. Concrete undergoes considerable irreversible shrinkage due to moisture loss at ambient temperatures and also creeps significantly under an applied load even under normal conditions of normal service.

These problems can be compensated by using suitable design and controlling them. A great deal of research effort has been devoted to improve these disadvantages of concrete and now new types of concrete have been developed such as ready mix concrete, fiber reinforced concrete, shrinkage compensate concrete and latex-modified concrete. In this paper the fiber reinforced concrete will be highlighted.

## 2.3 Cement

Cement has a very important influence in the development works in Bangladesh. Although, the actual growth of cement industry was started only about a decade ago, the development of cement industry in Bangladesh dates back to the early-fifties. Since 1990, about 95 percent of the country's demand for cement had been met through import. The country has been experiencing an increasing trend of cement production domestically for the last 6/7 years. Clinker, the major ingredient of cement reacts in presence of water within concrete and forms calcium silicate hydrate (C-S-H gel), which actually acts as binder of aggregates in concrete. The reaction with water is called hydration process. Hydration is the primary reason for strength gaining. Rate of hydration is high in first 7 days of concrete production and consequently strength rapidly increases in early stages. Hydraulic cements (such as Portland cement) are made of a mixture of silicates and oxides, which comes from clinker. It has four main components, which are Belite (2CaO·SiO2 or C2S); Alite (3CaO·SiO2 or C3S); Celite (3CaO·Al2O3 or C3A) and Brownmillerite (4CaO·Al2O3·Fe2O3 or C4AF). Both C3S and C2S provide strength to concrete by producing C-S-H gel. However, C2S hydrates at relatively lower rates than C3S. C3A is responsible for stiffening, setting and early strength development. The amounts of these elements are adjusted during cement production to attain desired properties

Types of Cement:

According to ASTM (American Society for Testing and Materials) the five types of cement are as follows:

Type I Ordinary Portland Cement (Used for general Construction works)

Type II Modified Portland Cement (Used where sulfate concentration is higher)

Type III High Early Strength Cement (Used where early strength is required)

Type IV Low Heat Portland Cement (Used where heat generation must be minimized)

Type V Sulfate Resistant Portland Cement (Used where structures are subjected to sulfate attack)

Excluding these five types of cement there is also some modified form of cements, which are used in the construction works. Among them Pozzolan Portland Cement (PPC) is a popular one.

### 2.3.1 Pozzolans Cement

Pozzolan is a volcanic dust found at Pozzuoli, Italy and used since Roman times as hydraulic cement when mixed with lime. All pozzolans contain silica and siliceous or aluminous minerals. Fly ash, slag (blast-furnace), silica fume are artificial pozzolans. Volcanic ash, diatomaceous earth, calcined clay, metakaolin clay and rice husk ash are natural pozzolan. Portland Pozzolan Cement produces less heat of hydration and offers greater resistance to the sulfate attack than OPC (useful for marine and hydraulic construction and mass concrete). Most pozzolans do not contribute to the strength at early ages, so strength gain of these cements is slow. Therefore they require larger curing period, but the ultimate strength is the same as OPC.

## 2.4 Fly Ash

It is a residue resulting from the burning of powdered coal especially from the electric-power generating stations. In 1937, University of California published that where available, fly ashes of suitable fineness and composition can be used with technical benefit and economy to replace 20 to 50% of the amount of Portland cement that otherwise would be required to produce concrete of specific strength and durability. The effect of fly ash on the fresh and hardened concrete is as follows.

### 2.4.1 Workability

The benefit of using fly ash is that it occupies approximately 25% greater volume than an equal mass of Portland cement (ACI Education Bulletin E3-13) without reacting with water. The additional volume of fly ash fills the void and increases the cohesion. As a result workability increases.

### 2.4.2 Compressive Strength

The additional bond produced by the fly ash reaction with available lime allows fly ash concrete to continue to gain strength over time. Mixtures designed to produce equivalent strength at early ages will ultimately exceed the strength of straight cement concrete mixes.

### 2.4.3 Flexural Strength

Flexural strength of fly ash concrete measured at ages as early as 7 days can be expected to be equivalent to a plain Portland-cement mixture.

### 2.4.4 Durability

The decrease in free lime and the resulting increase in cementitious compounds, combined with the reduction in permeability enhance concrete durability.

### 2.4.5 Shrinkage

Autogenously shrinkage is caused due to the stresses generated in partially saturated pores in concrete generated at or near the liquid-vapor interfaces in sealed cement pastes at constant temperature. This liquid-vapor interface is created due to chemical shrinkage, which is the reduction in the total volume of solids and liquids due to hydration. As hydration progresses and the relative humidity in concrete specimens reduce, this interface moves to finer pores and stresses increase. These stresses lead to shrinkage in the paste and may cause cracking in restrained specimens. It was seen that in normal strength concretes, the substitution of cement with fly ash leads to a significant reduction in the autogenous shrinkage, with a relatively smaller reduction in the early-age strength.

## 2.5 Ground Granulated Blast-Furnace Slag (GGBFS)

Slag cement is hydraulic cement formed when granulated blast furnace slag (GGBFS) is grounded to suitable fineness and is used to replace a portion of Portland cement. It is a recovered industrial by-product of an iron blast furnace. Molten slag diverted from the iron blast furnace is rapidly chilled, producing glassy granules that yield desired reactive cementitious characteristics when grounded into cement fineness. Once the slag has been cooled and grounded to a usable fineness it is stored and shipped to suppliers. Slag cement is commonly found in ready-mixed concrete, precast concrete, masonry, soil cement and high temperature resistant building products. While there are many applications and benefits of slag cement, a few are highlighted below.

### 2.5.1 Workability

The using of slag cement improves workability.

### 2.5.2 Strength

Concrete with slag cement added to the mixer gains strength more slowly, tending to have lower strength at early ages and equal or higher strength at later ages. The additional calcium silicate hydrate made with slag cement densifies the concrete matrix and enhances the strength. Slag cement has been used successfully in many high-strength applications.

### 2.5.3 Durability

Slag cement helps to reduce the permeability, sulfate attack and alkali-silica reaction creating a longer lasting and more resilient concrete.

### 2.5.4 Shrinkage

There is no significant difference in the shrinkage characteristics of concrete with and without slag cement as part of the cementitious materials.

## 2.6 Silica Fume

Silica fume or Micro silica is co-product of the ferrosilicon and silicon alloy industry which is very rich in amorphous silicon dioxide nearly 90%. Realizing the pozzolanic potential of the materials, this has been used successfully as an admixture in producing concrete. Initially, the micro silica was used as a cement replacement, due to its very high pozzolanic reactivity. But as more data came from laboratory and field, the material becomes the additional cementitious component giving increased performance in both fresh and hardened states. In the recent times, the use of high performance concrete is on demand in the construction industry. For improved strength and durability, the use of silica fume as the replacement of cement has been tried with success. Effects of silica fume on properties of fresh and hardened concrete are as follows.

### 2.6.1 Workability

The fineness of silica fume will increase the water demand of a concrete mixture. The increase in water demand will be proportional to the amount of silica fume being used. It is common to use a high-range, water-reducing admixture to control workability and slump while maintaining the desired *w/c*.

### 2.6.2 Strength

Silica fume is added to concrete to increase compressive strength. Properly proportioned silica fume concrete can achieve very-high-early and ultimate compressive strengths.

### 2.6.3 Durability

Silica fume enhances durability by decreasing the permeability while increasing the electrical resistance of concrete. With its reduced permeability, silica fume concrete has been extensively used in applications where limiting the entry of chlorides is essential, such as in bridge decks, parking structures, and marine structures.

### 2.6.4 Shrinkage

Fresh concrete made with silica fume is more cohesive and therefore less prone to segregation than concrete without silica fume. Because of the lack of segregation, silica fume concrete is readily pumped with the silica fume, allowing an increase in slump. Silica fume concretes are typically used for flatwork applications show little, if any, bleeding. Bleed-water channels can serve as shortcuts for chloride ions from deicing salt or seawater to get back into the concrete. The onset of bleeding may lead to plastic shrinkage cracking if precautions are not taken in the finishing operations to prevent moisture evaporation from the surface of the concrete.

In Bangladesh, only one type of cement (Ordinary Portland Cement) had been available till 2002 which followed the American Standard Method. From 2003, many types of cement became available in Bangladesh which has helped the cement industry provides differentiated and improved products to customers. The cement which is widely used from 2003 is the Portland Composite Cement (PCC). According to BDS EN 197-1: 2003, cements are mainly classified into five categories according to their composition and that has given below:

**Table 2-1 Classification of Cement as Per BDS EN 197-1(Mohammed and Hasan)**

| Composition (%) | Type of Portland Cement | | | | |
|---|---|---|---|---|---|
| | CEM I | CEM II/A-M | CEM II/B-M | CEM II/A-S | CEM II/A-L |
| Clinker | 95-100 | 80-94 | 65-79 | 80-94 | 80-94 |
| Blast-furnace Slag | - | | | 6-20 | - |
| Silica Fume | - | | | - | - |
| Pozzolana | - | 6-20 | 21-35 | - | - |
| Fly Ash | - | | | - | - |
| Burnt Shale | - | | | - | - |
| Limestone | - | | | - | 6-20 |
| Additional Constituents | 0-5 | 0-5 | 0-5 | 0-5 | 0-5 |

## 2.7 Fiber Reinforced Concrete (FRC)

### 2.7.1 Historical Background

The concept of using fibers as reinforcement is not new. Fibers have been used as reinforcement since ancient times. Historically, horsehair was used in mortar and straw in mud bricks. In the 1900s, asbestos fibers were used in concrete. In the 1950s, the concept of composite materials came into being and fiber-reinforced concrete was one of the topics of interest. Once the health risks associated with asbestos were discovered, there was a need to find a replacement for the substance in concrete and other building materials. By the 1960s, steel, glass, and synthetic (such as polypropylene) fibers were used in concrete. Research into new fiber-reinforced concretes continues today.

### 2.7.2 Benefits of Using of FRC

As we have discussed before that concrete is a tension-weak building material. The cracks generally develop with time and start to penetrate the concrete, thereby impairing the waterproofing properties and exposing the interior of the concrete to the destructive substances. The exposure acts to deteriorate the concrete, with the reinforcing steel corroding. To counteract the cracks, a fighting strategy has come into use, which mixes the concrete with the addition of discrete fibers. Because of the mixing action, the fibers are uniformly distributed throughout the concrete in all directions. In the fresh concrete, the uniformly distributed fibers reinforce against the formation of plastic shrinkage cracks. In the hardened concrete, the uniformly distributed fibers disallow the micro crack from developing into macro cracks and potential troubles. In addition, these fibers bridge and therefore hold together the existing macro cracks, thus reinforcing the concrete against disintegration. On the other hand, the nylon fibers stepped up the performance after the presence of cracks and sustained high stresses.

### 2.7.3 Uses of FRC

The concrete-reinforcing fibers include metal, polymer, and various others. Among the polymer fibers, the polypropylene fibers enjoy popularity in the domain of concrete and the nylon fibers show a rising acceptance. The polypropylene fibers claimed contribution to the concrete performance subjected to crack opening and slippage. Furthermore, the fibers reinforced the performance under not only compression, flexure, and tension, but also under impact blows and plastic shrinkage cracking. On the other hand, the nylon fibers stepped up the performance after the presence of cracks and sustained high stresses. FRC has been successfully used in the construction of the slab on ground, concrete runway, concrete canal, ware house slab, concrete slab on metal deck and pavements. It has also been used in the precast construction like as the precast pi sections, wave breakers and septic tanks.

### 2.7.4 Mechanism

Fiber reinforcement can change the post-crack response of concrete from brittle to ductile under various types of loads, including compression, tension, flexure, and impact. Fibers cannot be expected to modify the behavior of uncracked elements because fiber reinforcement mechanisms are mainly activated through crack development. After cracking, fibers bridge the cracks and start to carry tensile stresses, giving load-bearing capacity to FRC in its cracked state. This is usually referred to as residual strength or post-cracking strength.(ACI 544.4R Guide to Design with Fiber-Reinforced concrete)

During the application of compression load, the fibrous concrete cylinders may develop lateral tension, thus initiating cracks and advancing those cracks. As the advancing crack approached a fiber, the debonding at the fiber–matrix interface began due to the tensile stresses perpendicular to the expected path of the advancing crack. As the advancing crack finally reached the interface, the tip of the crack encountered a process of blunting. The blunting process reduced the crack-tip stress concentration, thus blocking the forward propagation of the crack and even diverting the path of the crack.(Song et al., 2005a)

Once the splitting occurred and continued, the fibers bridging across the split portions of the matrix acted through the stress transfer from the matrix to the fibers and, thus, gradually supported the entire load. The stress transfer improved the tensile strain capacity of the fiber-reinforced concretes and, therefore, increased the splitting tensile strength of the reinforced concretes.

When the flexural load applied to the beam the modulus of rupture increased in NFRC. The increase resulted primarily from the fibers intersecting the cracks in the tension half of the reinforced beam. These fibers accommodated the crack face separation by stretching themselves, thus providing an additional energy-absorbing mechanism and also stress starts relaxing the micro cracked region neighboring the crack-tip. Apart from the fiber–crack intersection, the nylon fibers topped the polypropylene fibers in the in-concrete fiber dispersion and the tensile strength.

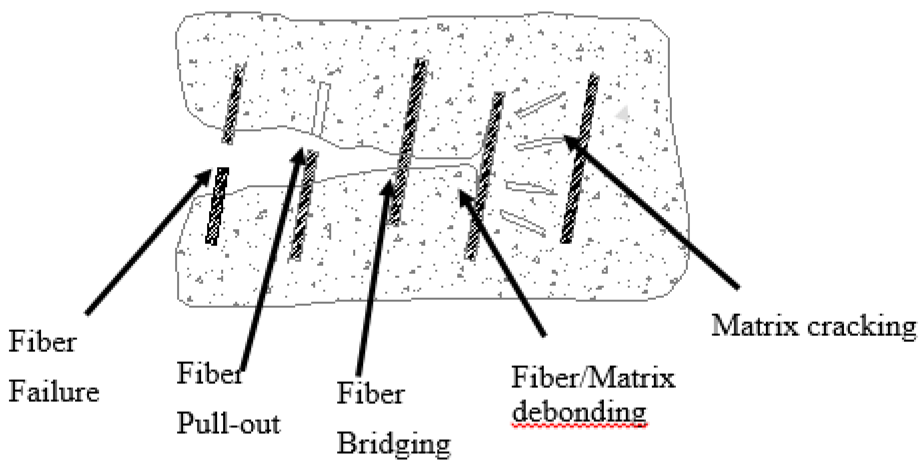


**Figure 2-1 Schematics of the mechanism in which fiber reinforcement works**

## 2.8 Different Types of Fibers

Fibers come in different material types, geometries and sizes. These fibers include steel, glass, synthetic and natural. Among them steel fibers and polymeric synthetic fibers are the most-used type fibers in construction industry.

### 2.8.1 Steel fibers

Steel fibers for concrete reinforcement are short, discrete lengths of steel which are sufficiently small to be randomly dispersed in concrete using common mixing procedures. In addition, fiber anchorage mechanisms in concrete include continuous deformations such as twists, dimples or crimps, end anchorage such as hooks, or simply bond for unreformed fibers. Bond to the concrete matrix is enhanced by mechanical anchorage, surface area, alloying surface roughness, or a combination of these. Fiber geometry and anchorage significantly affect resistance to pullout forces and overall performance of FRC. Another characteristic is the aspect ratio or the ratio of the length to diameter. Typically, for the same mixture proportions, as the fiber aspect ratio increases, so does the reinforcing performance. According to ASTM A820/A820M, the average tensile strength of fiber material should not be less than 50,000 psi (345MPa). Steel macro fibers have typical diameters in the range of 0.01 to 0.05 in. (0.3 to 1.3 mm) and length in the range of 1.2 to 2.5 in. (30 to 65 mm). The actual dosage for steel fibers depends on the specific application and the required engineering performance.

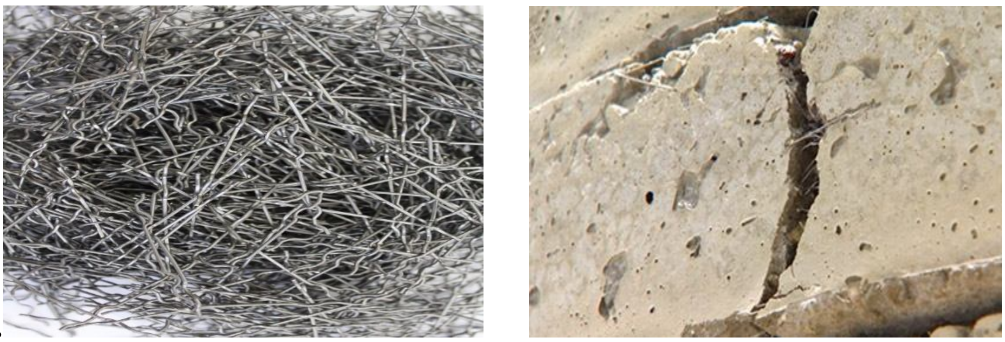

**Figure 2-2 Steel Fibers and the crack of the steel fiber reinforced concrete**

#### 2.8.1.1 Workability:

The addition of steel fibers decreased the slump-flow. Smaller values were recorded when more fibers are added to the concrete. The reason behind the low values in higher fiber content is the unit weight of the steel fibers and by that accelerating the funnel flow with the increase of their dosages. With the use of the steel fibers in mixtures, a less viscous mixture is observed and the addition of steel fibers led to the decrease in the workability, showing that fibers do not permit the aggregates to move more freely. [Mechanical Performance of Steel Fiber Reinforced Self-compacting Concrete in Panels]

**2.8.1.2 Compressive Strength:**

The presence of steel fibers alters the mode of failure of cylinders by making the concrete less brittle. Significant post-peak strength is retained with increasing deformation beyond the maximum load. Fibers usually have only a minor effect on compressive strength, slightly increasing or decreasing the test result. (Shah et al., 1988a)

**2.8.1.3 Tensile Strength:**

Results from the split cylinder tensile strength test (ASTM C 496) for SFRC specimens are difficult to interpret after the first matrix cracking and should not be used beyond first crack because of unknown stress distributions after first crack. (Shah et al., 1988a)

**2.8.1.4 Flexural Strength:**

The influence of fibers on flexural response of concrete is much greater than on compressive response. Two types of flexural strength values are commonly reported. One is termed as first-peak strength (first-crack flexural strength), corresponds to the load at which the load-deformation curve departs from linearity. This is when concrete matrix cracks. The other corresponds to the maximum load achieved, commonly called the ultimate flexural strength, peak strength, or modulus of rupture. (ACI 544.4R-18)

**2.8.1.5 Shrinkage:**

The influence of fibers on shrinkage cracking can be seen from Table 2-2 below where the widths of the crack were at the end of 6 weeks. It can be seen that addition of a small amount of fibers (0.25 percent) can substantially reduce the width of the cracks. The average crack width for plain concrete was almost 1 mm, (0.04 in.), whereas for a specimen reinforced with 0.25 percent steel fiber, it was less than 0.2 mm (0.008 in.), or one-fifth the value of plain concrete.

**Table 2-2 Crack width of different percentages of SFRC. (Grzybowski and Shah)**

| Specimen | Crack width(mm) |
|---|---|
| Plain Concrete | 0.9mm |
| SFRC (0.25%) | 0.3 mm |
| SFRC (0.5%) | 0.1 mm |
| SFRC (1%) | 0.075 mm |
| SFRC (1.5%) | 0.011 mm |

### 2.8.2 Glass Fiber

Straight diameter ranges from 0.005 to 0.015mm (maybe bonded together to form elements with diameter of 0.13 to 1.3 mm). Alkali resistant Glass fiber is used in the manufacture of glass reinforced cement (GRC) products, which have wide ranges of application. Glass fiber has high tensile strength (2-4 GPa) and modulus of elasticity (70-80 GPa) but has brittle stress strain characteristics (2.5%-4.8%) elongation at break) and low creep at room temperature. Claims had been made up to 5% glass fiber by volume has been used successfully in sand-cement mortar without balling. Figure 2.3 shows the glass fiber.

**Figure 2-3 Glass fiber**

#### 2.8.2.1 Strength:

Strength of GFRC is developed due to high contents of alkali resistant glass fibers and acrylic polymer. These materials also possess great tensile and flexural strength.

#### 2.8.2.2 Durability:

Being tough and resistant to cracking the GFRC has high ratio of strength-to-weight ratio, so the products of GFRC is durable and light.

### 2.8.3 Synthetic fibers

Synthetic fibers are made with polyolefin materials, which typically include polypropylene and polyethylene. ASTM D7508/7508M is the standard specification for synthetic fibers, including synthetic macro fibers and microfibers. ASTM D7508/7508M requires the minimum tensile strength of synthetic macro fibers to be 50,000 psi (345 MPa), whereas there are no restrictions on the tensile strength of microfibers. Synthetic macro fibers have typical diameters in the range of 0.012 to 0.04 in (0.3 to 1.0 mm) and a length in the range of 0.5 to 2.5 in (12 to 65 mm). The specified dosage for synthetic macro fibers depends on the application and the required engineering performance. These fibers are available in various configurations such as rope or tape filaments and they may be twisted or embossed. Bond to the concrete is achieved primarily through friction; however, chemical bonding in concrete has been reported. Synthetic microfibers are mainly used for controlling cracks from plastic shrinkage and sometimes from drying shrinkage. Their contribution to the mechanical properties of hardened concrete is insignificant. Synthetic microfibers are used in relatively small dosages, typically between 0.5 and 1.5 lb/yd3 (0.3 and 0.9 kg/m3) or 0.03 to 0.1 percent by volume. Some manufacturers carry blended fibers that typically includes synthetic microfibers (for plastic shrinkage crack control) and macro fiber (steel or synthetic) for enhancing the mechanical properties of concrete.

**Figure 2-4 Synthetic Fibers**

### 2.8.4 Nylon as synthetic fibers

Nylon is a generic designation for a family of synthetic polymers. These fibers are imparted by the base polymer type, addition of different levels of additive, manufacturing condition and fiber dimensions. Nylon is heat stable, hydrophilic, relatively inert and resistant to a wide variety of materials. It is particularly effective imparting impact resistance and flexural toughness and sustaining and increasing the load carrying capacity of concrete following first crack. It can be used as the matrix material in composite materials, with reinforcing fibers like glass or carbon fiber; such a composite has a higher density than pure nylon. Physical properties of nylon fibers are following:

**Table 2-3 Properties of Nylon Fiber**

| **Material** | 100% virgin fiber |
|---|---|
| Specific weight | 1.14 |
| Elastic modulus (GPa) | 5.17 |
| Tensile Strength (MPa) | 896 |
| Melting Point (°C) | 225 |
| Chemical Resistance | Good |
| Acids and Salt Resistance | Good |
| Electrical Conductivity | Low |
| Water Absorption | 4% |

#### 2.8.4.1 Workability:

The workability of concrete is reduced as nylon fiber percentage increases due to the absorption of water. As the fibers water absorption is more than the aggregates, so the reduction of the slump value occurs. To make the concrete workable on this case super plasticizer needed to be used.

#### 2.8.4.2 Compressive Strength:

The compressive strength of the nylon fiber concrete topped that of the polypropylene fiber concrete. The increase stemmed from the nylon fibers recording the higher tensile strength, which resulted in greater tensile stresses being transferred from a cracked matrix to the nylon fibers, thus leading to the increase in the compressive strength of the nylon fiber concrete. The improvements came principally from the fibers interacting with the advancing cracks. When withstanding an increasing compression load, the fibrous concrete cylinders may develop lateral tension, thus initiating cracks and advancing those cracks. As the advancing crack approached a fiber, the debonding at the fiber–matrix interface began due to the tensile stresses perpendicular to the expected path of the advancing crack. As the advancing crack finally reached the interface, the tip of the crack encountered a process of blunting because of the already present debonding crack. The blunting process reduced the crack-tip stress concentration, thus blocking the forward propagation of the crack and even diverting the path of the crack. The blunting, blocking, and even diverting of the crack allowed the fibrous concrete cylinders to withstand additional compressive load, thus upgrading its compressive strength over the nonfibrous control concrete.

#### 2.8.4.3 Tensile Strength:

Once the splitting occurred and continued, the fibers bridging across the split portions of the matrix acted through the stress transfer from the matrix to the fibers and, thus, gradually supported the entire load. The stress transfer improved the tensile strain capacity of the two fiber-reinforced concretes and, therefore, increased the splitting tensile strength of the reinforced concretes over the unreinforced control counterpart. Because of the slightly increased dispersion in the mixing water, a greater number of nylon fibers intersected the split sections, accordingly declaring the splitting tensile strength to be higher for the nylon fiber concrete. This declaration was consistent with the statement that the splitting tensile strength of fiber-reinforced concrete behaved in proportion to the number of fibers intersecting the fracture surfaces. As with the compressive strength, the declaration came partially from the nylon fiber carrying the higher tensile strength.

#### 2.8.4.4 Flexural Strength:

As stated for compressive and splitting tensile strengths, the nylon fiber additions made bearable differences in the variability carried by the flexural strength for the nylon fibrous concretes, compared to the plain concrete counterpart. The increase resulted primarily from the fibers intersecting the cracks in the tension half of the reinforced beam. These fibers accommodated the crack face separation by stretching themselves, thus providing an additional energy-absorbing mechanism and also stress reduces the micro cracked region neighboring the crack-tip.

### 2.8.5 Previous Study

Realizing the improved properties of the fiber reinforced concrete products, previous research and development on fiber reinforced concrete (FRC) had done since. In this paper an overview of the mechanical properties of different fibers has been explored and studied. A few of the previous study has given below.

**2.8.5.1 Steel Fiber:**

A study had been conducted on the flexure and split tensile strength of steel reinforced concrete using various percentage of steel fiber. The objective of that research investigation was to find out the flexure and spilt tensile strength behavior of steel fiber reinforced concrete using Round straight fibers with aspect ratio of 75. Specimens were cast without fibers and with fibers of 0.5%, 1%, 1.5% and 2 %.split tensile tests and Flexural Strength were conducted on cylinder and beam specimens respectively. The wires were properly cut to obtain 6 cm length. The diameter of steel fiber was 0.8 mm and tensile strength of steel fiber was 1500 N/mm2. They concluded that, the increase in the volume of fibers, increase approximately linearly with the tensile strength and toughness of the composite. Use of higher percentage of fiber was likely to cause segregation and hardness of concrete and mortar. The tensile strength of the concrete increased linearly with the increase in amount of steel added to it, but up to 1% of steel fiber inclusion. After that it decreases. The flexural strength increased with the increase in steel fiber inclusion but to a maximum of 1.5% by volume of concrete mix. After that the flexural strength decreases.(M.E Scholar, Structural Engineering Department MBM Engineering college JNV University Jodhpur, Rajasthan India. et al., 2017).

Another paper was presented to show the comparison between three different types of steel fibers i.e. Straight, Hooked, and Crimp on the basis of their effect on the mechanical properties of concrete. And they concluded that the workability of steel fiber reinforced concrete gets reduced as the percentage of steel fibers increases. Compressive strength was increased by increase in steel fiber percentage. And it was higher in the case of hooked fibers that were 45%. The favorable value of fiber content of steel fiber reinforced concrete was found to be 1%. The flexural strength of concrete also increased with the increase in fiber content up to the optimum value, and it was observed to be higher in the case of hooked fiber that was 40%. The optimum value for flexural strength of steel fiber reinforced cement concrete was found to be 0.75%. The tensile strength of concrete went on increased with the increase in fiber content up to the optimum value, and it was observed to be higher in the case of hooked fiber that was 98%.(Ranyal and Kamboj)

One more research was done based on the investigation of the use of steel fibers in structural concrete. The objective of the study was to determine and compare the differences in properties of plain concrete and concrete with fibers. Also to see the compressive and split tensile strength of concrete with variation of length of fiber in compare to different percentage of steel fiber. Comparison of 0.50%, 0.75%, 1.0% percentages of steel fiber by weight of concrete with 30mm, 50mm, 75mm length of fiber. Crimped steel fibers were used to determine the enhancement of mechanical properties of concrete. And the conclusions were, there was enhancement of compressive strength of 23%, 41.6%, and 33.69 % for 30mm, 50mm and 75mm length of steel fibers respectively for 7 days test and maximum strength have shown by 0.75% of fiber fraction with 50mm length of steel fiber. For 28 days test it was observed that there was enhancement of compressive strength of 24%, 40%, and 40.57 % for 30mm, 50mm and 75mm length of steel fibers respectively and maximum strength have shown by 0.75% of fiber fraction with 50mm length of steel fiber. It was also observed that there was enhancement of split tensile strength of 32.51%, 39.39%, and 43.59 % for 30mm, 50mm and 75mm length of steel fibers respectively for 7 days test and maximum strength have shown by 1.0% of fiber fraction with 75mm length of steel fiber. There was enhancement of split tensile strength of 26.28%, 37.11%, and 42.24 % for 30mm, 50mm and 75mm length of steel fibers respectively for 28 days test and maximum strength have shown by 1.0% of fiber fraction with 75mm length of steel fiber. (Suman et al., 2019)

#### 2.8.5.2 Polyethylene:

An experimental study was conducted to compare the effectiveness of fibrillated polypropylene and high-modulus polyethylene fibers, both used at relatively low volume fractions, in enhancing the mechanical properties of concrete materials. Replicated flexure, impact, and compression tests were conducted, and the results were analyzed statistically. It was concluded that lower volume fractions of high-modulus polyethylene fibers produce flexural and impact strengths comparable with those obtained at 0.1 percent volume fraction of fibrillated polypropylene fibers (Soroushian et al., 1992).

Another attempt had been made to study the influence of addition of polythene fibers (domestic waste plastics) at a dosage of 0.5% by weight of cement. The properties studied include compressive strength and flexural strength. The studies were conducted on a M20 mix and tests have been carried out as per recommended procedures of relevant codes. The influence of the addition of 0.5% fiber on the mixes tested was compared with plain concrete mix. It had been seen that the compressive strength is increased by 2.45%. It was well established that addition of fibers did not contribute much to improvements in the compressive strength of concrete. The comparison results of split tensile strength of the concrete mixes with and without fibers were done. Split tensile strength of fiber reinforced concrete specimen was 26.8% more than plain concrete. Generally, it should be borne in mind that the flexural strengths are increased to the tune of 20-25% with the addition of steel fibers. However, these fibers, was being obtained from domestic waste did not exhibit appreciable improvements in the flexural strength of concrete as in the case of steel fibers.(Kandasamy and Murugesan, 2011)

A research was carried out to investigate the performance of concrete containing Polyethylene Terephthalate (PET) bottle waste as fiber. PET bottle waste was chosen because it is being thrown after single use and cause environmental problem. One way to recycle wasted PET bottles was grinded into irregular fiber. Then, it was incorporate with the concrete and tested the performance of the concrete. A total of four batches of concrete were produced namely, normal concrete and concrete containing PET fiber of 0.5%, 1.0% and 1.5% fraction volume. The mechanical properties that were measured were compressive strength, splitting tensile strength and modulus of elasticity (MOE). The compressive strength, tensile splitting strength and modulus of elasticity value had increased with 0.5% PET fiber content in the concrete mix in compare to normal concrete. Concrete containing 1% and 1.5% PET fiber was lower than the normal concrete in compressive and splitting tensile strength and elastic modulus. Therefore it was concluded that, the fiber content will affect the strength of the concrete.(Irwan et al., 2013)

#### 2.8.5.3 Polypropylene:

An experimental research investigation of the fresh and hardened material properties of fibrillated polypropylene fiber reinforced concrete was reported. Fiber lengths were 1/2 in., and 3/4 in, volume fractions were 0.1%, 0.3%, and 0.5%. Fiber effects on concrete properties were assessed. The properties that were studied were slump, inverted slump cone time, air content, compressive and flexural behaviors, impact resistance and rapid chloride permeability, and volume percentages of permeable voids. An innovative method of characterizing the flexural behavior of fibrillated polypropylene fiber concrete was proposed. They concluded the result that fibrillated polypropylene fibers had no obvious effect on the compressive strength of concrete. However, 3/4-in. fibrillated polypropylene fibers enhanced the energy absorption and toughness characteristics of concrete under compression. This was evidenced by the increase in compressive toughness index of concrete as a result of fiber addition. And they also concluded that 1/2-in long polypropylene fibers improved the compressive strength of concrete when used at volumes (less than 0.5 percent) that did not caused adverse effects on workability (Bayasi and Zeng)

In another study, the effects of adding polypropylene fibers on physical and mechanical properties of concretes were investigated. Three concrete mixtures consisted of 6 mm, 12 mm and 19 mm polypropylene fibers were made and their physical and mechanical aspects were studied and compared with control concrete. They concluded that adding polypropylene fibers increased the flexural strength slightly and decreased the cracks width. Besides, the compressive strength decreased slightly. These properties were improved with increase of fibers length. (Najimi et al.)

A paper discussed the effect of exposure to elevated temperature upon fibrillated polypropylene fiber reinforced concrete. Literature review indicates that polypropylene fibers, when uniformly distributed within concrete, play an active role in improving spilling resistance of concrete induced to elevated temperature. The experimental program described there was included specimens 100 x 100 x 350 mm with fiber volume of 0.1 to 0.3% that were subjected to temperatures ranging from 100 to 200 C for durations of 1, 7, and 30 days. Post peak flexural strength was used to determine the effectiveness of fibrillated polypropylene fibers in concrete reinforcement. That paper showed that ultimate bending strength as well as post peak flexural strength decreased with increasing exposure temperature, duration, or both. Furthermore, exposure to temperatures below 100ºC did not seem to significantly affect the flexural behavior of polypropylene fiber reinforced concrete. Based on the data founded the decrease of fiber-dependent strength of polypropylene fiber cement composites was relatively slow for temperatures below 125ºC to 150ºC and accelerated for higher temperatures. Decrease of post peak flexural strength due to exposure at 125 C was fast for a period of 1 day and continued at approximately a constant rate until almost completed degradation after approximately 30 days. For relatively short exposure periods, 100ºC may be considered as a safe temperature. (Bayasi, Z. Dhaheri, M., 2002)

**2.8.5.4 Glass:**

An experiment was conducted on GFRC which had advantage of being light weight and thereby reducing the overall cost of construction. It was typically cast in a thin section of ½” to ¾”. Since the fibers cannot rust like steel, there is no need for a protective concrete cover thickness to prevent rusting. With the thin, hollow construction of GFRC products, they can weigh a fraction of weight of traditional precast concrete. The author observed that the inclusion of fibers decreased the workability of fresh concrete and this effect was more pronounced for fibers with higher aspect ratios. (Avinash Gornale, S Ibrahim Quadri, S Mehmood Quadri, Syed Md Akram Ali, Syed Shamsuddin Hussaini).

There was a study work focused on strength and durability characteristics of GFRC designed by M40 grade of Concrete and with a super plasticizer and water cement ratio 0.40. The performance of Cement Concrete with was varying percentage of glass fiber adding like 0.33%, 0.66%, 1%, 1.33%, 1.66%, and 2%. The strength and durability properties of glass fiber Reinforced Concrete compared to Control Concrete. After the experimental investigation they concluded that the addition of glass fiber in plain concrete increased the strength and durability characteristics. Initially addition of glass fiber in the plain concrete the strength characteristics like compressive, flexural and split tensile strength was gradually increased. Finally certain percent addition of glass fiber attained that gradually decreased in strength.

Maximum compressive, flexural and split tensile strength was attaining in 1.0% addition of glass fiber. The durability characteristics was gradually increased based on the addition of glass fiber.(Hemalatha and Rose)

In an experimental investigation the alkali resistance glass fibers had been used to study the effect on compressive, split tensile and flexural strength on M20, M30, M40 and M50 grades of concrete. The glass fibers used were of Cem-FIL Anti-Crack HD with modulus of elasticity 72 GPa, filament diameter 14 microns, specific gravity 2.68, length 12 mm and having the aspect ratio of 857.1. The number of fibers per kg was 212 million fibers. OPC cement was used and 0.03% by concrete volume glass fiber was used. The observed result had shown that a reduction in bleeding was observed by addition of glass fibers in the glass fiber concrete mixes. A reduction in bleeding improved the surface integrity of concrete, improved the homogeneity and reduced the probability of cracks. The percentage was increased of compressive strength of various grades of glass fiber concrete mixes compared with 28 days compressive strength was observed from 20 to 25% and The percentage increase of flexural and split tensile strength of various grades of glass fiber concrete mixes compared with 28 days was observed from 15 to 20%.(Chandramouli, Srinivasa Rao , Pannirselvam, Seshadri Sekhar and Sravana, 2010)

**2.8.5.5 Natural:**

The usages of natural fiber in construction are widely used in building materials engineering. However, using sugarcane fiber waste material as a natural in construction is very precious, because it can increase crack control and ductility, brittle concrete. Furthermore, the usage of sugarcane in construction can reduce of environmental pollution.

In a study, a mixture of sugarcane fiber was used in normal grade concrete and lightweight concrete to determine whether there was an increase in the compressive and tensile strength of the concrete. The objective of this study was to determine the compressive and tensile strength between control concrete and concrete mix with sugarcane fiber. In addition, the optimal volume of sugarcane fiber in the concrete mixture where the percentage of sugarcane fiber used was 0.5%, 1.0% and 1.5%.

Compressive strength was tested on days 7 and 28 after curing test was carried out. Meanwhile, the tensile test had been carried out to measure the tensile strength of sugarcane fiber relations in concrete mixes only at 28 day curing. Result of the testing showed that the optimum value containing admixtures of sugarcane was 0.5%. This percentage get the value of compressive strength was nearest with concrete control and the value of tensile strength was higher than concrete control and also the timing of concrete to cracked getting slower. Therefore, the use of sugarcane fiber was suitable for the addition of 0.5% of the concrete mixture.(Sheikh Khalid et al., 2017)

**2.8.5.6 Nylon:**

In a study, various proportions of nylon fiber were added in concrete and its effect on workability, compressive strength and tensile strength was reported. The paper states that nylon fiber material of diameter 0.35mm and length of 50mm with aspect ratio of 143 was used in different percentage from 0.5 to 1.5% by weight in cement. It was done on nylon fiber reinforced concrete by partial replacement of cement with metakaolin. After adding certain properties like compressive strength, split tensile strength, flexural strength was studied. On addition of Nylon fiber in concrete they concluded that tensile strength gets increased. Nylon fiber is a waste material so it can be utilized in concrete for the replacement of fine aggregate. The compressive strength, split tensile strength, flexural strength of concrete got increased on addition of 1% nylon fiber. Metakaolin mixed with concrete reduced the setting time of concrete. The increase in percentage of metakaolin increased the compressive strength, split tensile strength, flexural strength. There was no work done for both metakaolin and nylon fiber combined and mixed in concrete.(Ali et al.)

In another paper analysis of properties of concrete using nylon fiber as fiber reinforcement admixture was studied and verified the strength of concrete to the normal Portland cement. Using nylon fiber the compressive strength and flexural of concrete had increased to very limited extend. It was observed that M20 and M30 grade concrete with nylon fiber as fiber reinforcement admixture had shown gradual increment in withstanding compressive strength that was 20.67 and 28.22 MPa compared to normal concrete with 19.71 and 27.725 MPa respectively for 28 days. About 4.18% and 1.77% increment in the increment in compressive strength by M20 and M30 grade of concrete respectively. The increment of flexural strength that was 5.92 and 8.26 MPa obtained by nylon fiber concrete reinforcement compared to normal concrete obtaining 3.78 and 8.17 MPa, that clearly indicated about 2.36% and 1.09% increment in flexural strength by respective grades of concrete. That represents that the bonding within concrete increased by using nylon fiber as admixture. Thus helped in reduction of cracks and enhances durability.(Vishal Gadgihalli et al., 2017)

# 3 EXPERIMENTAL PROGRAM

## 3.1 General

The materials used in this study and their characteristics have been discussed through this chapter. The cement was obtained from commonly used cement companies. Nylon was obtained from the Old Dhaka Market area. The aggregates were collected from local sources. Super plasticizer also had taken from the local markets of construction materials.

## 3.2 Cement

Cement is usually manufactured from calcareous material (compounds of calcium and magnesium) and in many respects possesses hydraulic properties far better than hydraulic lime. There are numerous types of cement available, classified based on their components, properties and the purposes they serve. In this research, Portland Composite Cement (CEM-II/B-M) was used to prepare samples.

### 3.2.1 Portland Composite Cement (PCC)

PCC is the most available cement in Bangladesh. It reduces the permeability, increases workability, improves durability, reduces bleeding, provides more fineness, increases long age strength and provides less heat of hydration. The chemical composition of the used cement is CEM II/B, ASTM C-595, clinker: 65-79%, S-V-L: 21-35%, Gypsum: 0-5%. It means that in the cement contains the 65-79% basic material is clinker. Silica fume, Fly ash, and lime stone percentage is 21-35% and the Gypsum is 0 to 5%.


**Figure 3-1 Weighing of PCC cement**

## 3.3 Fine Aggregates

In Bangladesh, fine aggregates (sand) are available in two forms – Local Sand or White sand and Sylhet Sand or Red sand. Sylhet sand was collected from the river flowing in Sylhet regions and then supplied throughout the country. In this study the sand was collected from the local market in Dhaka city. Sand as a fine aggregate was sieving through No 4. ASTM sieve to ensure that no big particle or no rubbish was present into the samples. It was conducted according to ASTM C33-93, hence the fineness modulus of fine aggregate was obtained and a gradation chart was made. The unit weights (OD& SSD) and void content were calculated according to the ASTMC29. Rodding method was used to calculate the unit weight. Specific gravity and absorption capacity of the fine aggregate were determined according to the ASTM C127. Table 3-1 shows the properties of fine aggregates that have been tested in the laboratory and figure 3.2 shows the testing procedure of fine aggregates. After washing the sand, it had been dried in the laboratory and then SSD sand was prepared. Sand had been put into the pot and then pressed, while it tends to congregate, then it was assumed that sand was in SSD condition. After preparation of SSD sand, it had been put into air tied bags to avoid any moisture content lose.

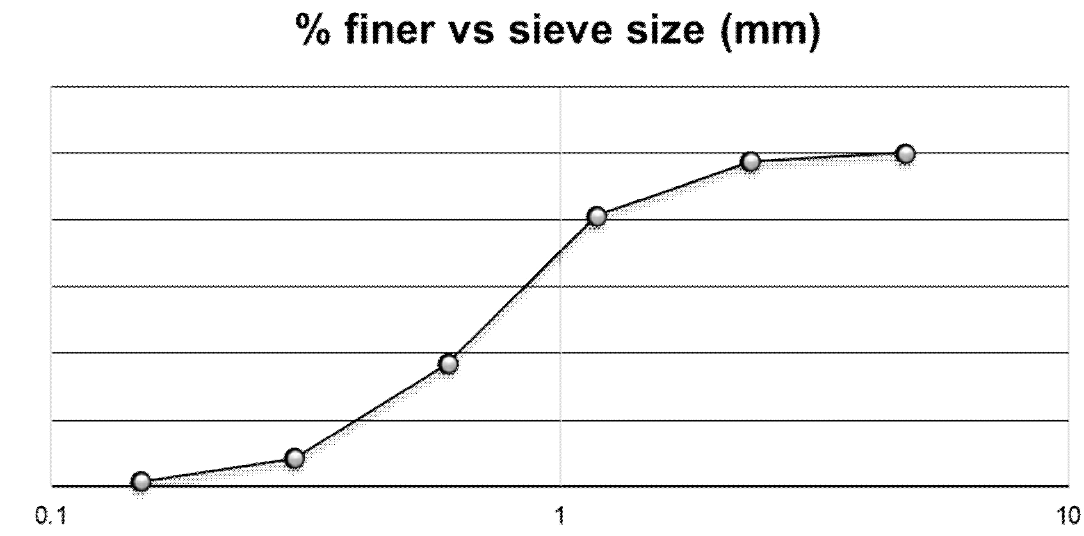


**Figure 3.2 Gradation Curve of Fine Aggregate**

### 3.4 Coarse Aggregate

Coarse aggregates are particles greater than 4.75mm, but generally range between 9.5mm to 37.5mm in diameter. They can be taken from Primary, Secondary or Recycled sources. Gravels constitute the majority of coarse aggregate used in concrete. Secondary aggregates are materials which are the byproducts of extractive operations and are derived from a very wide range of materials. Recycled concrete is a viable source of aggregate and has been satisfactorily used in granular sub-bases, soil-cement, and in new concrete.

Stone was used in mixed concrete which was sieved through the standard sieves as defined in Bangladesh Standard (BS 2011) to obtain a standardized coarse grain size distribution. According to the standardization, the coarse aggregate was well-graded.

**Table 3-1 Properties of Aggregates**

| Aggregate Properties | | |
|---|---|---|
| Properties | CA | FA |
| Apparent Specific Gravity, Sa | 2.68 | 2.69 |

| | | |
|---|---|---|
| Bulk Specific Gravity (O-D basis), Sd | 2.65 | 2.55 |
| Bulk Specific Gravity (SSD basis), Ss | 2.66 | 2.6 |
| Absorption Capacity (D) in % | 0.4 | 1.94 |
| Unit weight (lb/cu ft) | 95.03 | 94.146 |
| FM for FA | | 2.74 |

**Figure 3-2 Prepared Aggregates for mixing**

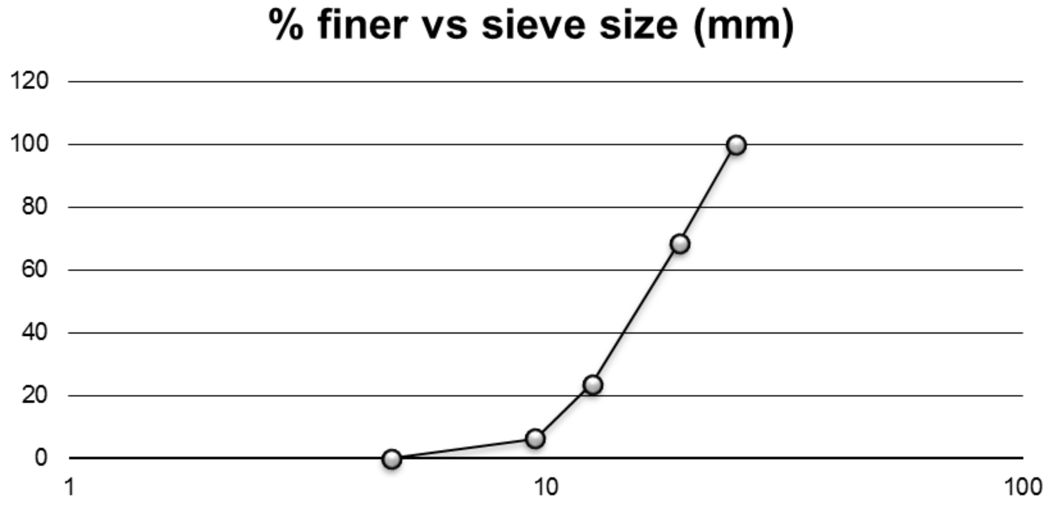


**Figure 3.3 Gradation Curve of Coarse Aggregate**

### 3.4.1 Nylon Fiber

Synthetic nylon fibers have been in use since the early 1980s for secondary temperature shrinkage reinforcement in concrete. Nylon fiber is locally available in Bangladesh and that is the reason of using nylon fiber in this experiment. In this study three types of lengths had been used and they are 19mm, 25mm and 50 mm to observe the of length effect on the properties of concrete. Several improvements can occur when nylon fibers are added to the concrete, typically at dosage rate of 0.6 to 0.9 kg/m3 of mixture. The first potential improvement is reduction in craze cracking due to compressive stress, plastic shrinkage cracking, and plastic settlement. The reduction in cracking and settlement prior to setting produces concrete with improved long-term durability.

**Table 3-2 Aspect Ratio of nylon fiber**

| Fiber Length(mm) | Fiber Diameter(mm) | Fiber percentages | Aspect Ratio |
|---|---|---|---|
| 19 | 0.07 | 0.25 | 266 |
| 25 | 0.07 | 0.37 | 350 |
| 50 | 0.07 | 0.5 | 700 |

**Figure 3-3 19 mm, 25 mm and 50 mm length of nylon fiber**

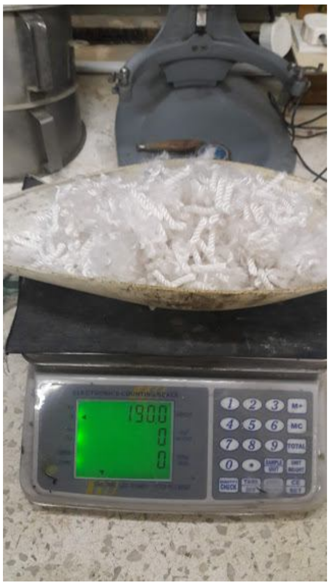

**Figure 3-4 Weighing of nylon fiber**

## 3.5 Super plasticizer

As the addition of the fibers in the concrete mix reduces the workability super plasticizer has been used in the study. It is a water reducing admixture which complies with ASTM C494 Type F. The properties of the

Specific gravity: 1.18 to 1.20 at 27º C

Chloride content: Nil to IS: 456

Setting times: Setting times are 1 - 2 hours approximately.

Air entrainment: Approximately 1% additional air is entrained.

Compatibility: Can be used with all types of Portland and slag cement except High Alumina Cements. It is recommended that admixtures if used in combination are added separately.

Workability: can be used to produce collapse slump concrete without reducing the water content. However, minor adjustments to mix design may be required to produce flowing concrete to prevent bleeding and segregation.

Compressive strength: Substantial reduction in the water content (10-20%) can result in high early compressive strength for a constant slump.

Permeability: Reduced water/cement ratio increases density and improves impermeability. Improved workability facilitates easy placing and good compaction.

Cohesion/segregation: The possibility of bleeding and segregation will be reduced because of increase in cohesion. A uniform close textured surface without sand runs or voids can be produced.

Pump ability: It will aid pumping of concrete by providing lubrication to cement particles and reducing line friction.

Dosages: The rate of addition should be in the range of 500ml to 1.5 litres /100 kg cement for high workability concrete.

Mix ratio can be defined as the process of 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. In Bangladesh the two types of mix ratio is most common and they are cement: fine aggregate: coarse aggregate ratio was 1:2:4 and the other one is cement: fine aggregate: coarse aggregate ratio is 1:1.5:3.The later one has been used in this project.

## 3.6 Test Specimen Design

A total of 80 concrete cylinder, and a total of 60 concrete beams (prism specimens) were prepared as per the specification ASTM C 31 in the experiment to study the effect of nylon fiber in concrete mixture. Among these concrete cylinders, 40 concrete cylinders were produced for compressive and 40 cylinders were produced for tensile strength tests and the beams were produced to conduct the flexural strength test. Each cylinder had a dimension of 100 mm diameter and 200mm height, and the beam dimension was 75mm×75mm×228mm. For the experiment, adopted variables were: concrete mix was mass design, aggregate type (stone, sand), cement type (PCC). To obtain a satisfactory and consistent result, four specimens for each variation were prepared. The specimens were marked on the unpainted surface for easier identification with mix type of fiber, length used and the fiber percentage. The specimen distribution among the three tests is shown in table 3-3:

**Table 3-3 Specimen distribution among the Four type of tests**

| Mix | % Fiber | Fiber Length(mm) | Compressive strength | Split Tensile strength | Flexural strength |
|---|---|---|---|---|---|
| M-1 | 0 | 0 | 4 | 4 | 3 |
| M-2 | 0.25 | 19 | 4 | 4 | 3 |
| M-3 | 0.25 | 25 | 4 | 4 | 3 |
| M-4 | 0.25 | 50 | 4 | 4 | 3 |
| M-5 | 0.37 | 19 | 4 | 4 | 3 |
| M-6 | 0.37 | 25 | 4 | 4 | 3 |
| M-7 | 0.37 | 50 | 4 | 4 | 3 |
| M-8 | 0.5 | 19 | 4 | 4 | 3 |
| M-9 | 0.5 | 25 | 4 | 4 | 3 |
| M-10 | 0.5 | 50 | 4 | 4 | 3 |

## 3.7 Sample Preparation

After the proper mixing of concrete for different fiber lengths and nylon fiber percentages the specimens were made using two different type of molds (cylindrical & rectangular). Then after proper curing of 28 days in lime water, the samples were prepared for 3 different types of tests (compressive strength test, splitting tensile test & flexural strength test). All the procedures were done according to the specification for the tests chronologically.

### 3.7.1 Mold Preparation

The cylindrical and the rectangular molds were prepared properly before putting the fresh concrete into these specimens. Molds were lubricated inside before casting of concrete specimens.

**Figure: 3-5 Mold tightening**

### 3.7.2 Concrete Mixing and Casting of Specimens

The mix design of concrete has been carried out as per ACI Mix Design Method (ACI Committee 211.1-91). A total of 80 cylinders and 60 beams were cast, 40 cylinders for compressive strength test, 40 cylinders for tensile, 30 beams for flexural strength and 30 beams for shrinkage test. The specimens were cured in limewater up to 28 days and then removed and those crushed on 28$^{th}$ days. Figure 3.5 through 3.6 shows different procedures of concrete casting.

**Figure 3-6  Sample preparation in the mold**

### 3.7.3 Measurement of Workability

The slump values obtained for every variation of the concrete mixes.

**Figure 3-7 Slump value measurement**

### 3.7.4 Compaction of the Concrete

Concrete specimens have been properly compacted following the specification of ASTM C 1435-99. Each and every cylindrical specimen was compacted by the vibrator. After compaction of these specimens, scaling and hammering was done to get a void free surface of the specimens.

**Figure 3-8 Concrete pouring in the molds**

**Figure 3-9 Compaction of concrete**

### 3.7.5 Curing of the Specimens

Curing of the specimens is completely ensured after the casting. Normal water is used for the curing. In this study, under water curing method is applied to ensure adequate moisture and temperature as requirements of specification by ASTM C192/C192M-02.

## 3.8 Testing of hardened concrete

Four types of tests are conducted for evaluating hardened concrete properties.

### 3.8.1 Compressive Strength Test

The compressive strength tests were performed according to ASTM C39. Cylinders of 100 mm diameter and 200 mm height were cast. This test method determines the compressive strength of cylindrical concrete specimens such as molded cylinders and drilled cores. The test was conducted by applying a compressive axial load to cylinders until the cylinder was crushed. The compressive strength of the specimen is calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen. The results of this test are used as a basis for quality control of concrete proportioning, mixing, curing, and placing operation (ASTM C39, 2005). The table below describes variation in concrete mixes used in this study and the number of cylinders required for each type of variation. As mentioned earlier, specimen of 28$^{th}$ days were submerged in saturated limewater. For each variation four cylindrical molds were used and the average strength of the four specimens was taken as the compressive strength test result.

**Table 3-4 Mix variation for compressive strength test**

| Fiber Length(mm) | Number of Specimens | | |
|---|---|---|---|
| | % fiber 0.25 | % fiber 0.37 | % fiber 0.50 |
| 19 | 4 | 4 | 4 |

| | | | |
|---|---|---|---|
| 25 | 4 | 4 | 4 |
| 50 | 4 | 4 | 4 |
| No fiber | | 4 | |
| Total | | 40 | |

The compressive strength test was conducted by applying a compressive axial load using the universal testing machine on concrete cylinders at a rate of 2500 N/sec or 560 lb/sec until failure occurred. After the test, the failure pattern was noted. Compressive strength testing machine is shown in figure below:

**Figure 3-10 Machine used for compressive strength test**

The compressive strength of the specimen was calculated by following equation:

$$C = P / \left(\frac{\pi d^2}{4}\right) \quad \text{Eqn (3.8.1)}$$

Where,

C = compressive strength, psi [MPa],

P = maximum applied load indicated by the testing machine, lbf [N],

d = diameter, in. [mm].

Detailed calculations are shown in the following chapter.

### 3.8.2 Split Tensile Strength Test

The tensile strength tests were performed according to ASTM C39. Cylinders of 100 mm diameter and 200 mm height were cast. This test method determines the tensile strength of cylindrical concrete specimens such as molded cylinders and drilled cores. The test was conducted by applying a compressive lateral load to cylinders until the cylinder was crushed. The tensile strength of the specimen was calculated by dividing the maximum load attained during the test by the cross-sectional area of the specimen. The results of this test are used as a basis for quality control of concrete proportioning, mixing, curing, and placing operation (ASTM C39, 2005). The table below describes variation in concrete mixes (10 different mixes) used in this study and the number of cylinders required for each type of variation. As mentioned earlier, specimens of $28^{th}$ days were submerged in limewater. For each day reading, three cylindrical molds were used and the average strength of the three specimens were taken as the tensile strength test result.

**Table 3-5 Mix variation for splitting tensile strength test**

| **Fiber Length(mm)** | **Number of Specimens** | | |
|---|---|---|---|
| | **0.25 % fiber** | **0.37 % fiber** | **0.50 % fiber** |
| **19** | 4 | 4 | 4 |
| **25** | 4 | 4 | 4 |
| **50** | 4 | 4 | 4 |
| **No fiber** | | 4 | |

| | |
|---|---|
| **Total** | 40 |

The tensile strength test was conducted by applying a compressive lateral load using the universal testing machine on concrete cylinders at a rate of 2500 N/sec or 560 lb/sec until failure occurred. After the test, the failure pattern was noted to be combined shear failure. Tensile strength test machine is shown in figure below:

**Figure 3-11 Splitting tensile strength test on sample**

The splitting tensile strength of the specimen was calculated by following equation:

$$T = {}^{2P}/_{\pi l d} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn (3.8.2)}$$

Where,

T = splitting tensile strength, psi [MPa],

P = maximum applied load indicated by the testing machine, lbf [N],

l = length, in. [mm], and

d = diameter, in. [mm].

Detailed calculations are shown in the following chapter.

### 3.8.3 Flexural Strength Test of prism Concrete Specimens

The testing specimen for flexural strength test was a simple beam of having the dimensions 75mm×5mm×225mm. The test was done in accordance with the standard test method as issued by ASTM C-78. Results were calculated and reported as the modulus of rupture.

The cured specimens were subjected to test shortly after removal from moist storage, as surface drying of the specimen would result in a reduction in the measured flexural strength. Then load was applied to the specimen continuously and without shock. The third point loading method was used in flexure tests of concrete specimen, which ensured that forces applied to the beams were perpendicular to the face of the specimen and applied without eccentricity.

To determine the dimensions of the specimen cross section for using in calculating modulus of rupture, measurements across one of the fractured faces were recorded after testing. For each dimension, one measurement at each edge and one at the center of the cross section were taken. The three measurements for each direction were used to determine the average width and the average depth. All measurements were rounded to the nearest 0.05 in.

**Figure 3-12  Flexural strength test on sample (before)**

As the fracture occurred in the tension surface outside the middle third of the span length by less than 5 % of the span length (11inch), the modulus of rupture was calculated by following equation:

$$f = {}^{3Pl}\!/_{bd^2} \quad \text{Eqn (3.8.3)}$$

Where,

f = modulus of rupture, psi, or MPa,

P = maximum applied load indicated by the testing machine, lbf, or N,

a = average distance between line of fracture and the nearest support measured on the tension surface of the beam, in., (or mm).

L = span length, in., or mm,

b = average width of specimen, in., or mm, at the fracture, and

d = average depth of specimen, in., or mm, at the fracture.

Detailed calculations are shown in the following chapter.

### 3.8.4 Toughness

Toughness is a measure of the energy absorption capacity of a material and is used to characterize the material's ability to resist fracture when subjected to static strains or to dynamic or impact loads. The simpler flexural test is recommended for determining the toughness of FRC. In addition to being simpler, the flexural test simulates the loading conditions for many practical applications of FRC. The first-peak strength characterizes the flexural behavior of the fiber-reinforced concrete up to the onset of cracking while residual strengths at specified deflections characterize the residual capacity after cracking. The appropriateness of each parameter depends on the level of acceptable cracking and deflection serviceability. Fiber reinforced concrete is influenced in different ways by the amount and type of fibers in the concrete. In some cases, fibers may increase the residual load and toughness capacity at specified deflections while producing a first peak strength equal to or only slightly greater than the flexural strength of the concrete without fibers. In other cases fibers may significantly increase the first peak strengths while affecting a relatively small increase in residual load capacity and specimen toughness at specified deflection.

The flexural toughness can be evaluated under third-point loading using the specified code ASTM C-1609. The flexural strength may also be determined from the maximum load reading in this test as an alternative to evaluation in accordance with ASTM C-78. Calculations are as following-

Step-1 Modulus of rupture was calculated from the stored data as per the equation 3.8.3.

Step-2 Determined the residual load values P150 and corresponding to net deflection values of 1/150 of the span length.

Step-3 Residual strength was determined for P150

Step-4 Toughness (T) was calculated by total area under the load-deflection curve up to a net deflection of 1/150 of the span length.

Step-5 Equivalent flexural strength ratio was calculated as per the following equation.

$$R = {}^{150 * T * 100\%}/_{fbd^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{ Eqn (3.8.4)}$$

Where,

f = residual strength at net deflection of L/150, psi, or MPa,

P = residual load at net deflection of L/150, lbf, or N,

T = area under the load vs. net deflection curve 0 to L/150

b = average width of specimen, in., or mm, at the fracture, and

d = average depth of specimen, in., or mm, at the fracture.

Detailed calculations are shown in the following chapter.

# 4 Result and Discussion

This chapter consists of the experimental results of the study. The principal tests that needed to describe the mechanical properties of concrete have been conducted at the same temperature and environmental conditions. Accordingly the outcomes had been described widely here such as Slump test, Compressive strength Test, Split Tensile Strength Test, Flexural Strength Test and Shrinkage Test.

## 4.1 Result of Fresh Concrete Properties

Workability is one of the properties of fresh concrete to measure the degree of consistency before casting the specimens. A slump cone having a dimension of 12 inch in height, 4 inch diameter in top and 8 inch diameter in bottom, is filled with 3 layers and on each layers 25 times temping with a 5/8″ diameter rod having a weight of 930 gm are accomplished. Therefore, a total 75 times tamping for three layers are carried out as described in ASTM Standard C-143.The mold is lifted, leaving the concrete to "slump," that is, to spread or drop in height.

**Table 4-1 Slump values for different fiber length and fiber percentages**

| Fiber Length(mm) | Fiber Percentage | Slump Value(mm) | % change compared to no fiber mix |
|---|---|---|---|
| No fiber | No fiber | 150 | |
| 19 | 0.25 | 96 | 36 |
| 25 | 0.25 | 90 | 40 |
| 50 | 0.25 | 90 | 40 |
| 19 | 0.37 | 20 | 86.67 |
| 25 | 0.37 | 16 | 89.33 |
| 50 | 0.37 | 15 | 90 |
| 19 | 0.5 | 16 | 89.33 |

| | | | |
|---|---|---|---|
| 25 | 0.5 | 14 | 90.67 |
| 50 | 0.5 | 16 | 89.33 |

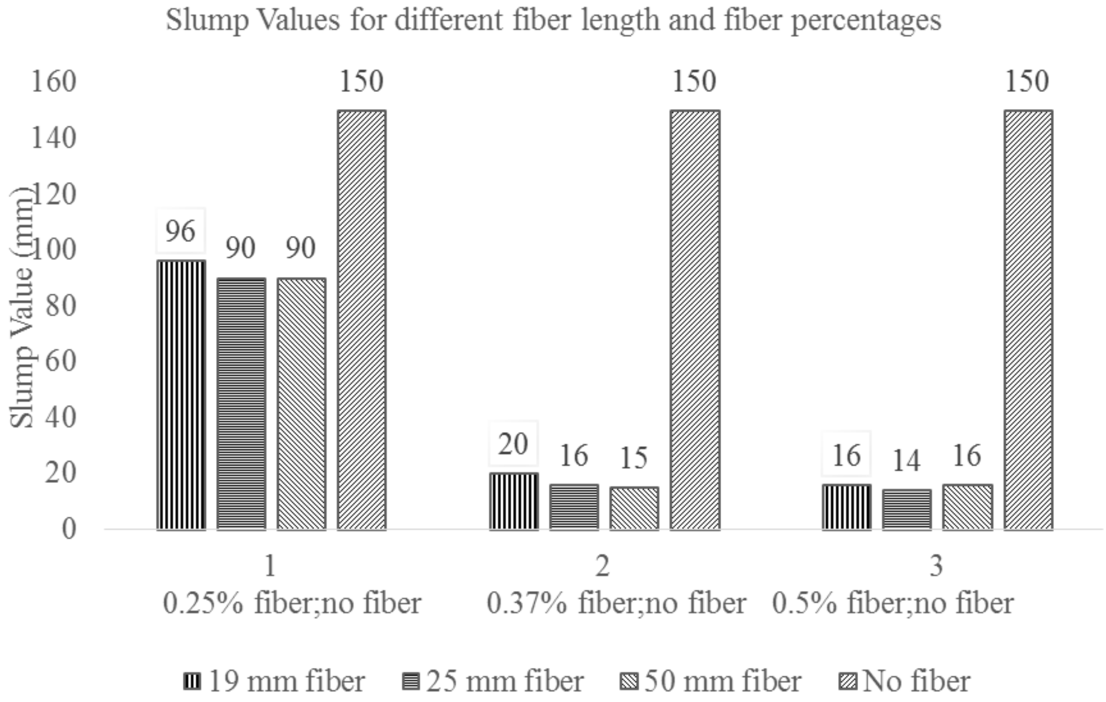


**Figure 4-1 Slump Test Result**

From the above figure it can be observed that Nylon fiber reinforced concrete mixes had low slump values than the plain concrete mix for the same w/c ratio.19 mm fiber provided more rational slump values than the other two type length (25mm and 50 mm). Although the slump value was less but the workability of the NFRC was better.

## 4.2 Compressive Strength

The experimental results on the nylon fiber reinforced concretes containing different percentages of nylon content and three types of lengths are given below. Each of the results was the average of 4 test specimens. ASTM C-39 standard was followed for the determination of the compressive strength of the concrete and external vibrator was used as internal vibrator may adversely influence the random fiber distribution and alignment.

**Table 4-2 Compressive strength for different fiber length and fiber percentages**

| Fiber Length(mm) | Fiber Percentage | Compressive Strength(MPa) | % change compared to no fiber mix |
|---|---|---|---|
| No fiber | No fiber | 11.08 | |
| 19 | 0.25 | 21.03 | 89.80 |
| 25 | 0.25 | 19.73 | 78.07 |
| 50 | 0.25 | 18.81 | 69.77 |
| 19 | 0.37 | 11.96 | 7.94 |
| 25 | 0.37 | 13.91 | 25.54 |
| 50 | 0.37 | 10.67 | 3.70 |
| 19 | 0.5 | 11.02 | 0.54 |
| 25 | 0.5 | 11.34 | 2.35 |
| 50 | 0.5 | 10.79 | 2.62 |

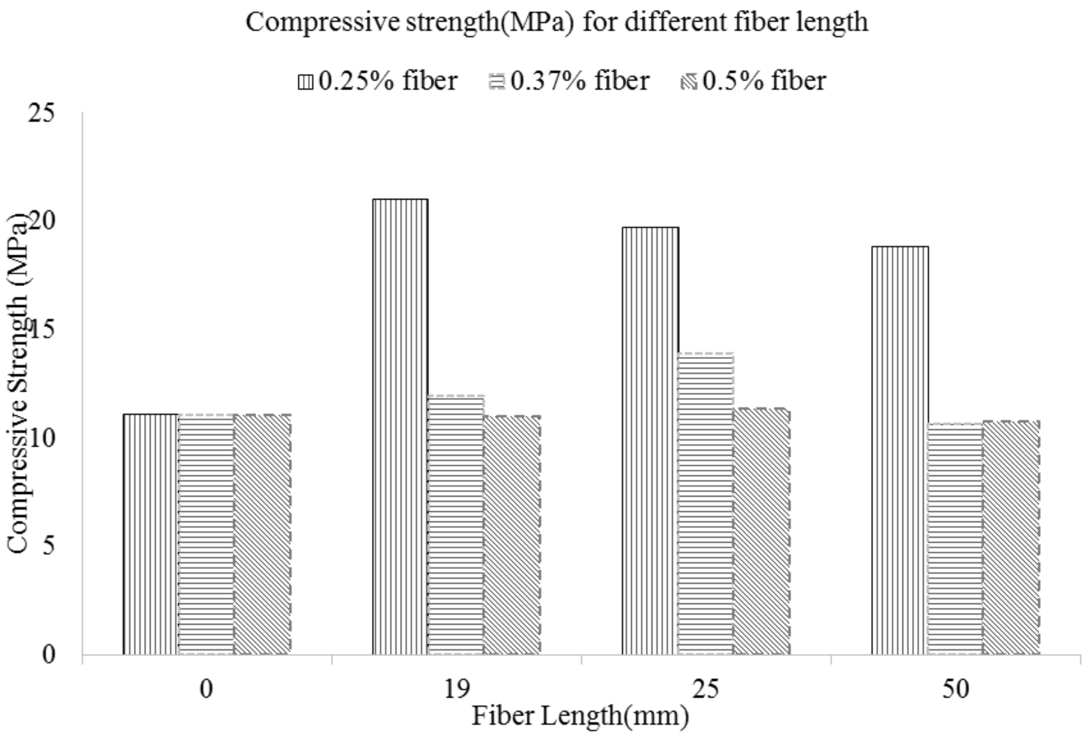


**Figure 4-2 Compressive Strength for Different Fiber Length**

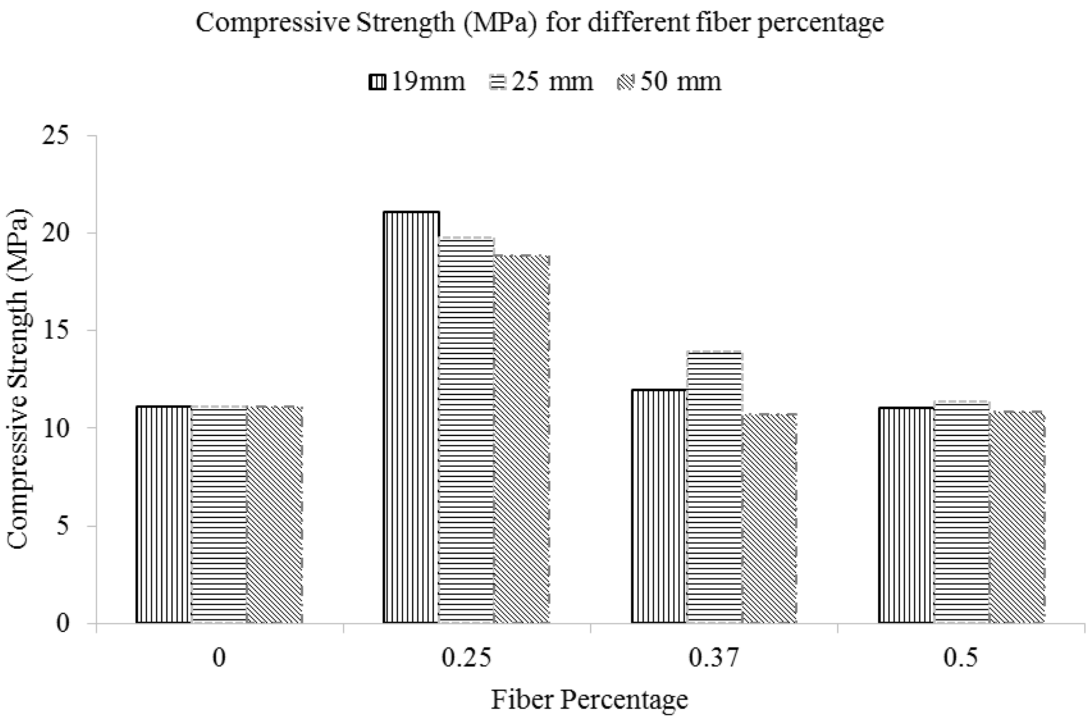


**Figure 4-3 Compressive Strength for Different Fiber Percentages**

**Figure 4-4 Sample after the compressive strength test (1)**

**Figure 4-5 Sample after the compressive strength test (2)**

Addition of Nylon fiber in concrete mix up to 0.25% of volume increases the compressive strength. Beyond that percentage no significance change in compressive strength is observed. Moreover among 19 mm, 25 mm and 50 mm fiber length 19 mm gives the best result. 19 mm with 0.25% fiber addition shows increased in compressive strength by almost 100% over plain concrete.

## 4.3 Split Tensile Strength

After 28 days the cylinders were tested to determine the indirect tensile strength according to the standard of ASTM C-496.For each data average of the 4 specimen cylinders were tested. The load was applied along the length of the cylinder until failure occurred. Then the maximum load sustained by the specimen is divided by appropriate geometrical factors to obtain the splitting tensile strength. The average data of the total 40 specimens of different fiber content and fiber lengths has described below.

**Table 4-3 Split tensile strength for different fiber length and fiber percentages**

| Fiber Length(mm) | Fiber Percentage | Split Tensile Strength (MPa) | % change compared to no fiber mix |
|---|---|---|---|
| No fiber | No fiber | 1.59 | |
| 19 | 0.25 | 2.25 | 41.51 |
| 25 | 0.25 | 2.28 | 43.40 |
| 50 | 0.25 | 1.79 | 12.58 |
| 19 | 0.37 | 1.36 | 14.47 |
| 25 | 0.37 | 1.46 | 8.18 |
| 50 | 0.37 | 1.55 | 2.52 |
| 19 | 0.5 | 1.68 | 5.66 |
| 25 | 0.5 | 1.58 | 0.63 |
| 50 | 0.5 | 1.57 | 1.26 |

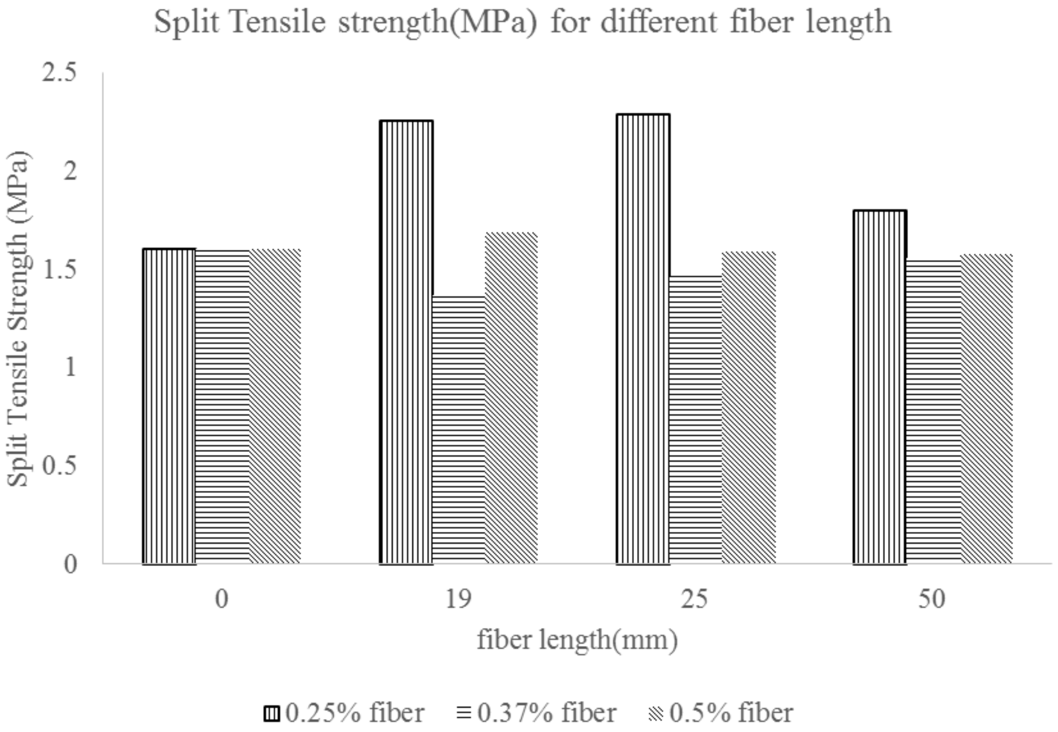


**Figure 4-6 Split Tensile Strength for Different Fiber Length**

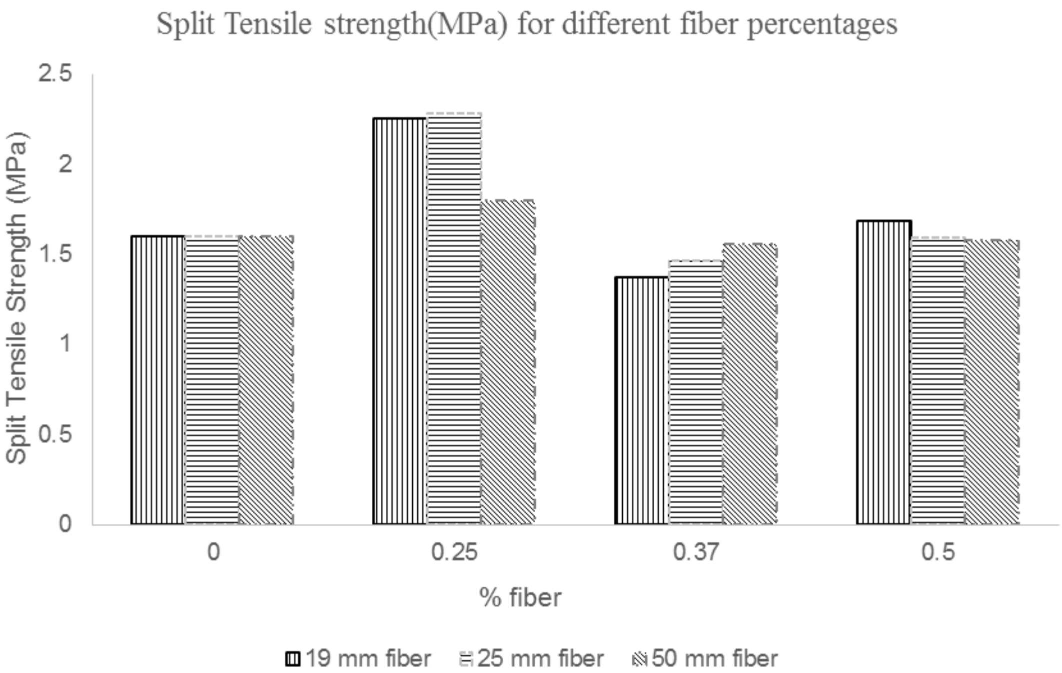


**Figure 4-7 Split Tensile Strength for Different Fiber Percentages**

Addition of Nylon fiber in concrete mix up to 0.25% of volume increases the Tensile strength. Beyond that percentage no significance change in tensile strength is observed. Moreover among 19 mm, 25 mm and 50 mm fiber length 19 mm gives the best result. The trend is somewhat similar to the result of compressive strength. 25 mm with 0.25% fiber addition shows increased in split tensile strength by almost 42% over plain concrete.

### 4.4 Flexural Strength

The influence of fibers on flexural response of concrete is much greater than on compressive response. Flexural strength was determined under third-point loading using ASTM C 78 standard. Three specimens of equal depth and width were prepared and tested for each result. The experimental data has been shown below the table and charts.

**Table 4-4 Flexural strength for different fiber length and fiber percentages**

| Fiber Length(mm) | Fiber Percentage | Flexural Strength(MPa) | % change compared to no fiber mix |
|---|---|---|---|
| No fiber | No fiber | 2.98 | |
| 19 | 0.25 | 2.98 | 0 |
| 25 | 0.25 | 3.56 | 19.46 |
| 50 | 0.25 | 2.78 | 6.71 |
| 19 | 0.37 | 2.76 | 7.38 |
| 25 | 0.37 | 2.8 | 6.04 |
| 50 | 0.37 | 2.76 | 7.38 |
| 19 | 0.5 | 2.61 | 12.42 |
| 25 | 0.5 | 2.86 | 4.03 |
| 50 | 0.5 | 3.49 | 17.11 |

**Figure 4-8 Flexural Strength Test**

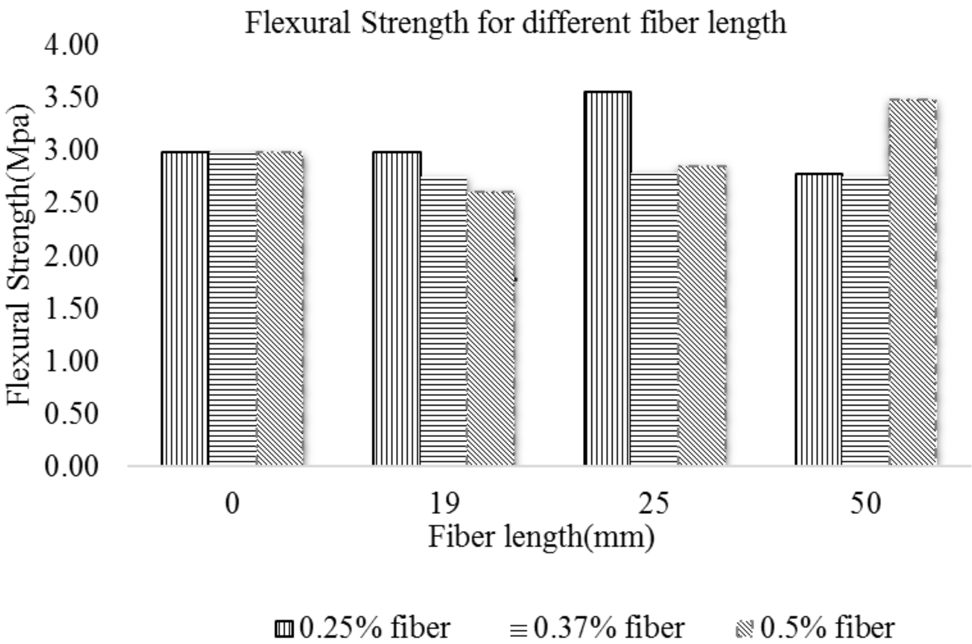


**Figure 4-9 Flexural Strength for Different Fiber Length**

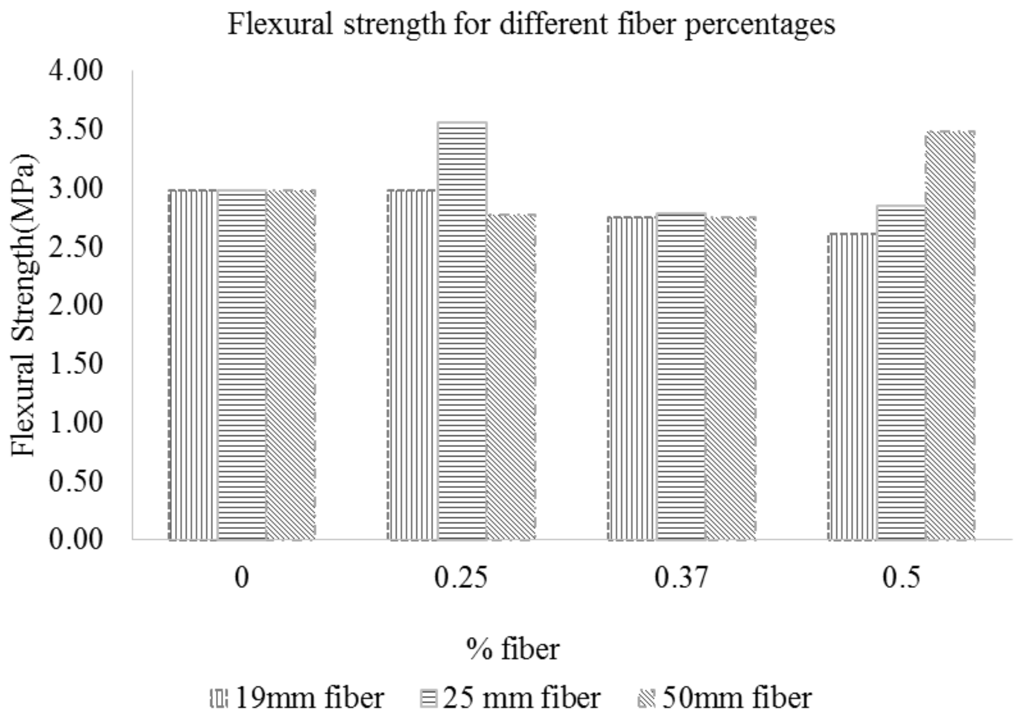


**Figure 4-10 Flexural Strength for Different Fiber Percentages**

Flexural strength increases while using 25mm fiber length for 25% of fiber volume. After that increase of fiber percentages the strength decreases. But for 0.5% volume of fiber content shows increasing strength with increasing aspect ratio.

### 4.4.1 Flexural Crack Behavior

After the flexural strength test the cracking patterns were observed and found that the parts of the specimen of the nylon fiber reinforced concrete were holding together by nylon fiber. In case of the mixes without fiber, samples were broken into two distinct parts. With the increase in fiber dosage, the failure of the concrete prisms were ductile and it was found that with 0.5% fiber dosage a significant residual strength was demonstrated by those samples.

**(a)** **(b)**

**(c)** **(d)**

**Figure 4-11 Flexural behavior of the specimen (a) without fiber (b) with 0.25% fiber (c) with 0.37% fiber (d) with 0.5% fiber**

## 4.5 Toughness

By the addition of fiber the improved toughness and energy absorption capacity was found. Toughness was calculated from the stored data of flexural strength test and by using the equations of ASTM C-1609 standards. The analyzed data has been shown below.

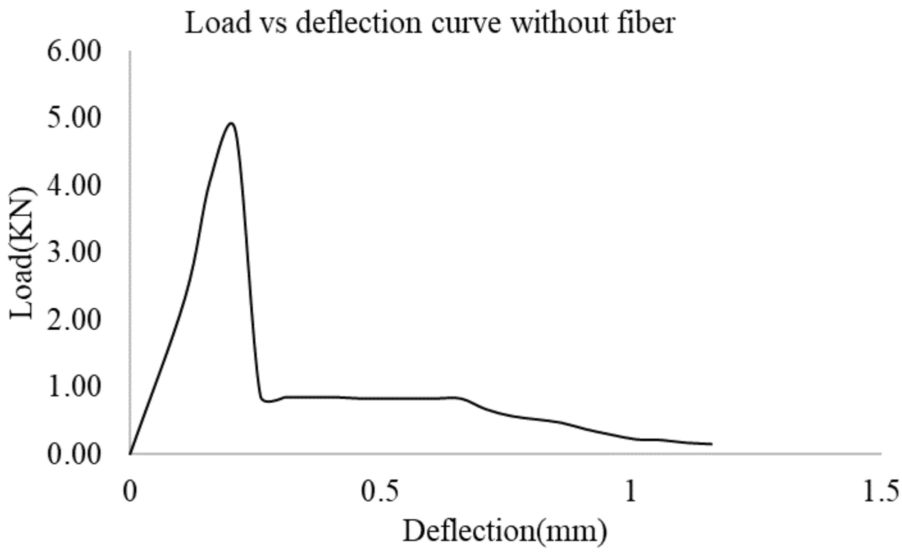


**Figure 4-12 Load vs. deflection Curve considering no fiber**

Area under the load vs. net deflection curve 0 to L/150, (T) = 1.19 J

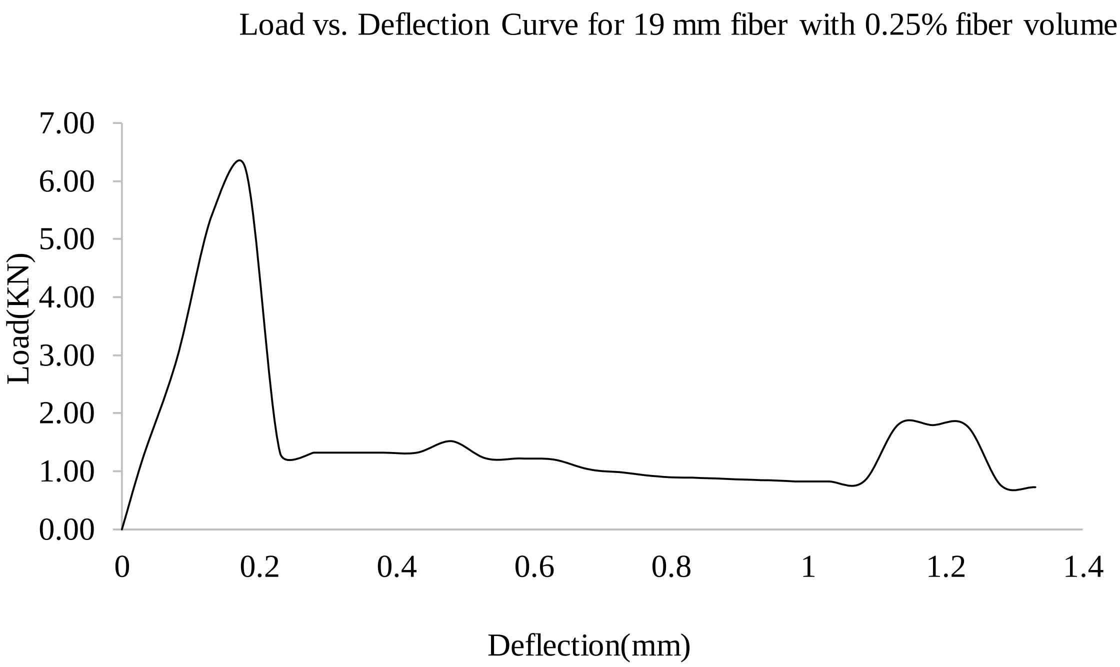


**Figure 4-13 Load vs. deflection Curve considering 19 mm fiber with 0.25% fiber volume**

Area under the load vs. net deflection curve 0 to L/150, (T) = 2.09 J

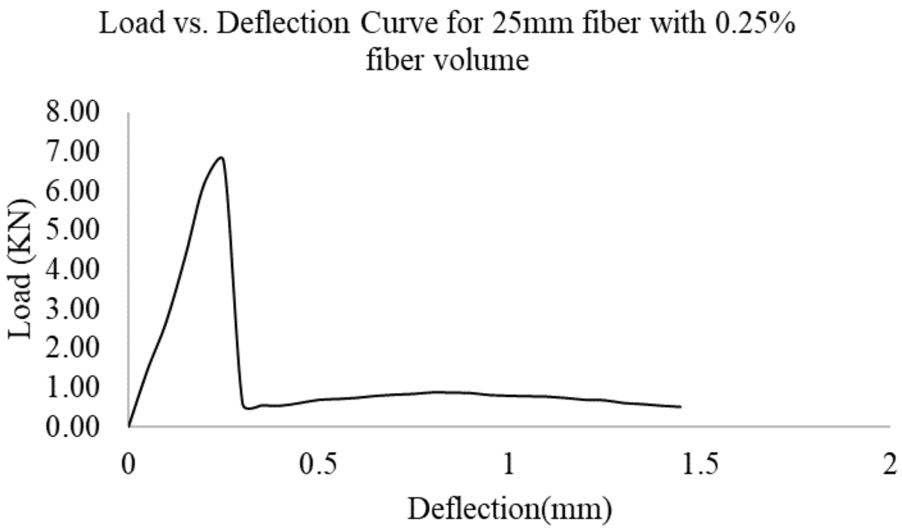


**Figure 4-14 Load vs. deflection Curve considering 25 mm fiber with 0.25% fiber volume**

Area under the load vs. net deflection curve 0 to L/150, (T) = 1.87 J

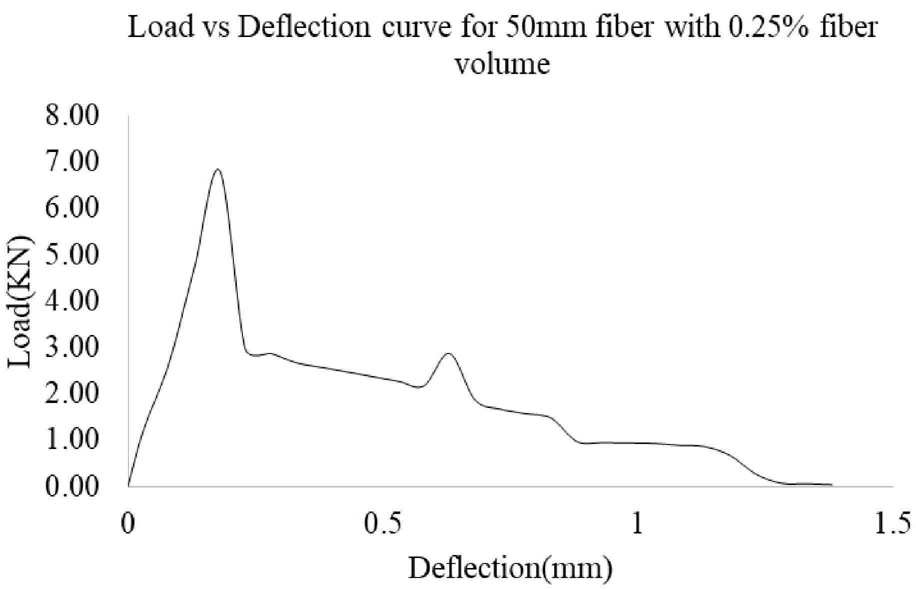


**Figure 4-15 Load vs. deflection Curve considering 50 mm fiber with 0.25% fiber volume**

Area under the load vs. net deflection curve 0 to L/150, (T) = 2.57 J

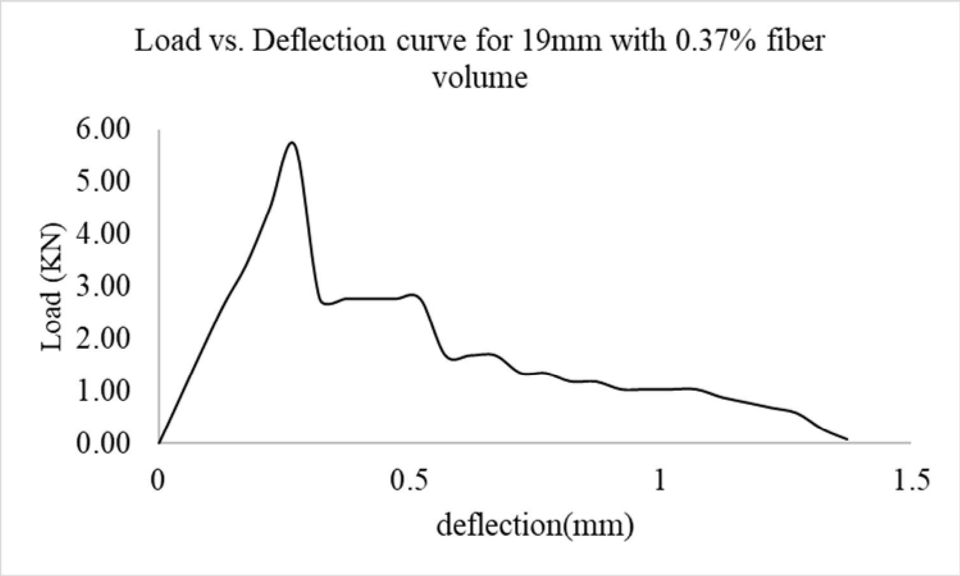


**Figure 4-16 Load vs. deflection Curve considering 19 mm fiber with 0.37% fiber volume**

Area under the load vs. net deflection curve 0 to L/150, (T) = 2.43 J

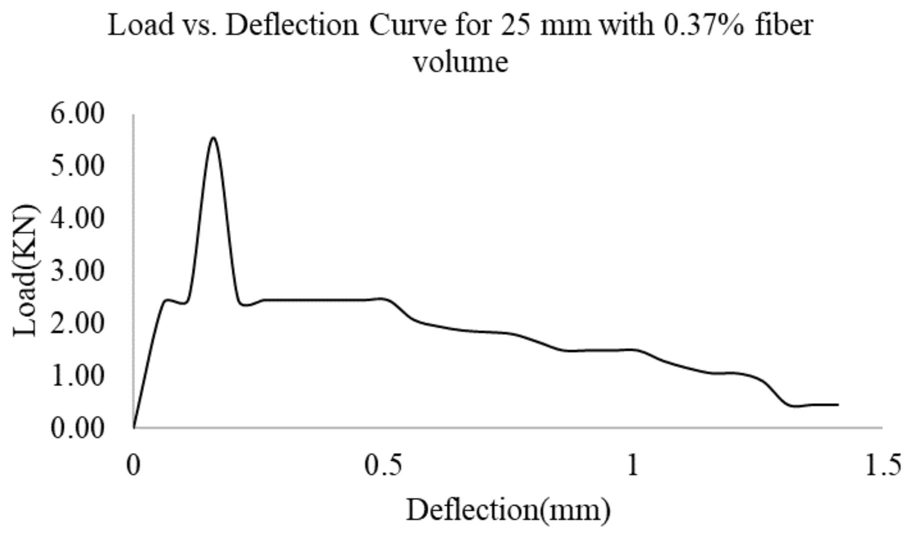


**Figure 4-17 Load vs. deflection Curve considering 25 mm fiber with 0.37% fiber volume**

Area under the load vs. net deflection curve 0 to L/150, (T) = 2.55 J

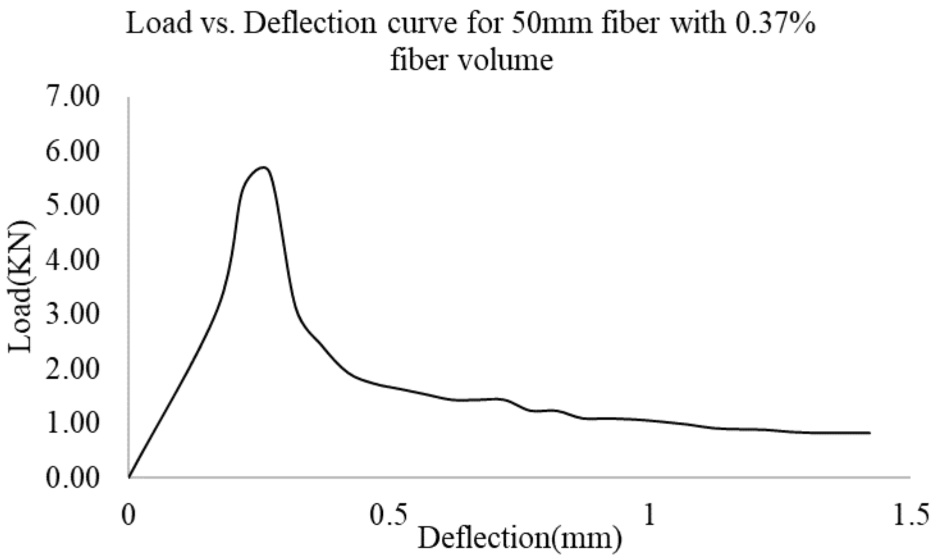


**Figure 4-18 Load vs. deflection Curve considering 50 mm fiber with 0.37% fiber volume**

Area under the load vs. net deflection curve 0 to L/150, (T) = 2.34 J

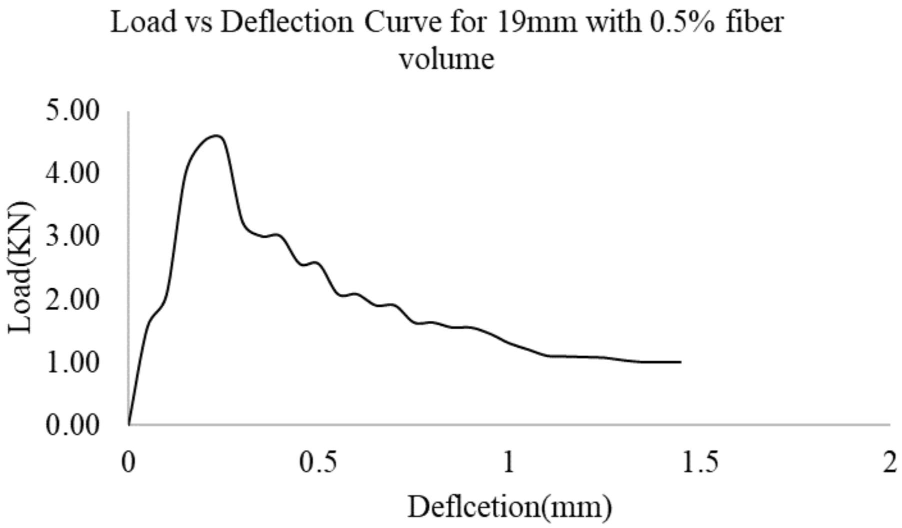


**Figure 4-19 Load vs deflection Curve considering 19 mm fiber with 0.5% fiber volume**

Area under the load vs. net deflection curve 0 to L/150, (T) = 2.81 J

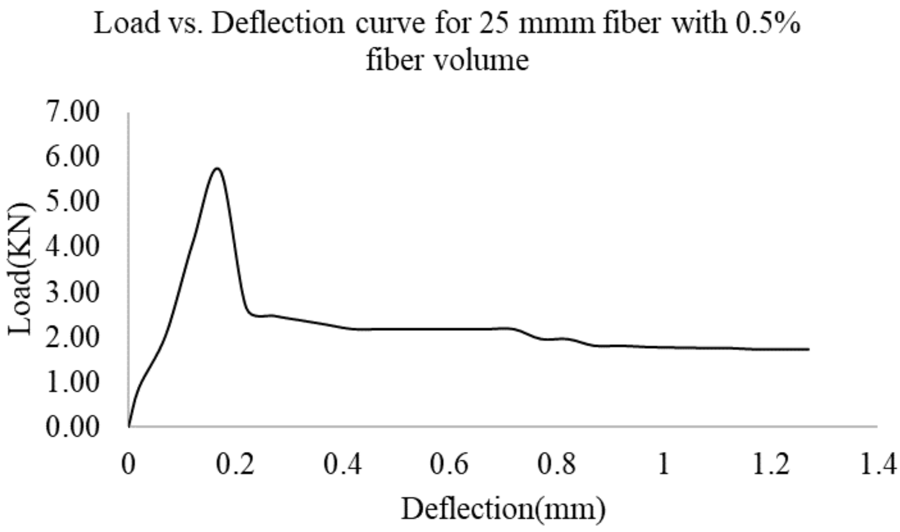


**Figure 4-20 Load vs. deflection Curve considering 25 mm fiber with 0.5% fiber volume**

Area under the load vs. net deflection curve 0 to L/150, (T) = 2.73 J

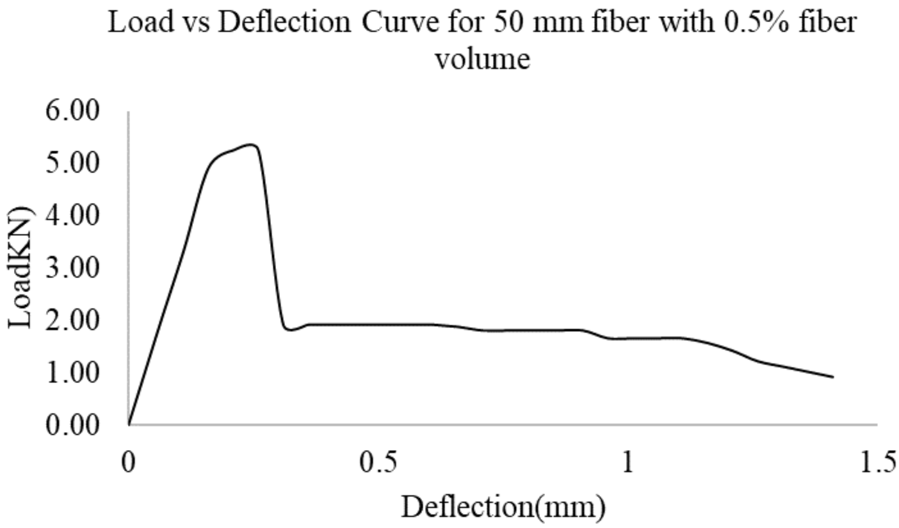


**Figure 4-21 Load Vs deflection Curve considering 50 mm fiber with 0.5% fiber volume**

Area under the load vs. net deflection curve 0 to L/150, (T) = 2.88 J

From the above calculations it can be seen that the addition of fiber to the mix increases the toughness or energy absorption capacity. For 19 mm fiber the toughness increases with the percent volume increase up to 0.37%.In case of 25 mm fiber the result shows increasing trend up to 0.5%. For the 50 mm fiber no significant change can be found for increasing the percent volume. In general for the same percent volume fiber content produces higher toughness for the higher fiber length.

### 4.6 Comparison of various mechanical strength

The ratios of the achieved strengths were plotted against the fiber length and fiber volume percentages to observe the relationship between split tensile strength with compressive strength, flexural strength with compressive strength and split tensile strength with flexural strength of nylon on the Fiber reinforced concrete. The description and the analyzed data has been given below through the graphical representation (Figure 4 - 22 to Figure 4 - 27).

From the Figure 4-22 it can be found that the split tensile strength and compressive strength ratio decreased due to the addition of the fiber but over the 19 mm length the ratio increased for different percentages. From the previous data we had found that for applying 0.25% nylon fiber was resulted better compressive strength and tensile strengths respectively. Whereas from the ratio of the tensile and compressive strength in can be seen that the tensile strength was not increased more than the compressive strength for the 19 mm length. And the result was different for the longer fiber i.e. for 25 mm and 50 mm length the tensile strength was better than the compressive strength. Again due to the addition of 0.37% fiber the tensile strength and the compressive strength were increased individually, but their ratio was less for the shorter fiber length. For the lengthier fiber the tensile strength was comparatively better than the compressive strength. In addition to that for 0.5% fiber adding the strength comparison had shown the same trend.

From the Figure 4-23 due to fiber addition, the ratio of the strengths had shown a few changes in the result. 19 mm fiber had shown reducing tendency of the tensile strength over compressive strength for different fiber dosages. So that it can be said that for lower fiber length the tensile strength was not that much increasing like the compressive strength with the increasing fiber dosages. In case of 25 mm fiber length the tensile strength and the compressive strength ratio was falling up to 0.37% fiber dosages. After that with the fiber dosages increased the tensile strength was also increased over the compressive strength. For 50 mm fiber length, the result had displayed increased ratio of split tensile and compressive strength. So used of the longer length of nylon fiber had shown the better split tensile strength over compressive strength. And at the 0.25% fiber dosages it was shown higher value. The relation between split tensile strength with compressive strength due to the addition of nylon fiber of different length and dosages has been represented through the next two figures.

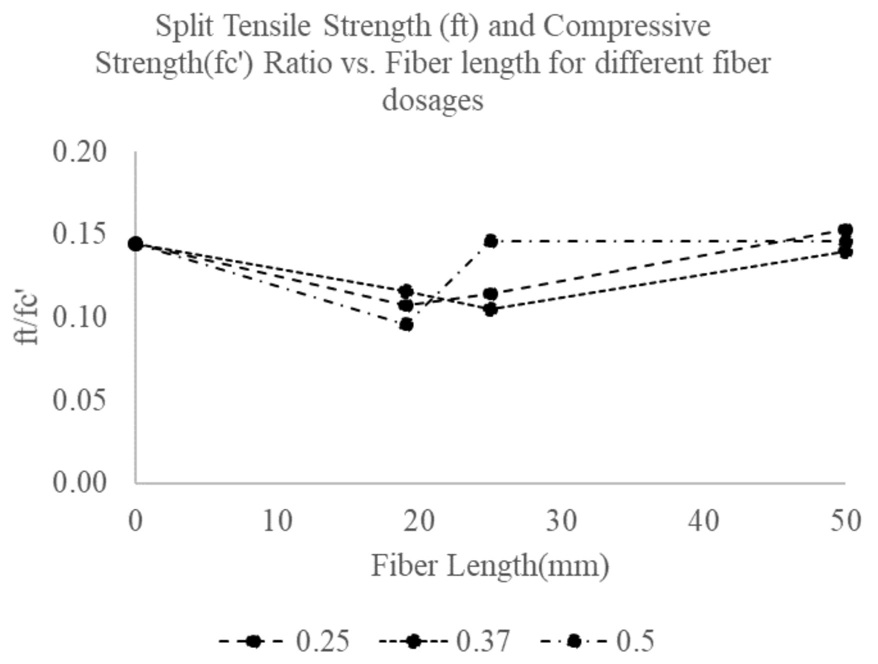


**Figure 4-22 Split Tensile Strength and Compressive Strength Ratio vs. Fiber length for different percentages**

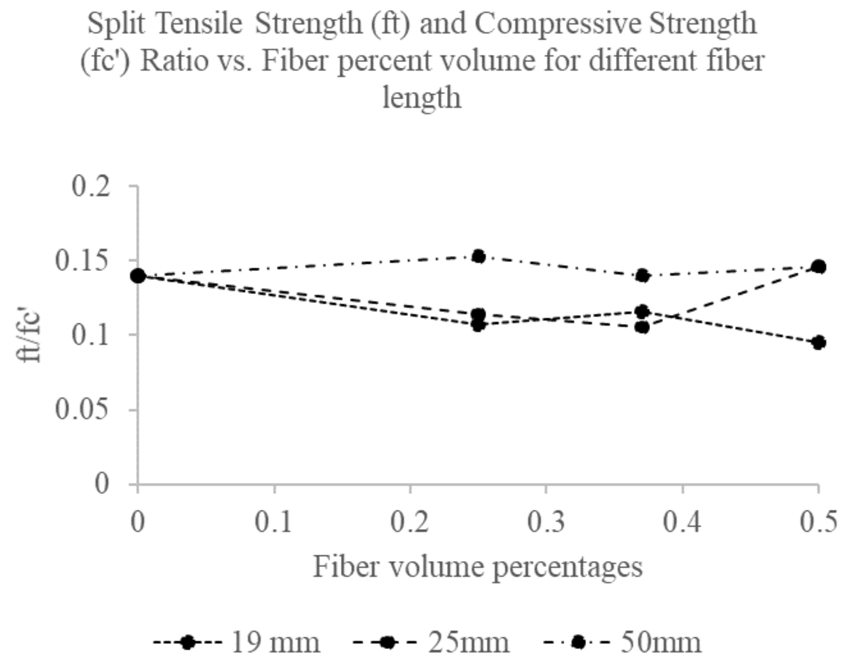


**Figure 4-23 Split Tensile Strength and Compressive Strength Ratio Vs Fiber percentages for different fiber length**

From the Figure 4-24 it can be said that the flexural strength and compressive strength ratio of the different fiber percentages initially decreased and with the increment of the fiber length it increased. While added 0.25% fiber content it had been found that, both the flexural and compressive strength individually improved over no fiber mix. But the ratio of the flexural strength and the compressive strength had shown different trend. For lower length of fiber the flexural strength improving rate is lower than the improving rate of compressive strength. Then again while the longer length fiber had been induced i.e. over 19 mm length the flexural strength was increasing more than the compressive strength. For 0.37% fiber addition the ratio of flexural strength and compressive strength was decreased for the lesser length fiber and the curve had shown different trend for the higher length of fiber. In lieu of adding 0.5% fiber volume percent the flexural strength had shown comparatively less significant value for the smaller fiber length than the compressive strength. After the increment fiber length the result was opposite as the flexural strength improved more over the compressive strength.

From the Figure 4-25 it can be said that the flexural strength and compressive strength ratio of the three different fiber lengths initially decreased and over 0.37% percent the ratio increased. For 19mm length the ratio of the flexural and the compressive strength decreased with the increasing fiber percent though the flexural strength and compressive strength was individually increased. So for lower fiber volume and lesser length fiber the flexural strength was comparatively lower than the compressive strength. Using the higher length like 25 mm fiber length the flexural strength had resulted better value than the compressive strength over 0.37% fiber content. On the other hand, by introducing the 50 mm length nylon fiber the as the both flexural and compressive strength had increased individually as their ratio also. The higher the percent content of fiber was used the higher the flexural strength over the compressive strength was found in case of the 50 mm fiber length instruction to the concrete mix.

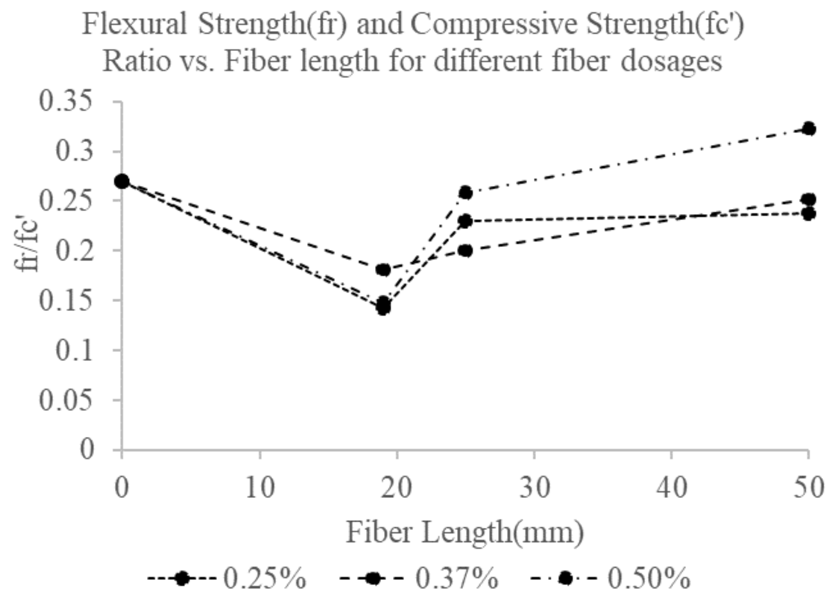


**Figure 4-24 Flexural Strength and Compressive Strength Ratio vs. Fiber length for different percentages**

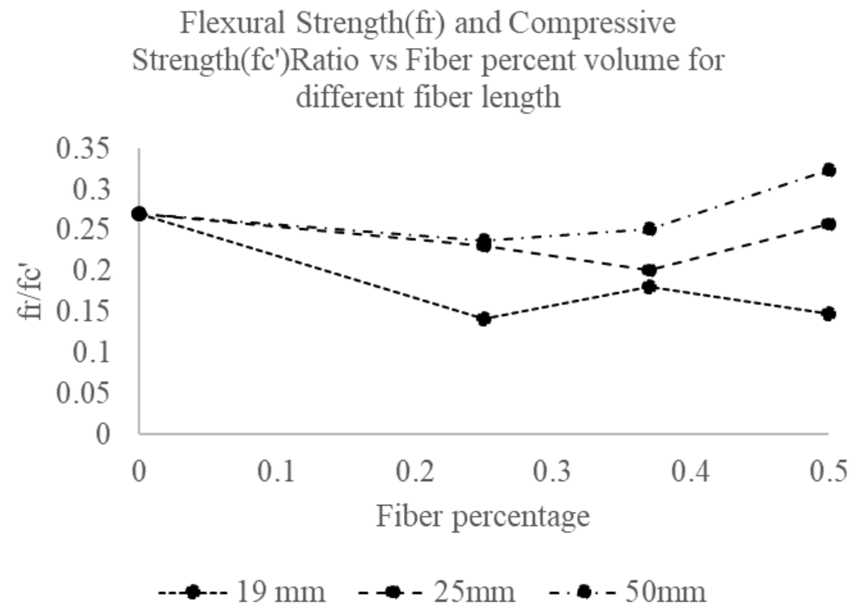


**Figure 4-25 Flexural Strength and Compressive Strength Ratio vs. Fiber percentages for different fiber length**

From the Figure 4-26 it had found that increased trend of the ratio of split tensile strength and flexural strength for 0.25% fiber content due to the addition. The other two percentages has not shown similar trends. Due to the addition of 0.25% fiber content the split tensile strength had increased more than the flexural strength up to 19 mm fiber length and then the ratio began to decrease up to 25 mm length and then again increased for higher fiber length like 50 mm nylon fiber. For the 0.37% fiber percent volume the split tensile strength had shown better result in compare to the flexural strength. Though the result was fluctuated in between the 19mm and 25 mm length but ultimately it was increasing for higher length fiber. In case of the 0.5% fiber addition, the split tensile strength was comparatively more than the flexural strength over the 25 mm fiber length. So through the resulted curve it can be said that the higher the fiber length the better the split tensile strength over the flexural strength.

From the Figure 4-27 it can be said that for 25 mm fiber length the ratio was not shown any significant trend for increasing volume content. For 19 mm and 50 mm fiber length the ratio is initially increases but over 0.37% fiber content is shows decreasing trend. 19 mm length had shown more tensile strength over the flexural strength for 0.25% fiber content and then the trend was changed up to 0.37% fiber content then again it was increased for 0.5% fiber content. In case of 25 mm fiber length the tensile strength was close to the flexural strength. On the other hand the for the addition of the 50 mm fiber length the tensile strength was more than the flexural strength for increasing fiber content up to the 0.25% but after that the ratio of the strength was decreased for increased fiber content. So that it can be said that though the split tensile strength and the flexural strength increased individually, their ratio had shown different trends.

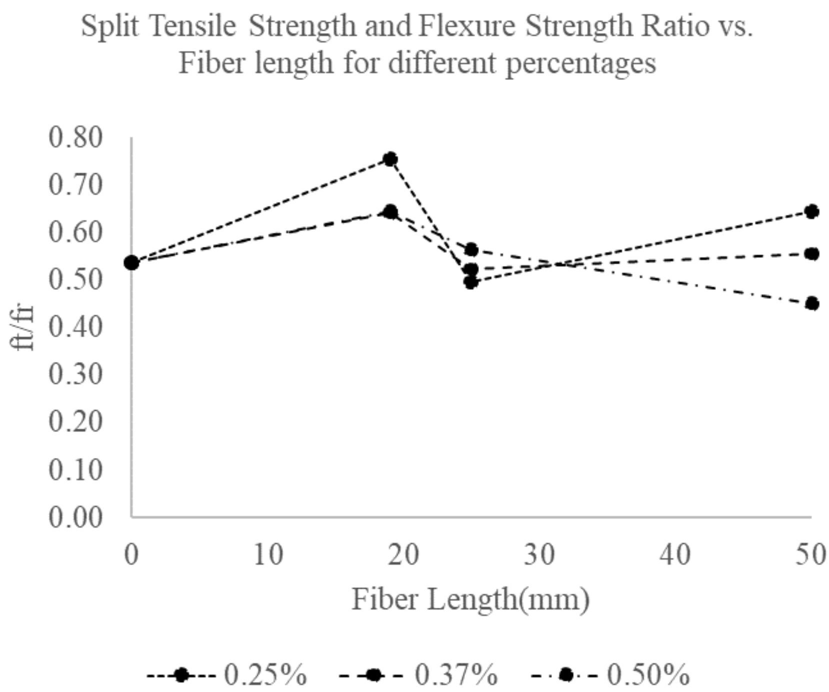


**Figure 4-26 Split Tensile Strength and Flexure Strength Ratio vs. Fiber length for different percentages**

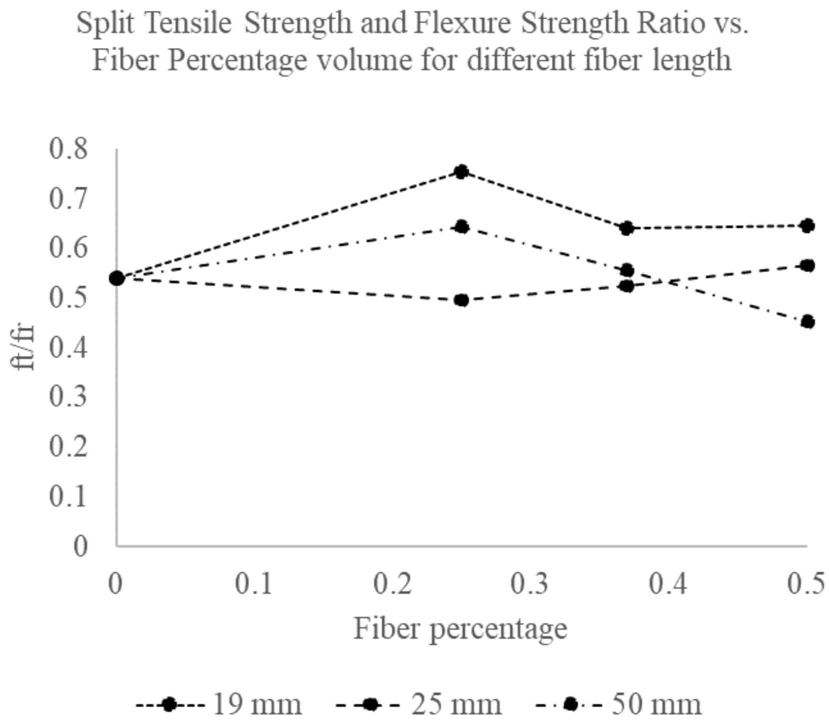


**Figure 4-27 Split Tensile Strength and Flexure Strength Ratio vs. Fiber Percentages for different fiber lengths**

## 4.7 Comparison and discussion

**Polyethylene**

The have considered the following mixes with 0.01% to 0.1 % of polyethylene as FRC.

**Table 4-5 Flexural strength and Compressive Strength for polyethylene fiber percentages**

| Mix type | Flexural (psi) | compressive(psi) |
|---|---|---|
| Plain | 617 | 6764 |
| PE,Vf=0.1% | 669 | 6493 |
| PE,Vf=0.025% | 698 | 5390 |
| PE,Vf=0.05% | 732 | 5674 |
| PE,Vf=0.01% | 744 | 5185 |

Observations:

1. Polyethylene fibers increased the flexural and impact strengths, and decreased the compressive strength, of concrete materials; with 0.1 percent volume fraction of polyethylene fibers, the average flexural and impact strengths were, respectively, 21-percent greater and 5.8 times, and the average compressive strength was 23 percent less than the corresponding values for plain concrete.

2. Polypropylene fibers at 0.1 percent volume fraction as well as polyethylene fibers at 0.025 and 0.05 percent volume fractions had negligible effects (considering variations in test results at 95 percent level of confidence) on the flexural strength of concrete; only 0.1 percent volume fraction of polyethylene fibers could improve flexural strength.

3. All the fiber reinforcement conditions considered in this study produced considerable improvements in the impact resistance of concrete.

4. Polyethylene fibers, when used at 0.05 percent volume fraction, produced impact strengths comparable to those obtained with polypropylene fibers used at 0.1 percent volume fraction.

**Polypropylene:**

The experimental considerations and the achieved results are given below:

**Table 4-6 Slump and Compressive strength of polypropylene fiber**

| Mix no | fiber length | fiber volume fraction | slump | compressive(psi) |
|---|---|---|---|---|
| 1 | 0 | 0 | 8.5 | 5700 |
| 2 | 0.5 | 0.1 | 9.5 | 6550 |
| 3 | 0.5 | 0.3 | 8 | 6800 |
| 4 | 0.5 | 0.5 | 7.5 | 5560 |
| 5 | 0.75 | 0.1 | 10.5 | 5400 |
| 6 | 0.75 | 0.3 | 9.5 | 5800 |
| 7 | 0.75 | 0.5 | 1 | 5600 |

Observations:

1. Fibrillated polypropylene fibers have no detectable effect on the workability and air content of fresh concrete at volumes below 0.3 percent. An adverse effect on workability and an increase in air content of concrete was resulted from the application of polypropylene fibers at 0.5 percent volume.

2. Fibrillated polypropylene fibers tended to increase the permeability of concrete. With 112-in.-long fibers, the increase was relatively mild. With 3/4-in.-long fibers, the increase was significant.

3. Polypropylene fibers had a relatively small favorable effect on compressive strength of concrete when 1/2-in.-long fibers were used, and on compressive toughness when 3/4- in.-long fibers were used.

4. It was proposed that the flexural behavior of polypropylene fiber concrete be characterized by the post-peak flexural resistance (load or stress).lt was found that, for volumes equal to or less than 0.3 percent, 3/4-in.-long fibers were more favorable for enhancing the post-peak resistance. For 0.5 percent volume, 1/2-in.-long fibers were more effective.

**Glass:**

The test results were as follows:

**Table 4-7 Compressive strength, Flexural Strength, split tensile strength of polypropylene fiber**

| | Compressive Strength N/mm² | | Flexural Strength N/mm² | | Split Tensile Strength N/mm² | |
|---|---|---|---|---|---|---|
| | Without GF | With GF | Without GF | With GF | Without GF | With GF |
| M20 | 30.7 | 38.89 | 14.33 | 18.75 | 3.16 | 4.1 |
| M30 | 40.3 | 49.04 | 15.58 | 20.08 | 4.1 | 5.18 |
| M40 | 49.6 | 61.2 | 16.67 | 21.57 | 4.34 | 5.65 |

Observations:

1. It has been observed that the workability of concrete decreases with the addition of Glass fibers. But this difficulty can be overcome by using plasticizers or super-plasticizers.

2.The increase in Compression strength, Flexural strength, Split tensile strength for M-20, M-30 and M-40 grade of concrete at 3, 7 and 28 days are observed to be 20% to 30%, 25% to 30% and 25% to30% respectively when compared with 28 days strength of Plain Concrete

3. It has been also observed that there is gradual increase in early strength for Compression and Flexural strength of Glass Fibers Reinforced Concrete as compared to Plain Concrete, and there is sudden increase in ultimate strength for Split tensile strength of Glass Fibers Reinforced Concrete as compared to Plain Concrete.

**Table 4-8 Relation among fiber dosage, percentage and compressive strength of Polypropylene (Bayasi and Zeng)**

| Mix type | Fiber length (in) | Fiber volume percentage | Slump (in) | Compressive Strength (psi) |
|---|---|---|---|---|
| **1** | - | | 8.5 | 5700 |
| **2** | 0.5 | 0.1 | 9.5 | 6550 |
| **3** | 0.5 | 0.3 | 8.0 | 6800 |
| **4** | 0.5 | 0.5 | 7.5 | 5560 |
| **5** | 0.75 | 0.1 | 10.5 | 5400 |
| **6** | 0.75 | 0.3 | 9.5 | 5800 |
| **7** | 0.75 | 0.5 | 1 | 5600 |

From the above comparison it can be concluded that the effect of the aspect ratio on polypropylene fiber is almost same as the nylon fiber. Up to a certain percentage the compressive strength increases and beyond that the strength decreases.

**Table 4-9 Strength test result on nylon- and polypropylene-fiber-reinforced concretes versus plain control concrete (Song et al., 2005)**

| Concrete type | Compressive strength (MPa) | Split Tensile Strength (MPa) | Modulus of Rupture (MPa) | Slump (cm) |
|---|---|---|---|---|
| NFRC | 25.88 | 2.54 | 6.54 | 12.5 |
| PFRC | 24.35 | 2.38 | 5.98 | 12 |
| Plain Concrete | 23.02 | 2.17 | 5.89 | 16 |

From the above discussion it can be seen that nylon fiber has a potential future for sustainable concrete structure. The depending factors like volume percentages and aspect ratio of nylon fiber are needed to explore to ensure the appropriate performance of the fiber in the concrete matrix. For this, the next chapter includes the analysis of the effect of aspect ratio of nylon fiber on the concrete properties using environmental friendly and durable Portland Composite Cement (CEM-II/B-M).

# 5 Conclusions and Recommendations

## 5.1 Conclusions

Fibrous composite concrete is one of the outstanding solutions to overcome the limitations of concrete. The previous studies have been shown that fiber has a positive effect on the compressive, tensile and flexural strength of the concrete properties. Among so many types of fibers nylon fiber has achieved popularity due to inherent properties. The use of nylon fiber in the concrete provides a good change to the environment by reusing the waste material thereby reducing pollution. In this project the effect of the nylon fiber length and percentages of on concrete had been assessed as a part of the improvement research works regarding concrete. From the results and analysis of the study it can be concluded that:

a) The increases in the aspect ratio of the nylon fiber decreases the workability of the fresh concrete. In addition to this the increasing volume percentages of fibers also showed lower slump value.
b) From of the compressive strength, it can be concluded that using 19mm length fiber has shown significant improvement in the concrete composite. Moreover lower of fiber volume percentage has given comparatively higher compressive strength. The splitting tensile strength of the concrete was increased at 0.25% fiber volume of nylon fiber. Concrete mixes with 19 mm and 25 mm fiber showed higher strength at that fiber volume percentage.
c) Effect of nylon fiber length and fiber dosages have been found insignificant on the flexural strength of concrete. However, concrete mix with 0.25% fiber volume of the 25 mm fiber length showed 20% increase in flexural strength.
d) Toughness values were also more in the nylon fiber reinforced concrete than the concrete composite without fiber. And also the energy absorption capacity increased with the increment of the fiber length.

## 5.2 Limitations of the Present Study

In spite of being cautious at every phase of the study, some limitations were faced.

1. No physical and mechanical properties of nylon fiber was not investigated in the laboratory.
2. Some portion of the nylon fibers were not cut according to the expected sizes Almost 5% variation in the length was observed.

## 5.3 Future Recommendations

This study provides the following recommendations for the use of nylon fiber in construction:

1. Nylon fiber reinforcement for concrete slab-on-grade construction should not serve as a direct replacement for welded wire fabric, nor should nylon fiber reinforcement be used to allow a larger spacing of control joints than in unreinforced concrete.

2. Since nylon lose their tensile properties at 225°C, it is recommended that nylon fiber reinforcement be used in applications where the maximum ambient temperature is limited to the range of 225ºC.

3. Nylon fiber reinforcement to be used in concrete that will be subjected to prolonged conditions of high humidity should be composed of alkali-resistant synthetic fibers such as polypropylene or polyethylene.

4. Nylon fibers should be used to prevent plastic shrinking cracking in placements susceptible to this condition.

5. Research should be continued to develop the uses for nylon fiber-reinforcing material in concrete, especially in the use of higher contents of nylon fibers to prevent drying shrinking cracking.

6. In this study the nylon fiber percentages used were 0. 25%, 0.37% and 0.5%. The effect of lower fiber dosages on the mechanical properties of concrete needs to be evaluated.

7. For the further study concrete mixes with different water-cement ratio and different mix proportions can be considered to explore the mechanical properties of the nylon fiber reinforced concrete.

8. In order to explain the performance of nylon fiber reinforced concrete the bond performance of single nylon fiber needs to be evaluated.

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# Appendix

**Table A.1 Sieve analysis of CA**

| Coarse Aggregate | | | | | |
|---|---|---|---|---|---|
| Total sample = 5 kg | | | | | |
| Temp = 27° C | | | | | |
| Sieve | Sieve size (mm) | Retained(kg) | % Retained | Cumulative % Retained | % finer |
| 1" | 25 | 0 | 0 | 0 | 100 |
| 3/4" | 19 | 1.57 | 31.4 | 31.4 | 68.6 |
| 1/2" | 12.5 | 2.24 | 44.8 | 76.2 | 23.8 |
| 3/8" | 9.5 | 0.87 | 17.4 | 93.6 | 6.4 |
| # 4 | 4.75 | 0.32 | 6.4 | 100 | 0 |
| Total= | | 5 | 100 | | |

**Table A.2** Sieve analysis of FA

| Fine Aggregate | | | | | |
|---|---|---|---|---|---|
| Total sample = 500 g | | | | | |
| Temp = 27° C | | | | | |
| Sieve | Sieve size (mm) | Retained(g) | % Retained | Cumulative % Retained | % finer |
| # 4 | 4.75 | 0 | 0 | 0 | 100 |
| # 8 | 2.36 | 12.9 | 2.58 | 2.58 | 97.42 |
| # 16 | 1.18 | 81 | 16.2 | 18.78 | 81.22 |

| | | | | | |
|---|---|---|---|---|---|
| # 30 | 0.6 | 221.6 | 44.32 | 63.1 | 36.9 |
| # 50 | 0.3 | 141.8 | 28.36 | 91.46 | 8.54 |
| # 100 | 0.15 | 33.8 | 6.76 | 98.22 | 1.78 |
| PAN | | 8.9 | 1.78 | 100 | 0 |
| Total | | 500 | 100 | | |
| | | FM= 2.74 | | | |

**Table A.3** Specific gravity test of CA

| | | | |
|---|---|---|---|
| Specific Gravity of CA | | | |
| Temp = 27.5$^{o}$ C | | | |
| SSD wt. (air), S | 2500 gm | | |
| Bucket (air), B | 576 gm | | |
| Bucket (Water), E | 510 gm | | |
| Bucket+CA (water), G | 2070 gm | | |
| Aggregate wt (oven dry), A | 2490 gm | | |
| SSD wt. of sample in water, C = G-E | 1560 gm | | |
| Apparent Specific Gravity, Sa | A/(A-C) | 2490/(2490-1560) | 2.68 |
| Bulk Specific Gravity (O-D basis), Sd | A/(S-C) | 2490/(2500-1560) | 2.65 |
| Bulk Specific Gravity (SSD basis), Ss | S/(S-C) | 2500/(2500-1560) | 2.66 |
| Absorption Capacity (D) in % | (S-A)/A×100 | | 0.4 |

**Table A.4** Specific gravity test of FA

| | | | |
|---|---|---|---|
| Specific Gravity of FA | | | |
| Temp = 27.5$^o$ C | | | |
| SSD wt. of sand, (S) | 500 gm | | |
| Pycnometer, (P) | 328 gm | | |
| Pycnometer + Water, (B) | 1322 gm | | |
| Pycnometer + Water + Sand, ( C ) | 1630 gm | | |
| Aggregate wt (oven dry), (A) | 490.5 gm | | |
| Capacity of pycnometer, (V=B-P) | 994 gm | | |
| wt of water added, (W=C-S-P) | 802 gm | | |
| Apparent Specific Gravity, Sa | A/(V-W)-(S-A) | 490.5/(994-802)-(500-490.5) | 2.69 |
| Bulk Specific Gravity (O-D basis), Sd | A/(V-W) | 490.5/(994-802) | 2.55 |
| Bulk Specific Gravity (SSD basis), Ss | S/(V-W) | 500/(994-802) | 2.6 |
| Absorption Capacity (D) in % | (S-A)/A×100 | (500-490.5)/490.5×100 | 1.94 |

**Table A.5** Unit weight test of CA

| | | | |
|---|---|---|---|
| Unit weight of CA | | | |
| Temp = 27$^o$ C | | | |
| volume of container, (V) | 0.1 cft | | |

| | kg | lbs | |
|---|---|---|---|
| Container wt. (T) | 3.96 | 8.7516 | |
| Container + CA (G) | 8.26 | 18.2546 | |
| wt. of CA (G-T) | 4.3 | 9.503 | |
| unit wt, M= (G-T)/V | 9.503/.1 | 95.03 | lb/cft |
| | | 1552.25 | kg/m3 |

**Table A.5** Unit weight test of FA

| | | | |
|---|---|---|---|
| Unit weight of FA | | | |
| Temp = 27° C | | | |
| Density of Water = | | | |
| volume of container, (V) | 0.1 cft | | |
| | kg | | |
| Container wt., (T) | 3.96 | 8.7516 | |
| Container + FA, (G) | 8.22 | 18.1662 | |
| wt. of FA, (G-T) | 4.26 | 9.4146 | |
| unit wt, M= (G-T)/V | 9.4146/.1 | 94.146 | lb/cft |
| | | 1508.15 | kg/m3 |

**Table A.6** Compressive Strength Test Result

| Mix no | slump | fiber length | compressive Load KN Machine | Calibrated Load y=0.9691x+0.4978 KN | Area(mm²) | Compressive Strength MPa |
|---|---|---|---|---|---|---|
| **2 19mm 0.25%** | 96mm 3.7 in | 19 | 175 | 170.09 | 7857.14 | 21.65 |
| | | 19 | 178 | 173.00 | 7857.14 | 22.02 |
| | | 19 | 157 | 152.65 | 7857.14 | 19.43 |
| **Average** | | **19** | | **165.24** | | **21.03** |
| **3 25mm 0.25%** | 90mm 3.5 in | 25 | 156 | 151.68 | 7857.14 | 19.30 |
| | | 25 | 156 | 151.68 | 7857.14 | 19.30 |
| | | 25 | 170 | 165.24 | 7857.14 | 21.03 |
| | | 25 | 156 | 151.68 | 7857.14 | 19.30 |
| **Average** | | 25 | | **155.07** | | **19.74** |
| **4 50mm 0.25%** | 90mm 3.5 in | 50 | 150 | 145.86 | 7857.14 | 18.56 |
| | | 50 | 164 | 159.43 | 7857.14 | 20.29 |
| | | 50 | 144 | 140.05 | 7857.14 | 17.82 |
| | | 50 | 150 | 145.86 | 7857.14 | 18.56 |
| **Average** | | | | **147.80** | | **18.81** |
| **5 19mm 0.37%** | 20mm 0.8 in | 19 | 146 | 141.99 | 7857.14 | 18.07 |
| | | 19 | 93 | 90.62 | 7857.14 | 11.53 |
| | | 19 | 57 | 55.74 | 7857.14 | 7.09 |
| | | 19 | 90 | 87.72 | 7857.14 | 11.16 |
| **Average** | | 19 | | **94.02** | | **11.97** |
| **6 25mm 0.37%** | 100mm 4 in | 25 | 122 | 118.73 | 7857.14 | 15.11 |
| | | 25 | 119 | 115.82 | 7857.14 | 14.74 |
| | | 25 | 68 | 66.40 | 7857.14 | 8.45 |
| | | 25 | 140 | 136.17 | 7857.14 | 17.33 |
| **Average** | | 25 | | **109.28** | | **13.91** |
| **7 50mm 0.37%** | 15mm 0.6 in | 50 | 104 | 101.28 | 7857.14 | 12.89 |
| | | 50 | 110 | 107.10 | 7857.14 | 13.63 |
| | | 50 | 72 | 70.27 | 7857.14 | 8.94 |
| | | 50 | 58 | 56.71 | 7857.14 | 7.22 |
| **Average** | | 50 | | **83.84** | | **10.67** |
| **8 19mm 0.5%** | 16mm 0.63 in | 19 | 50 | 48.95 | 7857.14 | 6.23 |
| | | 19 | 48 | 47.01 | 7857.14 | 5.98 |
| | | 19 | 30 | 29.57 | 7857.14 | 3.76 |
| **Average** | | 19 | | **41.85** | | **5.33** |
| **9 25mm 0.5%** | 14mm 0.55 in | 25 | 66 | 64.46 | 7857.14 | 8.20 |
| | | 25 | 94 | 91.59 | 7857.14 | 11.66 |
| | | 25 | 96 | 93.53 | 7857.14 | 11.90 |
| | | 25 | 110 | 107.10 | 7857.14 | 13.63 |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Average** | | 25 | | **89.17** | | **11.35** |
| **10<br>50mm<br>0.5%** | 16mm<br>0.63 in | 50 | 112 | 109.04 | 7857.14 | 13.88 |
| | | 50 | 88 | 85.78 | 7857.14 | 10.92 |
| | | 50 | 48 | 47.01 | 7857.14 | 5.98 |
| | | 50 | 100 | 97.41 | 7857.14 | 12.40 |
| **Average** | | 50 | | **84.81** | | **10.79** |
| **1** | | 0 | 90 | 87.72 | 7857.14 | 11.16 |
| | 150mm<br>6 in | 0 | 88 | 85.78 | 7857.14 | 10.92 |
| | | 0 | 90 | 87.72 | 7857.14 | 11.16 |
| **Average** | | | | **87.07** | | **11.08** |

**Table A.7** Splitting Tensile Strength Test Result

| Mix no | slump | fiber length | Area(mm²) | Length | Dia | split tensile KN Machine | Calibrated y=0.991x-4.557 | Split Tensile Strength Mpa |
|---|---|---|---|---|---|---|---|---|
| **2<br>19mm<br>0.25%** | 96mm<br>3.7 in | 19 | 7857.14 | 200 | 100 | 80 | 74.72 | 2.38 |
| | | 19 | 7857.14 | 200 | 100 | 72 | 66.80 | 2.13 |
| | | 19 | 7857.14 | 200 | 100 | 76 | 70.76 | 2.25 |
| **Average** | | **19** | | | | | **70.76** | **2.25** |
| **3<br>25mm<br>0.25%** | 90mm<br>3.5 in | 25 | 7857.14 | 200 | 100 | 74 | 68.78 | 2.19 |
| | | 25 | 7857.14 | 200 | 100 | 66 | 60.85 | 1.94 |
| | | 25 | 7857.14 | 200 | 100 | 88 | 82.65 | 2.63 |
| | | 25 | 7857.14 | 200 | 100 | 80 | 74.72 | 2.38 |
| **Average** | | 25 | | | | | **71.75** | **2.25** |
| **4<br>50mm<br>0.25%** | 90mm<br>3.5 in | 50 | 7857.14 | 200 | 100 | 60 | 54.90 | 1.75 |
| | | 50 | 7857.14 | 200 | 100 | 56 | 50.94 | 1.62 |
| | | 50 | 7857.14 | 200 | 100 | 60 | 54.90 | 1.75 |
| | | 50 | 7857.14 | 200 | 100 | 70 | 64.81 | 2.06 |
| **Average** | | | | | | | **56.39** | **1.70** |
| **5<br>19mm<br>0.37%** | 20mm<br>0.8 in | 19 | 7857.14 | 200 | 100 | 52 | 46.98 | 1.49 |
| | | 19 | 7857.14 | 200 | 100 | 42 | 37.07 | 1.18 |
| | | 19 | 7857.14 | 200 | 100 | 48 | 43.01 | 1.37 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 19 | 7857.14 | 200 | 100 | 50 | 44.99 | 1.43 |
| **Average** | | 19 | | | | | **43.01** | **1.35** |
| **6** | 100mm | 25 | 7857.14 | 200 | 100 | 60 | 54.90 | 1.75 |
| **25mm** | 4 in | 25 | 7857.14 | 200 | 100 | 48 | 43.01 | 1.37 |
| **0.37%** | | 25 | 7857.14 | 200 | 100 | 48 | 43.01 | 1.37 |
| | | 25 | 7857.14 | 200 | 100 | 48 | 43.01 | 1.37 |
| **Average** | | 25 | | | | | **45.98** | **1.49** |
| **7** | 15mm | 50 | 7857.14 | 200 | 100 | 64 | 58.87 | 1.87 |
| **50mm** | 0.6 in | 50 | 7857.14 | 200 | 100 | 50 | 44.99 | 1.43 |
| **0.37%** | | 50 | 7857.14 | 200 | 100 | 56 | 50.94 | 1.62 |
| | | 50 | 7857.14 | 200 | 100 | 46 | 41.03 | 1.31 |
| **Average** | | 50 | | | | | **48.96** | **1.64** |
| **8** | 16mm | 19 | 7857.14 | 200 | 100 | 50 | 44.99 | 1.43 |
| **19mm** | 0.63 in | 19 | 7857.14 | 200 | 100 | 40 | 35.08 | 1.12 |
| **0.5%** | | 19 | 7857.14 | 200 | 100 | 38 | 33.10 | 1.05 |
| **Average** | | 19 | | | | 58 | **52.92** | **1.20** |
| **9** | 14mm | 25 | 7857.14 | 200 | 100 | 56 | 50.94 | 1.62 |
| **25mm** | 0.55 in | 25 | 7857.14 | 200 | 100 | 54 | 48.96 | 1.56 |
| **0.5%** | | 25 | 7857.14 | 200 | 100 | 50 | 44.99 | 1.43 |
| | | 25 | 7857.14 | 200 | 100 | 60 | 54.90 | 1.75 |
| **Average** | | 25 | | | | | **49.95** | **1.54** |
| **10** | 16mm | 50 | 7857.14 | 200 | 100 | 52 | 46.98 | 1.49 |
| **50mm** | 0.63 in | 50 | 7857.14 | 200 | 100 | 50 | 44.99 | 1.43 |
| **0.5%** | | 50 | 7857.14 | 200 | 100 | 58 | 52.92 | 1.68 |
| | | 50 | 7857.14 | 200 | 100 | 58 | 52.92 | 1.68 |
| **Average** | | 50 | | | | | **49.45** | **1.54** |
| **1** | 150mm | 0 | 7857.14 | 200 | 100 | 50 | 48.95 | 1.56 |
| | 6 in | 0 | 7857.14 | 200 | 100 | 54 | 52.83 | 1.68 |
| | | 0 | 7857.14 | 200 | 100 | 50 | 48.95 | 1.56 |
| **Average** | | | | | | | **50.24** | **1.60** |

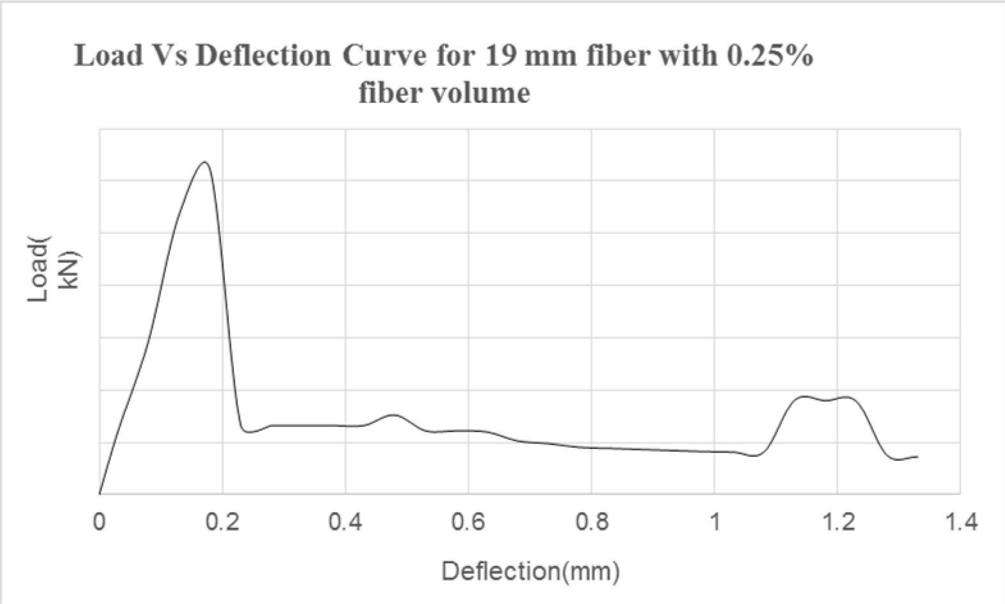
**Table A.8** Flexural Strength Test Result

| Fiber Length (mm) | Fiber Percentage | deflection (mm) | load(KN) | L | b | d | R=PL/bd² | Average |
|---|---|---|---|---|---|---|---|---|
| 19 | 0.25 | 0.35 | 6.23 | 229 | 75 | 75 | 3.38 | |
| 19 | 0.25 | 0.6 | 7.77 | 229 | 75 | 75 | 4.22 | **2.99** |
| 19 | 0.25 | 0.6 | 2.5 | 229 | 75 | 75 | 1.36 | |
| 25 | 0.25 | 0.75 | 6.42 | 229 | 75 | 75 | 3.48 | |
| 25 | 0.25 | 0.35 | 6.8 | 229 | 75 | 75 | 3.69 | **3.56** |
| 25 | 0.25 | 0.95 | 6.47 | 229 | 75 | 75 | 3.51 | |
| 50 | 0.25 | 0.35 | 6.9 | 229 | 75 | 75 | 3.75 | |
| 50 | 0.25 | 0.25 | 4.33 | 229 | 75 | 75 | 2.35 | **2.78** |
| 50 | 0.25 | 0.45 | 4.14 | 229 | 75 | 75 | 2.25 | |
| 19 | 0.37 | 0.3 | 6.7 | 229 | 75 | 75 | 3.64 | |
| 19 | 0.37 | 0.25 | 2.76 | 229 | 75 | 75 | 1.50 | **2.76** |
| 19 | 0.37 | 0.45 | 5.79 | 229 | 75 | 75 | 3.14 | |
| 25 | 0.37 | 0.25 | 5.71 | 229 | 75 | 75 | 3.10 | |
| 25 | 0.37 | 0.3 | 5.66 | 229 | 75 | 75 | 3.07 | **2.79** |
| 25 | 0.37 | 0.35 | 4.06 | 229 | 75 | 75 | 2.20 | |
| 50 | 0.37 | 0.25 | 5.71 | 229 | 75 | 75 | 3.10 | |
| 50 | 0.37 | 0.4 | 5.77 | 229 | 75 | 75 | 3.13 | **2.76** |
| 50 | 0.37 | 0.4 | 3.76 | 229 | 75 | 75 | 2.04 | |
| 19 | 0.5 | 0.85 | 6.19 | 229 | 75 | 75 | 3.36 | |
| 19 | 0.5 | 0.7 | 3.69 | 229 | 75 | 75 | 2.00 | **2.61** |
| 19 | 0.5 | 0.3 | 4.57 | 229 | 75 | 75 | 2.48 | |
| 25 | 0.5 | 0.3 | 4.32 | 229 | 75 | 75 | 2.34 | |
| 25 | 0.5 | 0.45 | 5.63 | 229 | 75 | 75 | 3.06 | **2.86** |
| 25 | 0.5 | 0.45 | 5.83 | 229 | 75 | 75 | 3.16 | |
| 50 | 0.5 | 0.35 | 5.41 | 229 | 75 | 75 | 2.94 | |
| 50 | 0.5 | 0.35 | 7.34 | 229 | 75 | 75 | 3.98 | **3.49** |

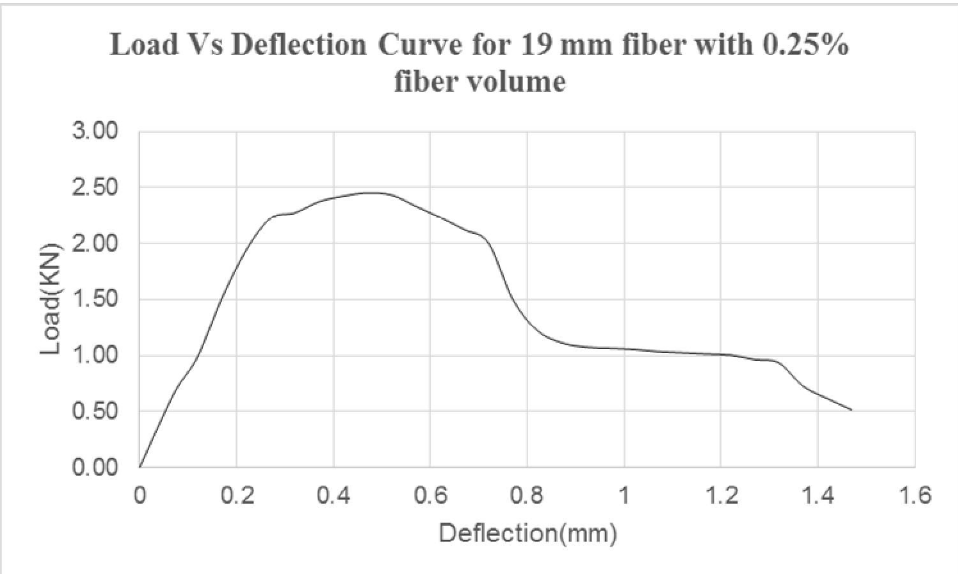
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 50 | 0.5 | 0.55 | 6.53 | 229 | 75 | 75 | 3.54 | |
| 0 | 0 | 0.35 | 5.04 | 229 | 75 | 75 | 2.74 | |
| 0 | 0 | 0.35 | 6.73 | 229 | 75 | 75 | 3.65 | **2.98** |
| 0 | 0 | 0.55 | 4.72 | 229 | 75 | 75 | 2.56 | |

**Table A.9** Load Deflection curve:

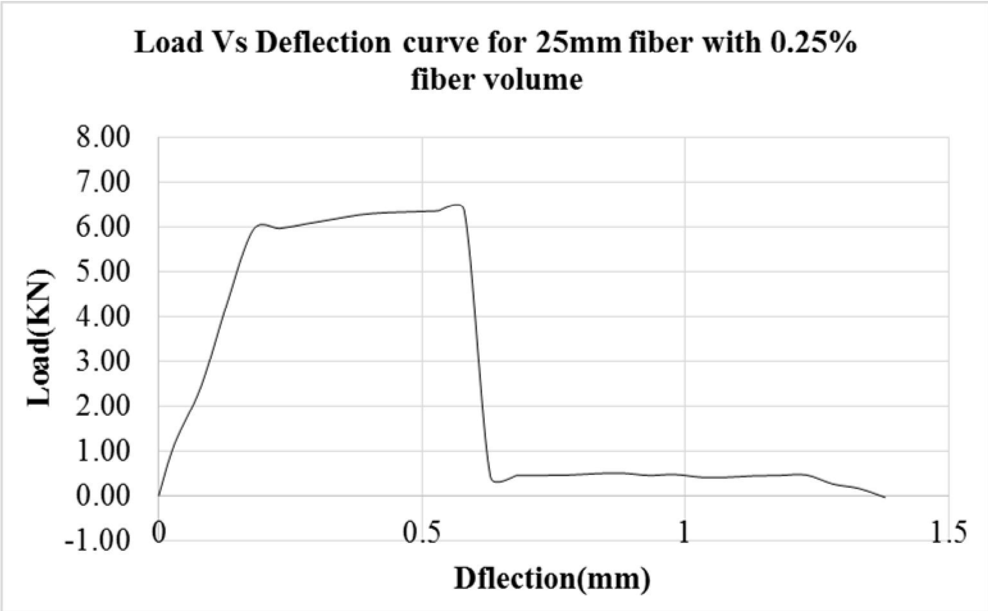
**Sample 1 for Mix 2**



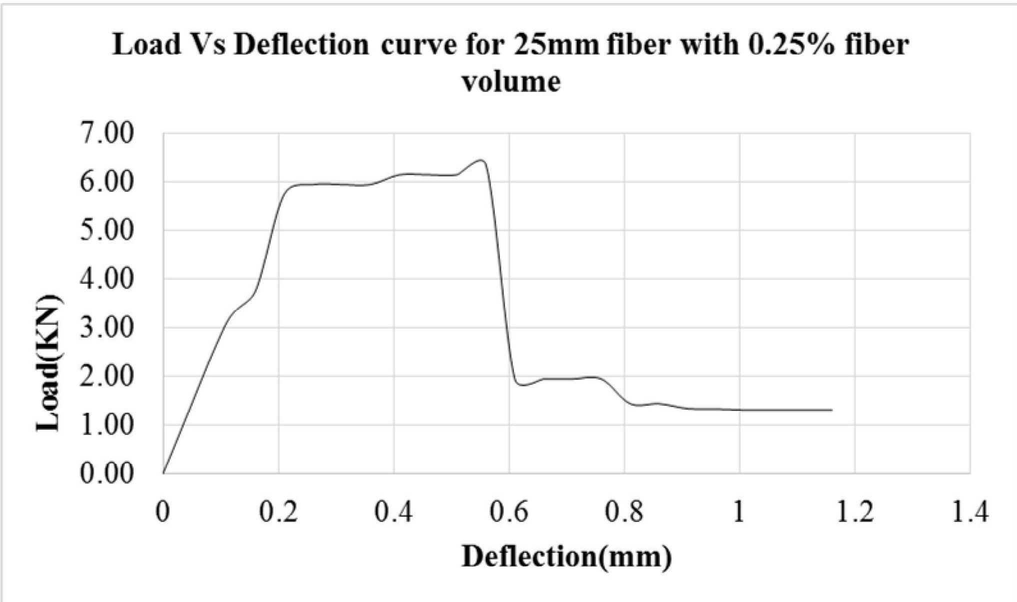

**Sample 3 for Mix 2**



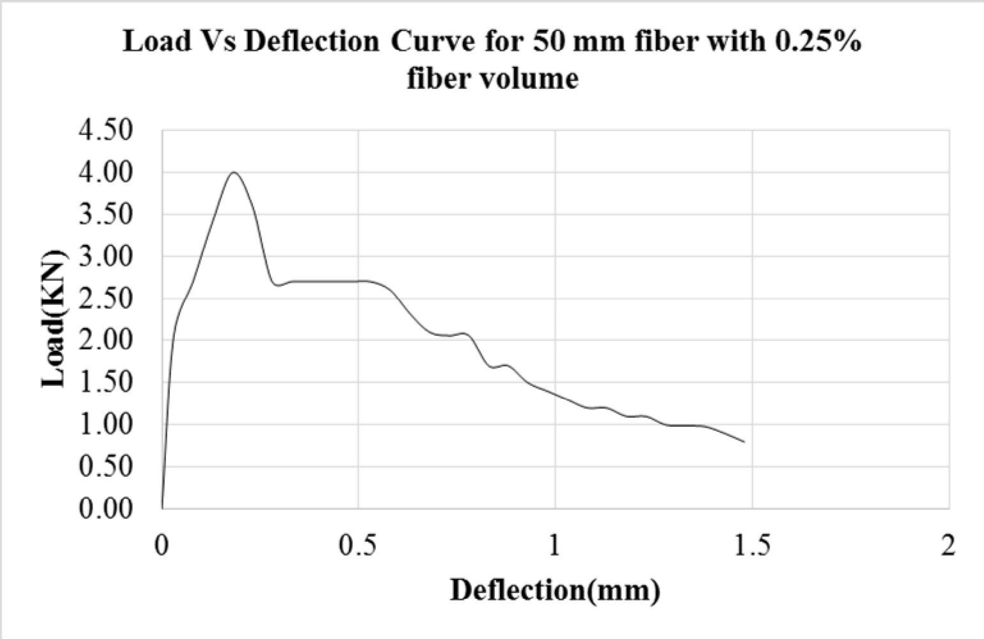
**Sample 1 for Mix 3**



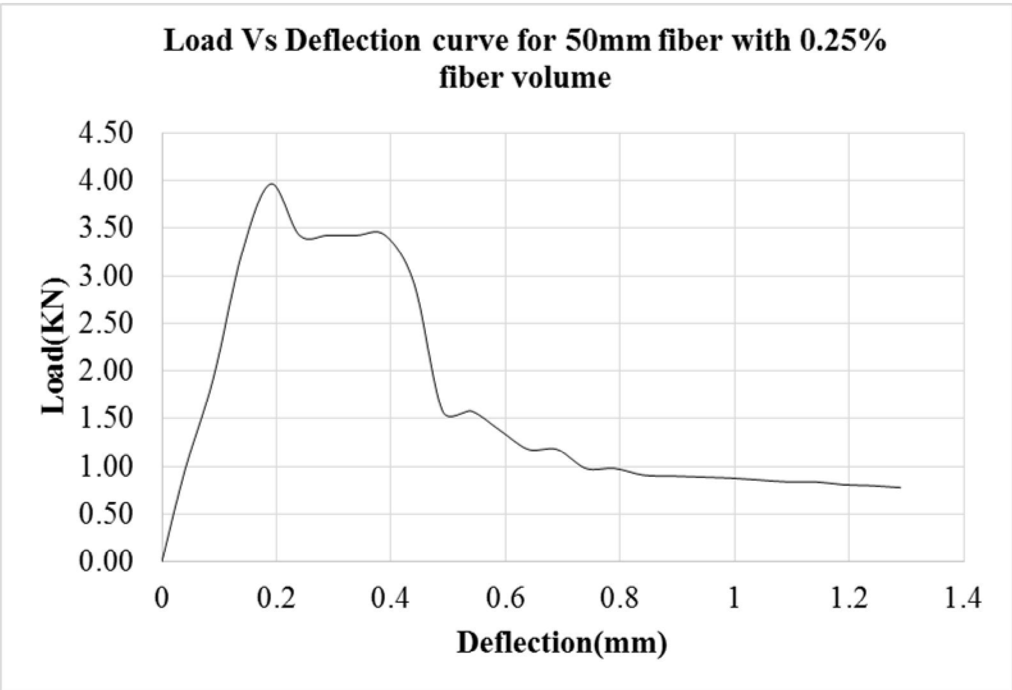

**Sample 3 for Mix 3**



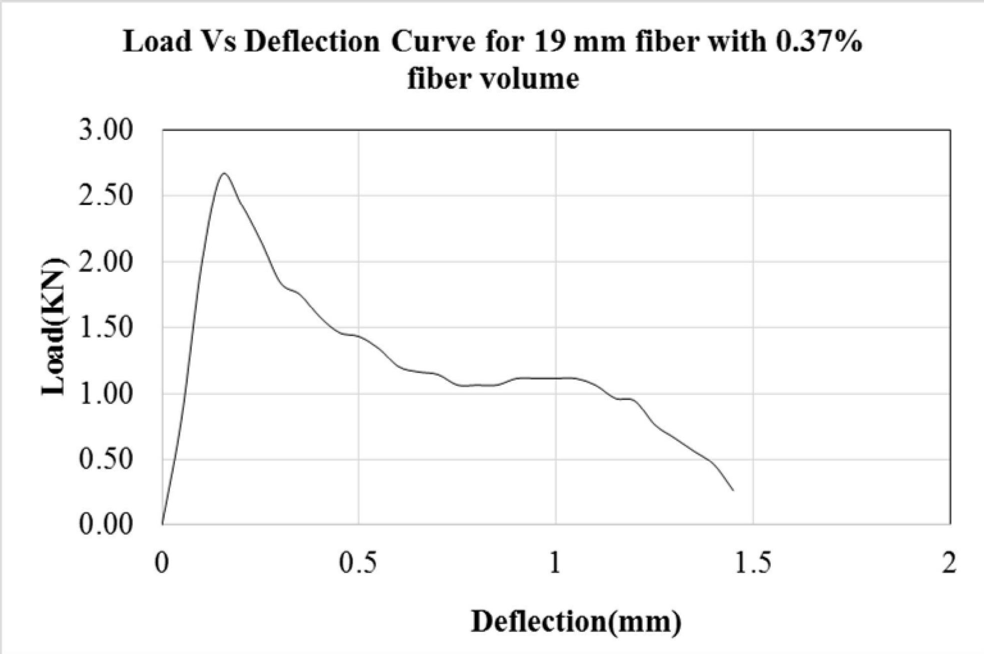
**Sample 2 for Mix 4**



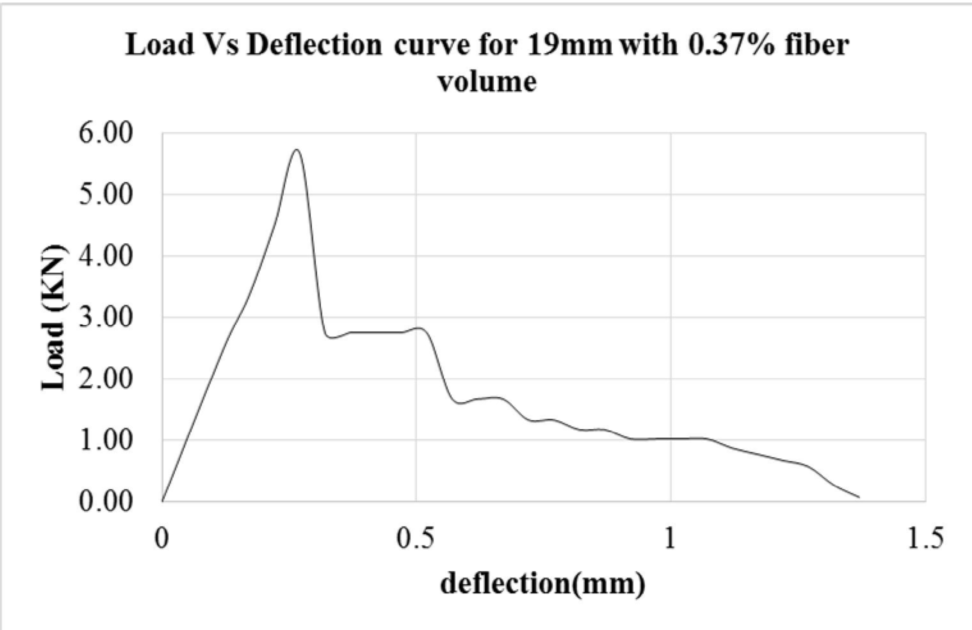

**Sample 3 for Mix 4**



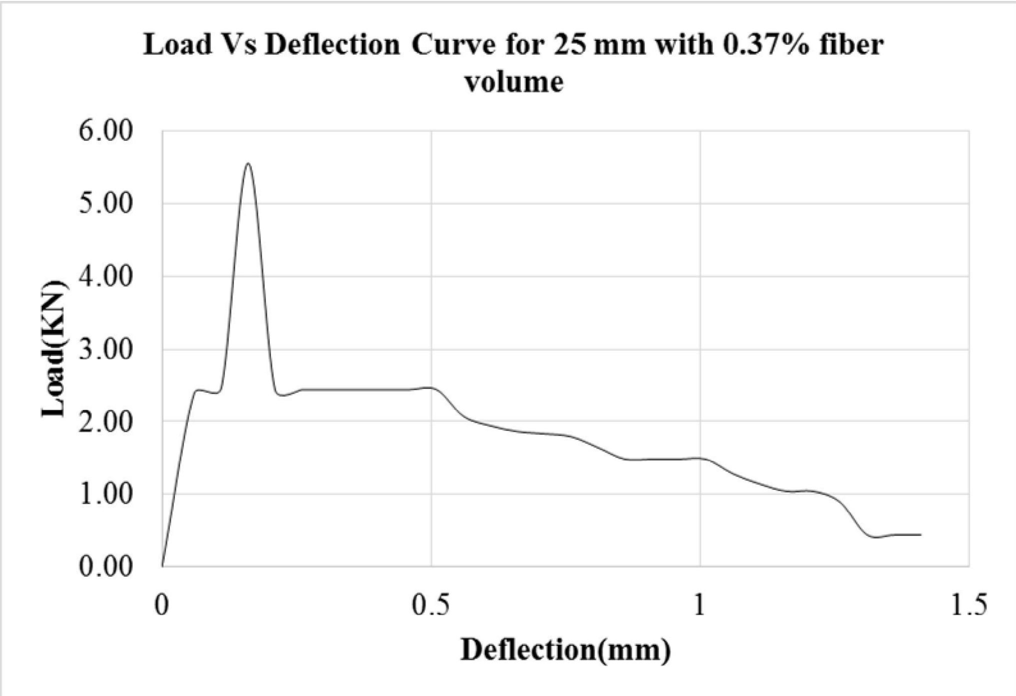
**Sample 2 for Mix 5**



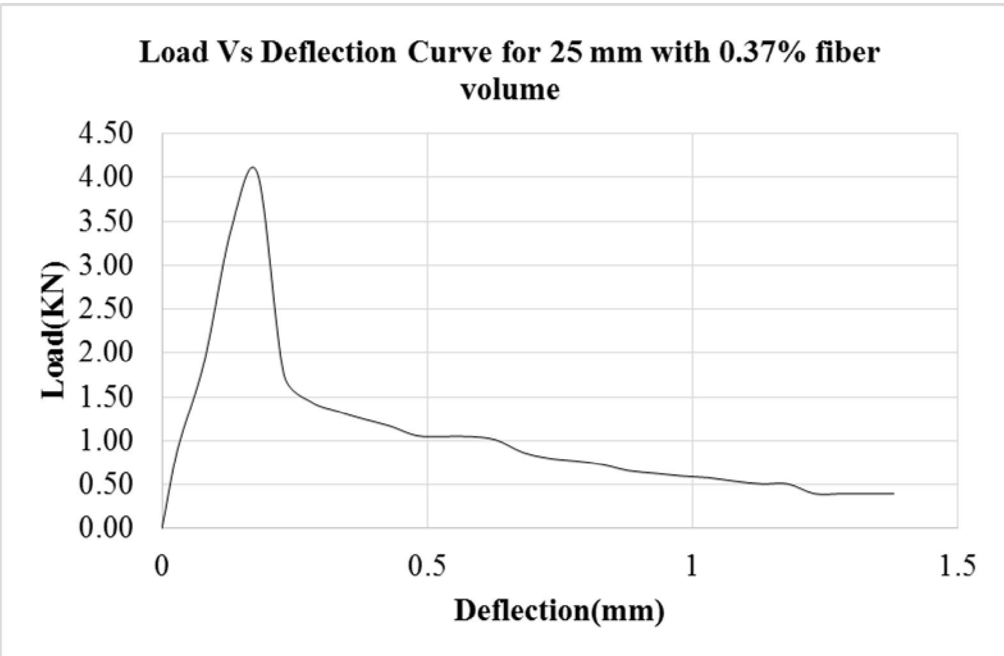

**Sample 3 for Mix 5**



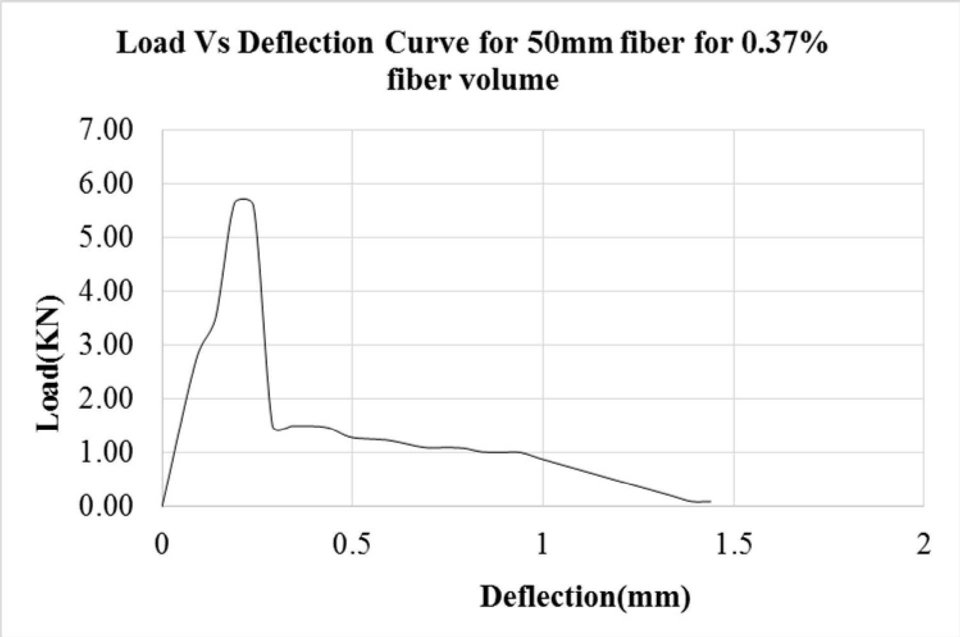
**Sample 2 for Mix 6**



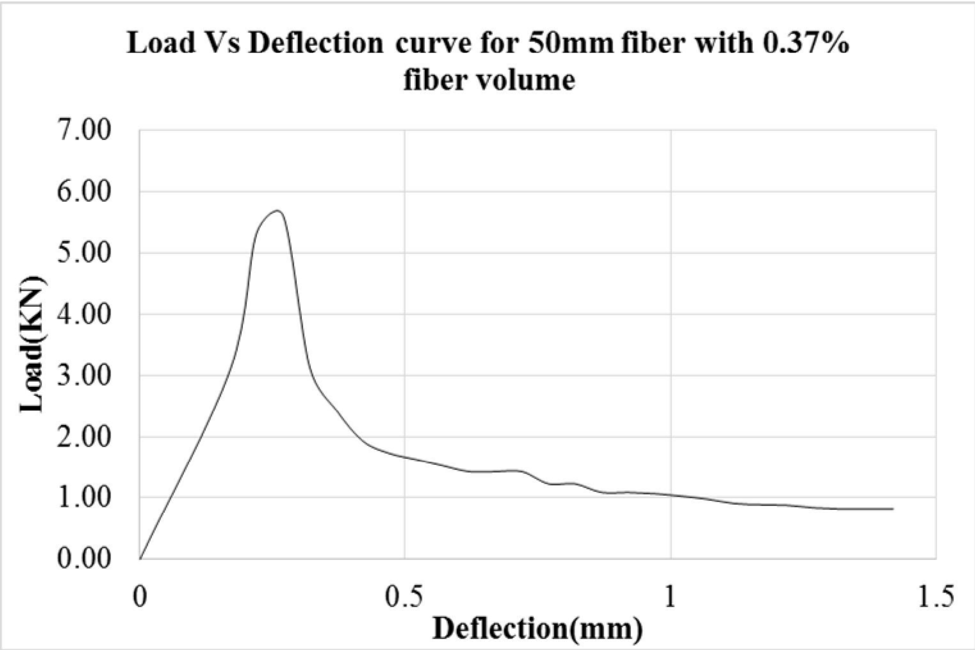

**Sample 3 for Mix 6**



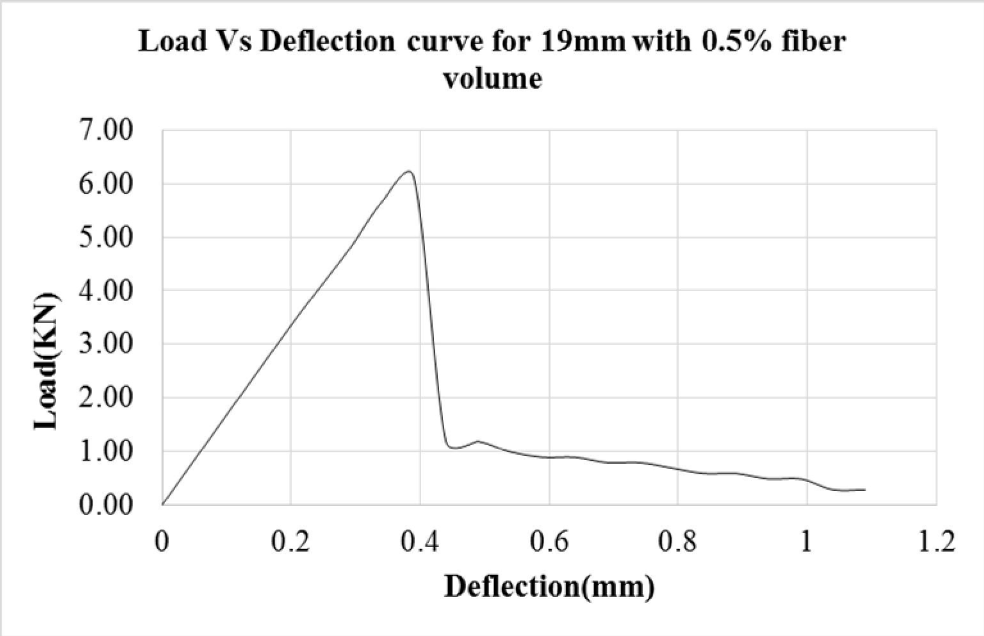
**Sample 1 for Mix 7**



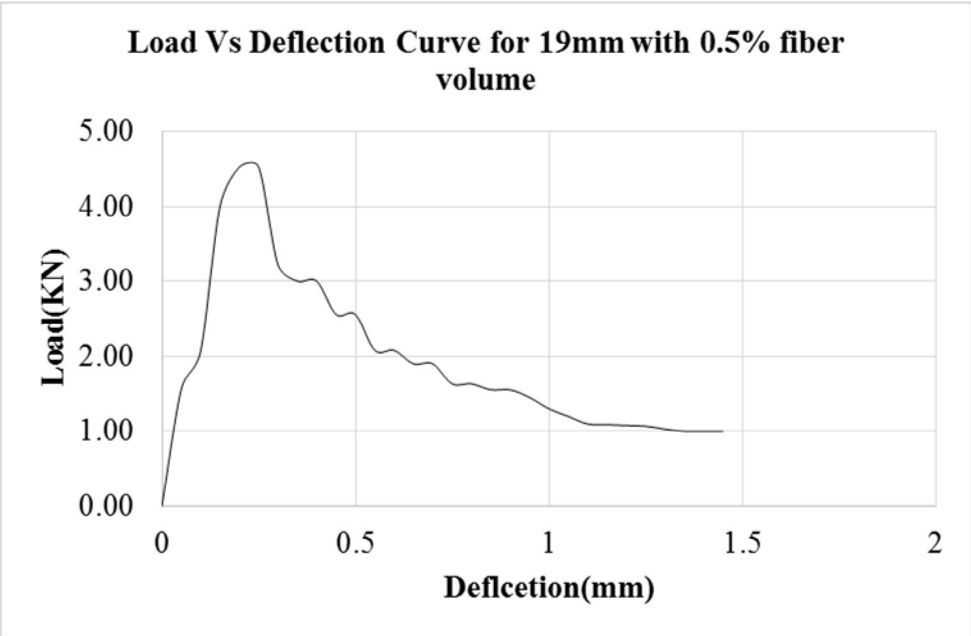

**Sample 2 for Mix 7**



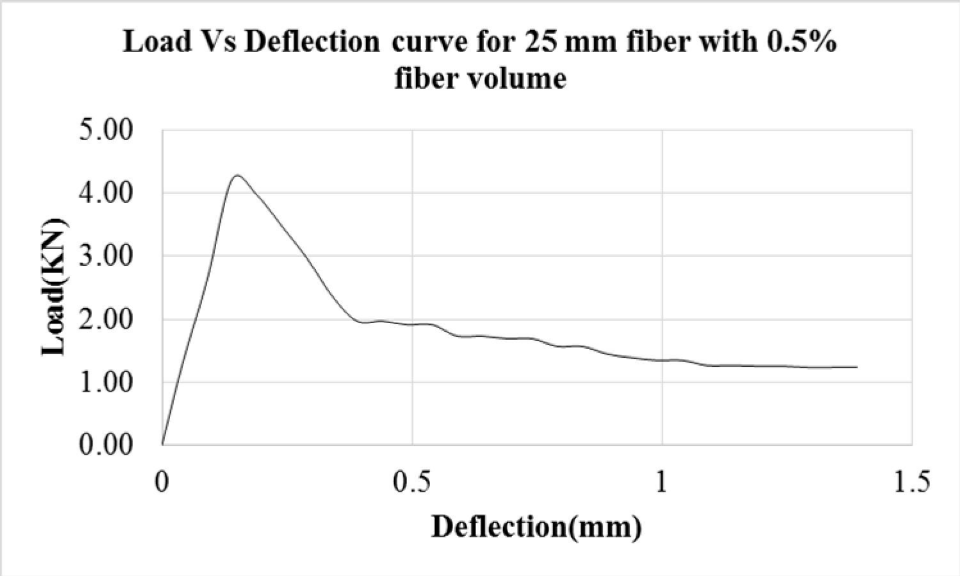
**Sample 1 for Mix 8**



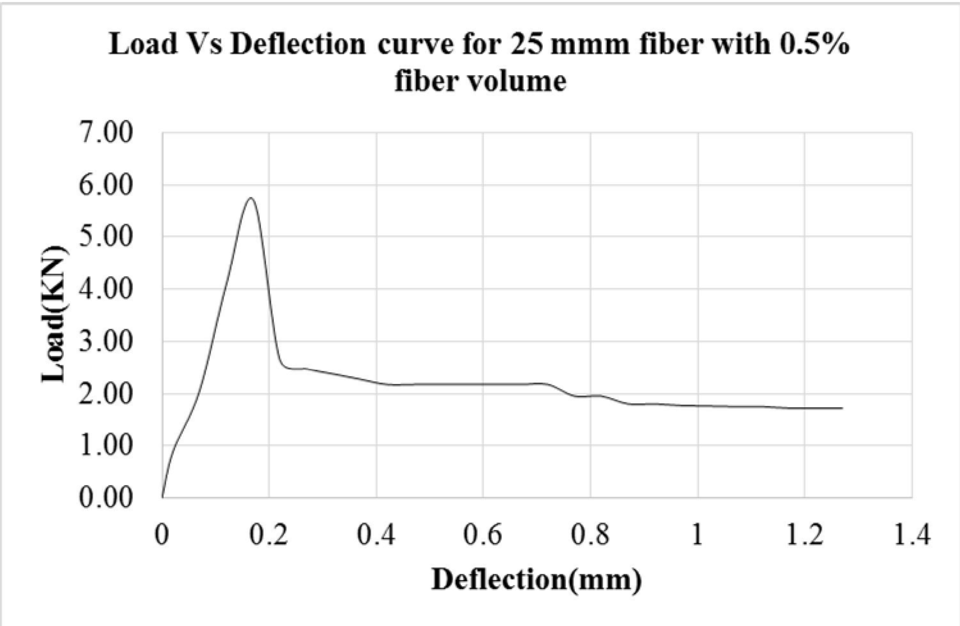

**Sample 3 for Mix 8**



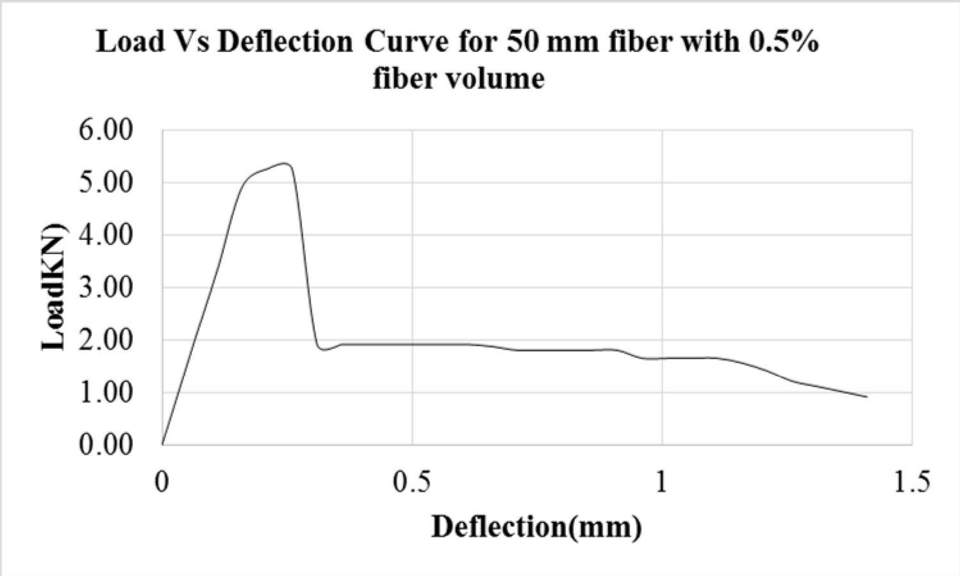
**Sample 1 for Mix 9**



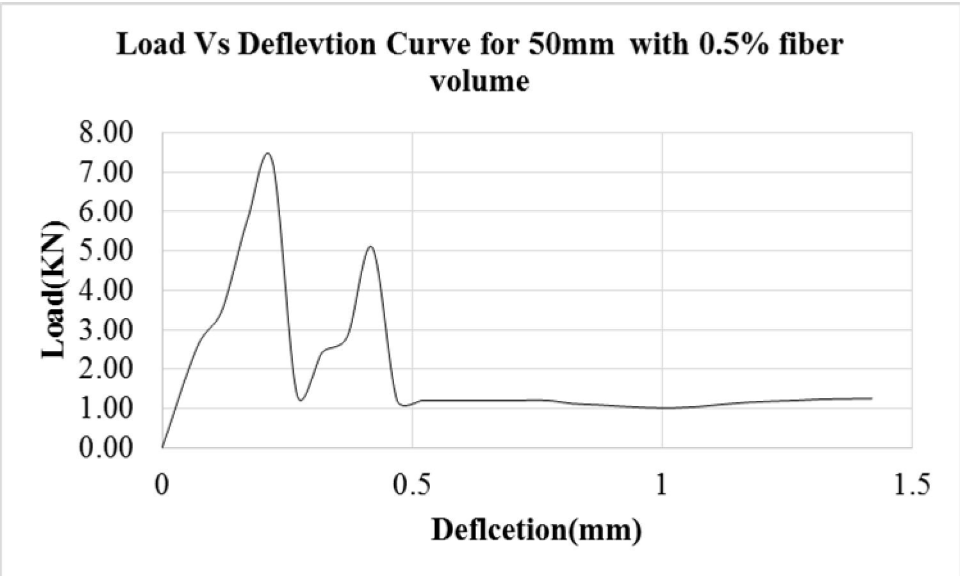

**Sample 3 for Mix 9**



**Sample 1 for Mix 10**




**Sample 2 for Mix 10**



**Sample 2 for Mix 1**