EXPERIMENTAL INVESTIGATION OF UTILIZING STEEL FIBER AS CONCRETE REINFORCEMENT IN BRIDGE DECKS

by

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Abstract

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Research on utilizing steel fiber vs concrete reinforcement in bridge deck to replace more traditional reinforcing bars is sparse, therefore a research into this topic is interesting to identity opportunities for speeding up of construction by avoiding laying and tying reinforcement and verifying clear cover to reinforcing bars which is one of the most time-consuming processes involved in construction. This study investigates the efforts of steel fiber on the bridge deck from the strength and economical implementation. Four concrete mix design with vary steel fiber dosages of 0.0%, 0.5%, 1.0%, and 1.5% used in this study. The physical properties of steel fiber reinforced concrete were calculated through various tests at the Civil Engineering Laboratory Building. In total, 12-cylinder specimens of 4-inch diameter and 8-inch height, 12-cylinder specimens of 6-inch diameter and 12-inch height, 12- beam specimens of 6x6x20 inch and 12-slabs 45x20x3.5 inch were produced and tested after 28 days of curing. The specimens were tested for their compression, modules of rapture, flexural behavior as well as the split tensile test.

The experiments revealed that the increase in the dosage of steel fiber fraction increases the compressive strength of the concrete by 17.4%, 23.5%, and 19.6% respectively for normal weight concrete without steel fiber. The breakout strength of concrete in tension increased by 21.6%, 33.6%and 54.8% for 0.5%, 1% and 1.5% volume fraction of steel fiber in concrete respectively. It is also found that adding steel fiber improves the ductility of slabs specimens behavior, the area under the load-deflection

curves increases compare with normal concrete. Also adding steel fiber to the concrete matrix decreases the crack width and preventing the sudden collapse as in normal concrete. The cost analysis showed that utilizing steel fiber as concrete reinforcement in bridge decks improved the opportunity for economical construction, speeding up construction, more corrosion resistant options over the conventional reinforcing bars as corrosion of reinforcing steel in the most common path to failure of the bridge deck.

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CHAPTER ONE

INTRODUCTION

Plain concrete slabs are known to have low strength and low strain capacity, however, these structural properties could be improved by the addition of fibers, allowing the thickness of the layer to be reduced. There are different fibers that are used in the concrete namely glass fiber, steel fiber, synthetic fibers, and natural fibers. The improvement in the material behavior of the fiber-reinforced concrete depends on the dosage and characteristics of the used fibers.

The main important effect of fibers as reinforcement is to influence and control the tensile cracking of concrete. Yet, the fiber-reinforced concrete is known to have a considerable impact on the slab cost owing to reduced thickness needs, prolonged useful life and reduction in maintenance costs.

Amongst the fibers mentioned, steel fibers are the most researched and more practical. Steel fiber reinforced concrete is a type of concrete that contains randomly oriented discrete steel fibers. The main aim of the addition of steel fibers to concrete is to control crack widening and crack propagation after the concrete matrix has cracked. By control of the cracking the mechanical properties of the composite material as a result will be improved significantly.

The addition of randomly distributed steel fibers SFRC improves concrete properties, such as static flexural strength, ductility and flexural toughness. SFRC has been largely used in airport pavements due to the extreme and damaging loads acting on the pavement. (Johnston, 1982) Some other examples of the structural and non-structural applications of SFRC are hydraulic structures, airport and highway paving and overlays, industrial floors, refractory concrete, bridge decks, concrete linings and coverings, and thin-shell structures. The elasticity modulus of steel fibers is as high as 30 Ksi providing very high tensile strength with minimal deformation. A large number of fibers used for concrete members enables a uniform distribution of fibers through the compound, thereby creating a composite material possessing homogeneous mechanical behavior. They provide a cohesive mix, creating a three-dimensional reinforced net system (Tokgoz, 2012). The important characteristic in FRC material is the bond between the fibers and the matrix. Fibers are designed in different geometries to increase the bond and interfacial friction between aggregates and cement paste. The forces induced in a SFRC when subjected to load are redistributed within the concrete, which restrains the formation and extension of cracks. The result is a more ductile reinforced concrete that is able to maintain a residual capacity in the post-cracking phase (Tokgoz, 2012). Thus resulting in an increased load-carrying capacity, improved shear and bending strength of concrete, superior flexural ductility, toughness, and fatigue endurance. In addition, SFRC has a higher life cycle and the maintenance requirements are reduced resulting in lower costs. (Elsaigh, 2001) Another advantage of the SFRC is that at an adequate volume fraction they can replace conventional steel reinforcement when designed properly and it reduces the construction time since the steel fibers are added directly as one of the concrete mix constituents, hence no steel fixing or adjustment is required. (Association of Concrete Industrial Flooring Contractors,1999)

The research on the SFRC members and slabs under static loads showed that they can provide equivalent performance compared to conventionally reinforced concrete slabs when equivalent amounts of reinforcement are used. (Bischoff et al., 2003)

Researchers during recent years have stated that steel fibers significantly improve the impact resistance of concrete material (Nataraja, 2005) making it a suitable material for structures subjected to impact loads. Overall, the above factors suggest that SFRC is potentially the most beneficial type of material from engineering and economical perspective to be considered for structural slabs subjected to high loads. The aim of this study is explained below.

Steel fiber reinforced concrete (SFRC) is a composite material similar to normal concrete but with fibers as part of mixture constituent. It is made of cement, fine aggregate, coarse aggregate and other components or admixtures that can commonly be used in concrete with the dispersion of discrete small steel fibers. It has been used in concrete since the early seventies and for different applications like a slab on ground, pavements, and bridge decks. Fibers have different geometries also they vary in dimensions. The length of fibers could vary from 10mm to 75mm and the diameter from 0.2mm to 1.3mm. the Steel fiber used in this experiment is DRAMIX 13/0.2 illustrated in Figure 1-1.

Figure 1- 1. The shape of Steel Fiber DRAMIX 13/0.2

The addition of fibers to concrete has shown improvement in concrete flexural strength, toughness, ductility, impact resistance, fatigue strength and resistance to cracking. In addition, the deformation at peak stress is much greater than plain mortar. Fibers help to alter the behavior of concrete after the initiation of cracking. The crack-bridging behavior of fibers is what improves the ductility of the matrix.

The main advantageous property of SFRC is its superior resistance to cracking and crack propagation. The fibers are able to hold the matrix together even after extensive cracking due to its bridging effect. SFRC has the ability to arrest cracks; therefore, fiber composites retain increased extensibility and tensile strength, both at first crack and at ultimate stress. The net result is the fiber composite will have a marked post-cracking behavior and ductility which is unremarked in ordinary concrete in which the tension post crack is negligible. The material is therefore transformed from a brittle to a ductile type of material which would increase substantially the energy absorption characteristics of the fiber composite and its ability to withstand repeating applied load such as shock or impact loads.

1.1 Objectives

The main objective of this study is to investigate experimentally the flexural strength performance of Steel Fibers Reinforced concrete (SFRC) slab compared with a conventionally reinforced concrete slab. Utilizing steel fibers to replace more traditional reinforcing could be a significant step in speeding up bride construction. This includes investigating whether SFR slab has the capability to outperform RC slab and whether SFRC slab can be used as an alternative to RC slab. To meet this objective, four concrete design mixtures were created with different dosage rates. Specimens of four design mixtures were tested to their physical properties, twelve slabs were tested with and without steel fibers. Table 1-1 shows the formwork of this research.

Table 1- 1. The framework of the Research Study

CONCENTRATED LOAD INVESTIGATION OF STEEL FIBER REINFORCED CONCRETE SLABS		
Concrete Slabs Specimens	12 Slab 45”x20”x3.5”	3 Reinforced concrete Slabs with transverse reinforcement (RC)
		3 Steel Fiber Reinforced Concrete Slabs with V_f=0.5% (SFRC 0.5%)
		3 Steel Fiber Reinforced Concrete Slabs with V_f=1% (SFRC 1%)
		3 Steel Fiber Reinforced Concrete Slabs with V_f=1.5% (SFRC 1.5%)
Testing Specimens	12 Cylinders for compressive strength test 4”x8”	3 Cylinders with V_f=0% (Plain Concrete)
		3 Cylinders with V_f=0.5% (SFRC 0.5%)
		3 Cylinders with V_f=1% (SFRC 1%)
		3 Cylinders with V_f=1.5% (SFRC 1.5%)
	12 Cylinders for tensile strength test 6”x12”	3 Cylinders with V_f=0% (Plain Concrete)
		3 Cylinders with V_f=0.5% (SFRC 0.5%)
		3 Cylinders with V_f=1% (SFRC 1%)
		3 Cylinders with V_f=1.5% (SFRC 1.5%)
	12 beams for flexure strength test 6”x6”x20”	3 Beams with V_f=0% (Plain Concrete)
		3 Beams with V_f=0.5% (SFRC 0.5%)
		3 Beams with V_f=1% (SFRC 1%)
		3 Beams with V_f=1.5% (SFRC 1.5%)

1.2 Research Contribution

Research on utilizing steel fiber as concrete reinforcement in bridge decks to replace more conventional reinforcing bars is sparse, therefore a research into this topic is interesting to identify opportunity for speeding up construction by avoiding laying and tying reinforcement and verifying clear cover to reinforcing bars which is one of the most time-consuming processes involved in construction, steel fiber have been shown to offer more corrosion-resistant option over conventional reinforcing bars. Also, using steel fiber could improve the opportunity for more economical implementation

1.3 Outline for Dissertation

This research is organized into the seven following chapters respectively:

Chapter 1 – Introduction: This chapter explains the nature of concrete in tension and why fibers have been introduced to the concrete mixture.

Chapter 2 – Literature Review: This chapter presents the background of fiber reinforced concrete.

Chapter 3 – Experimental Program: This chapter presents design and fabrication of large-slab specimens, test set-up and procedure, curing of all the specimens in this study.

Chapter 4 – Experimental Results and Analysis: This chapter presents the failure mode and mechanism of slabs, load-deflection response.

Chapter 5 – Cost analysis: This chapter compares the cost of conventional concrete and Steel Fiber concrete.

Chapter 6 – Summary and Conclusions: The findings of this research are summarized and the conclusions are presented.

CHAPTER TWO

LITERATURE REVIEW

This chapter summarizes the work that has been conducted to date by other researchers on the steel fiber reinforced concrete and its structural performance focusing on concentrated load on the concrete slab

2.1 Steel fiber reinforced concrete and the effect of fiber reinforcement

There are several types of steel fibers that have been used in the past. Apart from other mix constituents, there are four important features of steel fiber that are found to have an effect on the properties of the composite, namely: type (i.e. shape), volume fraction, aspect ratio (the ratio of length to the diameter of the steel fiber) and orientation of fibers in the matrix. Recently, optimization of these parameters has been studied to improve the fiber-matrix bond characteristics and to enhance fiber dispensability (Soroushian and Bayasi,1991). It was found that SFRC containing hooked end stainless steel wires has superior physical properties compared to straight fibers. This was attributed to the improved anchorage provided and higher effective aspect ratio than that of the equivalent length of the straight fiber (Ramakrishnan,1985)

Laboratory scale tests conducted by many agencies and researchers indicate that the addition of steel fibers to concrete significantly increases the total energy absorbed prior to complete separation of the specimen (Johnston, 1985). The presence of steel fibers was also found to improve fatigue properties, flexural strength, shear strength and impact strength (Johnston and Zemp, 1991, Morgan and Mowat, 1984). The improvement of the mechanical properties of SFRC is attributed to the crack controlling mechanism. Bekaert Company suggested that there are two mechanisms that play a role in reducing the intensity of stress in the vicinity of the crack. These mechanisms are:

- The higher load resistance of steel fibers near the crack tip due to their higher young's modulus compares to the surrounding concrete.
- Steel fibers bridge the crack and transmit some of the load across the crack.

The ability of steel fibers to resist crack propagation is primarily dependent on the bond between the concrete and fibers as well as fiber distribution (i.e. spacing and orientation). The bond between the concrete and fibers is the mechanism whereby the stress is transferred from the concrete matrix to the steel fibers.

Steel fiber reinforced concrete (SFRC) appears stiffer (lower slump) compared with conventional concrete without fibers even when the workability (judged by any test using vibration) is the same (Johnston, 2001). Steel fibers tend to interlock together. Vibration is encouraged to increase the density, to decrease the air void content and to improve the bond with reinforcement bars. In spite of a stiff appearance, a well-adjusted fiber mixture can be pumped (ACI 544). "The size of the fibers relative to that of the aggregates determines their distribution. It is recommended to choose fibers not shorter than the maximum aggregate size to be effective in the hardened state. Usually, the fiber length is 2-4 times that of the maximum aggregate size." (Johnston, 1996 and Coetze, 1990) It is recommended to reduce the volume of coarse aggregates by 10% compared with plain concrete to facilitate pumping. The initial slump of plain concrete should be 2-3 inches more than the desired final slump; to obtain the desirable workability, superplasticizer should be added to the mixture rather than excess water (Johnston, 2001).

The size, the shape and the content of the coarse aggregates as well as the geometry and the volume fraction of steel fibers affect the workability of concrete. At a given fiber diameter and volume fraction, the compact ability is linearly related to the aspect ratio (l_f/d_f) of the fibers. The relative fiber to coarse aggregate volume and the 'balling up' phenomenon govern the maximum possible content of steel fibers. The performance of different types of steel fibers can be characterized by the following three parameters (Figure 2-1):

- The aspect ratio (L/D)
- The tensile strength
- The bond between fibers and the matrix (dependent on fiber type)

Steel fibers, compared to traditional fabric reinforcement, have a tensile strength typically 2-3 times greater and a significantly greater surface area to develop a bond with the concrete matrix (ACIFC, 1999). These parameters will affect the performance of steel fiber in concrete as well as the interaction between fibers and concrete matrix. For example, a steel fiber with high tensile strength which has a bad bond in concrete most likely will not perform as the steel tensile strength could permit. The combination of these three parameters will give a toughness value at a certain dosage. However, for different dosages (volume fraction of fibers in concrete), the toughness value for a specific steel fiber will vary.

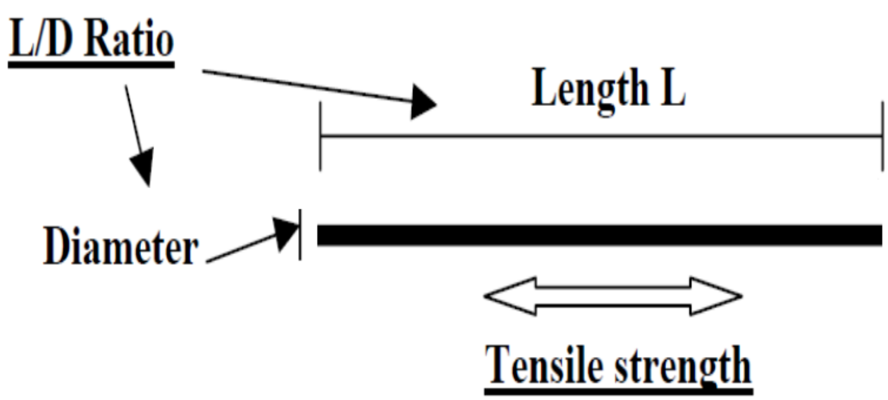


Figure 2- 1. The three important parameters of a steel fiber

Steel fiber concrete is mainly used for industrial floors and pavements applications. The stresses induced on a concrete slab are complex depending on the load that is applied to the member. In addition, there is a number of stresses which are difficult to measure, arising from a number of causes such as shrinkage and thermal effects, sharp turns from forklift trucks, and impact loads (Knapton, 2003).

Regarding the economic aspect, the main energy component of concrete slabs is the energy used for manufacturing cement and steel reinforcement. Although current material and energy prices already indicate that concrete slabs can be more cost-effective but the energy efficiency and further reduction in the total structural element dimensions could be obtained in the production of concrete slabs.

2.2 Mechanical properties of SFRC

Fibers are known to enhance the mechanical performance of concrete with regard to its tensile and shear strength, toughness, ductility, durability, fatigue, and shrinkage resistance (Gopalaratnam, 1991). The following are an overview of these characteristics.

2.2.1 Compressive strength

The effect of steel fibers on the concrete compressive strength is much debated in literature. It has been found by many researchers (e.g. Winterberg, 1998) that the inclusion of steel fiber in concrete increases its compressive strength value. This increase ranges between marginal and significant increases in compressive strength. The effect of fibers on the compressive strength is attributed to two stabilizing actions. First, a larger amount of pores in the concrete admixture, which decreases the compressive strength and second factor, would be the fiber bridging effect across the micro-cracks, which results in increased compressive strength. The concrete compressive strength of the material depends on the magnitude of these effects and it may change. The effect of steel fibers on the compressive strength, therefore, depends on the concrete mixture, the kind and amount of steel fibers and the manufacturing process. Despite the increase in the compressive strength of the concrete, it is unclear whether the addition of steel fibers influences the rotation capacity of plastic hinges. It is generally agreed that steel fibers enhance the ductility of concrete in compression (Grübl et al., 2001). Steel fibers, as well as stirrup reinforcement, increase the confining capacity of concrete. This is reflected in the stress-strain relationship of concrete with a more ductile post-peak behavior. For steel fibers, the orientation of the fibers needs to be perpendicular to the compressive loading in order to be effective. It is therefore expected that the addition of steel fibers increases the rotation capacity of plastic hinges in case of concrete failure as a result of the increase of concrete ductility in compression.

2.2.2 Flexural strength

The low flexural strength of plain concrete could be overcome and improved by the addition of steel fibers. A review of the literature on SFRC indicates that in general the addition of short, randomly-oriented steel fibers increases the flexural strength of plain concrete by about 1.5 to 3.0 times, taking into account the type and content of the steel fibers. Roesler (2003) used a different type of fibers and analyzed the flexural resistance of beams and large scale slabs on ground and concluded that discrete fibers contribute to the flexural strength of concrete slabs beyond what is predicted by beam tests. The slab flexural strength was 1.8 to 2.2 times greater than the beam flexural strength for the fiber reinforced concrete and 1.4 times greater for the plain concrete. The flexural cracking load of fiber reinforced concrete slab was 25 to 55 percent higher than the plain concrete slab. The addition of steel fibers increased the “flexural cracking load relative to plain concrete slabs by 30 percent. The crimped steel fibers at 2.4 lb/ft^3 showed the greatest increase to the flexural strength (55 %) which was attributed to its higher concrete flexural strength" with the inclusion of steel fibers.

2.2.3 Ductility

FRC is known to provide higher ductility than ordinary concrete. Ductility is the ability of concrete to undergo maximum plastic deformation before the collapse. It is considered a good warning indicator before failure. Mahalingam et al. (2013) study the ductility behavior of steel fiber on concrete beams. They used steel fiber content of 0.5, 1 and 1.5 % by volume. They concluded that the ultimate load-carrying capacity of concrete beams was improved by 14, 20 and 32%, respectively, compared to the conventional reinforced concrete beam. The ductility could also be increased using fibers (Roesler, et al., 2006, Sounthararajan and Sivakumar, 2013). However, ductility in concrete beams could only be achieved with a higher dosage of fiber added at approximately 5% but the effect of fibers on early-age shrinkage is not well established at this amount. Considering that only a low dosage amount of fiber is needed, ductility would have very little effect on early-age shrinkage.

The Modulus of Rupture (MOR) beam tests conducted by Tadepalli et al. (2010) revealed that "the non-fibrous beams had no ductility. In these beams, once the maximum tensile stress was reached, the beams failed suddenly without any warning." However, for the SFRC, "after the onset of initial crack at the beam bottom, the specimen did not fail suddenly, but it demonstrated considerable residual strength."

2.2.4 Fracture toughness

Fracture toughness measures the energy absorption capacity of material under static or dynamic load. Fracture toughness is used to evaluate the post-cracking behavior for concrete at the deflection at mid-span. Specimen toughness is a measure of the energy absorption capacity of the test specimen and it is related to ductility. In SFRC the amount and type of fibers in the concrete influence this property of the material in different ways. By adding steel fiber in concrete its post-crack behavior or toughness of SFRC is improved, which is considered as one of the main effects of fibers in the concrete matrix. This effect is useful regarding the design of hyperstatic construction such as slab on ground. When the first crack appears, the fibers in concrete start to act and have the ability to absorb and redistribute the loads, hence redistribute the energy, so that the SFRC will still be able to bear loads even after the formation of cracks. In fact, SFRC has a ductile behavior or toughness and therefore, that excess of flexural capacity from the plastic phase (i.e. post crack behavior) can be used for design of structure when deformation is essential and must be controlled such as in the design of slabs or for structures where deformations are important in the design such as underground linings. The higher fracture toughness is the reason for a higher load capacity of SFRC slab on the ground when compared to a conventional concrete slab with the same thickness. Balaguru et al. (1992) studied the effect of fiber length and stated that the length of the fiber did not have a significant effect on the toughness for steel fibers with hooked ends. Tadepalli et al. (2010) studied the effect of different steel fibers at two 0.5% and 1.5% volume fraction of steel fiber and it was concluded that plain concrete did not demonstrate any toughness since it didn't have any residual strength. The mix with short fibers at the dosage of 1.5% had the greatest toughness value. Overall, steel fibers improve the concrete fracture toughness. The improvement depends on the dosage amount but in most cases, the fracture toughness increases with increasing dosage rate. Many literature reports on how toughness is affected by the fiber type, dosage, fiber material properties, and bonding conditions are available in more detail in ACI 544 report and elsewhere.

2.3 Advantages and Disadvantages of Steel Fibers in Concrete

The advantage of using steel fiber can be summarized as follow:

- Produce more ductile concrete with a smaller number of cracking
- Reduction of the influence of shrinkage cracking
- High tensile strength
- High compressive strength
- Higher economically efficient compared to conventional steel solutions and enhance costs with lesser fiber amount
- Reducing scheduled time due to fast installation
- Reduce the permeability in concrete, which ensures the protection of concrete due to the negative effects of moisture
- Easy material handling
- High durability
- Can replace wire mesh in most elevated slabs.

Disadvantage:

- There are problems involved in attaining uniform distribution of fibers and dependable concrete properties
- At aggressive exposure condition the corrosion of the surface could take place, influencing the look of the surface
- The use of SFRC requires more accurate configuration as opposed to normal concrete
- Reduced workability
- Though, as the amount of fibers is increased, the workability of the concrete is influenced. Therefore, special techniques and concrete mixtures are used for steel fibers such as the addition of superplasticizer. Finishing problems may arise if

proper techniques and proportions are not used, with the fibers coming out of the concrete.

2.4 Crack control

Steel fibers effectively limit the extension of micro-cracks which are always present in concrete. In concrete without fibers, tension cannot be transmitted across the crack, that is, once the tensile capacity of the plain concrete is exceeded, the microcrack will extend rapidly resulting in brittle failure. The action of the steel fibers in a concrete slab is to reduce the concentration of stresses near the micro-cracks by:

- Fibers bridging the crack and therefore transmitting some of the load across the crack
- Fibers near the crack tip resisting more loads owing to their higher modulus of elasticity compared to that of the surrounding concrete.

The fiber anchorage will affect on the ductile behavior. If the anchor is too uneven then the fiber will fail in a brittle manner. The anchorage must have the following concepts:

- Allow the fiber to progress to its full potential i.e. reach maximum stress
- start to slip earlier than the fiber breakage to avoid brittle failure
- Absorb energy as the fiber is being pulled out

In the case of floor slabs, a crack is formed where the ultimate stress on the floor is exceeded locally. Steel fibers cause the crack to behave like a hinge, resulting in a redistribution of stresses. Unlike a broken zone in a brittle material, this hinge can still resist stresses depending on the type and dosage used and thus increases the load-bearing capacity of the member.

2.5 Load deflection behavior of SFRC ground slabs

Extensive research has been carried out to investigate the effect of the steel fibers on the load capacity of ground slabs (Kaushik et al. 1989, Beckett, 1990, Falkner and

Teutsch,1993, Elsaigh, 2001, Bischoff et al. 2003, Chen, 2004). In these studies, full scale slab tests were conducted to compare the behavior of centrally loaded SFRC slabs to plain concrete or welded wire fabric reinforced concrete slabs. It was shown that by adding steel fibers to the concrete mix the load-carrying capacity of the ground slabs will increase significantly. Figure 2-2.a and Figure 2-2.b show the load-displacement (P-Δ) responses from two investigations conducted by Chen (2004) and Falkner and Tuetch (1993) respectively. It is prominent that SFRC containing hooked-end steel fibers yields greater load-carrying capacity compared to both plain concrete and SFRC containing mill-cut fibers (straight fibers having a relatively low tensile strength).

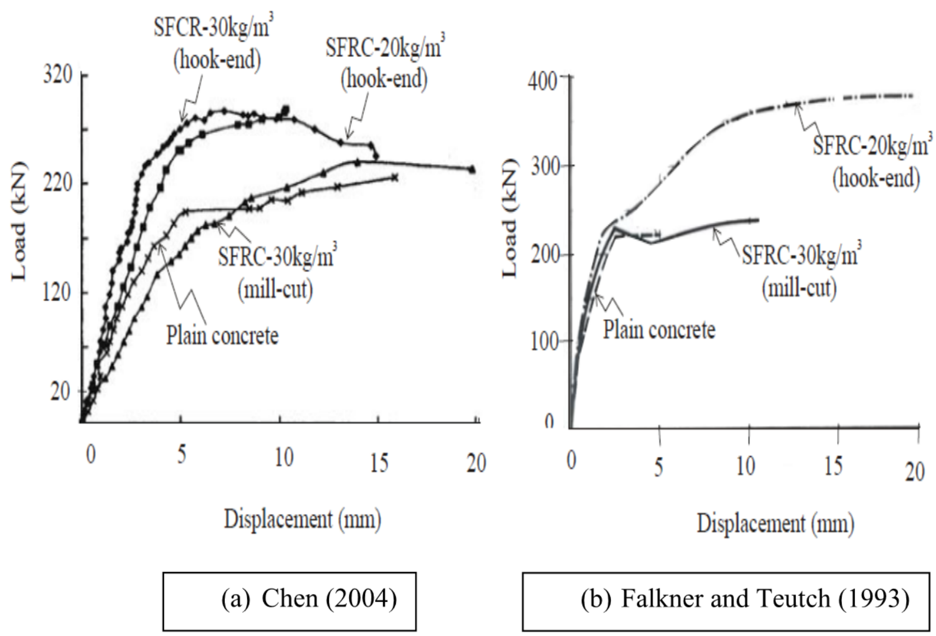


Figure 2- 2. Comparison between SFRC and plain concrete ground slabs

Several explanations for the increased carrying capacity of SFRC ground slab have been suggested. As well as the structural ductility of the statically indeterminate slab, it has been recognized that the post cracking strength of steel fiber reinforced concrete is the reason behind the increased load-carrying capacity of SFRC ground slabs (Kearsley and Elsaigh, 2003).

The result from the static tests on the full-scale ground slabs indicated that an appreciable thickness reduction, depending on steel content, is possible for SFRC ground slabs when compared to counterpart plain concrete slabs. Indeed, it was found that about 16% thickness reduction is possible when (0.9 lb/ft^3) 15kg/m^3 of hooked-end steel fibers were used (Elsaigh, 2001). Bischoff et al. (2003) stated that the thickness reduction is justified by the following

arguments:

1. The post cracking strength of the SFRC allows for redistribution of stresses leading to an increased load carrying capacity and therefore the slab thickness can be reduced.

2. Steel fibers significantly increase the flexural capacity and therefore the slab thickness can be reduced.

3. Steel fibers will improve the fatigue resistance of the concrete and can lead to thinner slabs as the allowable stress is increased. SFRC is deemed to be a superior material for concrete roads due to its improved mechanical properties compared to plain concrete. Although support provided by the subgrade means that bending stress in slabs is generally low, the flexural capacity of the slab remains an important aspect to be considered. This is especially crucial when bending stresses increase significantly due to unnoticed subgrade erosion, as is common in the case when the subgrade subside at the pavement corner or edge. In conventional reinforced concrete slabs, the steel reinforcement is placed between the mid to two third depth of the slab to mainly resist stresses induced by changes in the environmental conditions (Paramasivam et al. 1994). The load carrying capacity of concrete slab can be enhanced by placing the reinforcement

in the bottom of the slab. Thus, allowing the concrete in the bottom surface to crack and the reinforcement there to withstand the positive moment. Top reinforcement can also be provided especially at corners and edges to resist a negative moment. Fiber-reinforced concrete has many applications due to its increased strength and ductility. However, this type of concrete is not widely used due to ongoing research on its long term properties. FRC can be used in beams to take advantage of the higher ductility and tensile strength of this material for better crack control and material cost saving. Structural elements can be produced with fibers completely replacing conventional reinforcement. Generally, the Main use of fiber reinforcement has been in applications such as highways, pavements, runways, tunnels, deck slabs and wall panels in buildings.

2.6 Conclusion

According to previous researches, the mechanical properties of the concrete with steel fiber have been improved namely the flexural strength of the beam from 1.5 to 3 times. Previous research mainly considered different volume fractions ranging between 0.5% - 1.5%. While 2.0% steel fiber is found to become common in the industry recently. The main research was conducted on straight fiber, twisted fibers, also some research on crimped and end hooked fibers. But no comprehensive and complete test was done on the end hooked fiber to test all mechanical properties for the end hooked steel fiber. Therefore, this study focused on straight fiber and considered the 1.5% steel fiber as well as the 0.5%-1% to be able to compare all contents of the fibers and make a good comparison. SFRC has been of interest to be used in the infrastructures in previous researches due to its bridging effect hence considered for extreme loads such as impact. The research in this area has mainly focused on plates and slab behavior is fairly new. Especially the research is mainly considering the plain concrete for the impact analysis of the slabs.

CHAPTER THREE

EXPERIMENTAL WORK

3.1 Introduction:

The experimental study aims to understand the material behavior of SFRC. To predict the effect of concentrated load on concrete slab different approaches such as experimental and numerical methods could be used. Experimental research gives a realistic insight to the problem and results, while the numerical model is another direction of the research activities to study the behavior of structural members in which with the aid of simulation tools the real behavior can be represented under ideal condition. Experimental work could be impractical or expensive; however, the significant development in computer technology development in recent years makes the numerical techniques more popular for obtaining detailed results. This provides researchers with the opportunity to extend the application of the numerical models to perform parametric studies by virtual experiments. On the other hand, it is important to validate the numerical results with an experiment. For better numerical modeling extensive experimental results on material behavior are required to be able to model the material as accurate as possible in the finite element software.

The material experiment will be conducted to give sight into the real material behavior of the SFRC and study its mechanical behavior using the straight SFRC and also make the results available to other researchers for future research works

3.2 Material and mix design

Concrete is a composite material that its constituents contain cement, fine aggregate, coarse aggregate and water. The concrete mixture was prepared of the concrete includes mixing of fine aggregate, coarse aggregate and cement and then water is added to the mix. For each batch, cylindrical specimens and beams were casted and tested to determine the compressive strength, split tensile strength and flexural strength of the concrete.

The straight steel fibers are chosen for this research. According to previous studies and recommendation of industrial companies such as Maccaferri Limited and Bekaert (Dramix), the weight fraction of these fibers will vary from 0.5 % to 2.0%. see Figure 3-1 (a) and (b).

Figure 3- 1. (a). Steel Fiber DRAMIX bag (b) Steel Fibers DRAMIX 13/0.2

below summarizes the properties of steel fibers to be used in this study.

Table 3- 1. Steel fiber properties

Type of Fiber	Length (mm)	Diameter (mm)	Aspect ratio (L/D)	Tensile Strength (N/mm^2)	Young's Modulus (N/mm^2)
Bright, High Carbon wire/Straight	13	0.2	13/0.2	2.75	200

3.3 Concrete mix design

The plain concrete is designed for a target compressive strength of 4000 psi. For the SFRC the same proportions are used with different dosage of steel fibers. Table 3-2 below shows different concrete types cast for this study as well as the concrete mix design proportions for this experimental work. Portland cement type I, sand for fine aggregate, and shingle gravel aggregate were used. Figure 3-2 shows all materials used for the mix.

Table 3- 2. Mix proportions of the concrete mixtures for 1 Cubic Yard

Mixture name	Cement (lbs)	Water (lbs)	Fine Aggregate (lbs)	Coarse Aggregate (lbs)	w/c	% Fiber*	Fiber (lb)
PC	680	306	1752	1263	0.45	0.0	0
SFRC 0.5	677	304	1743	1257	0.45	0.5	20.0
SFRC 1.0	674	302	1734	1251	0.45	1.0	40.0
SFRC 1.5	671	300	1725	1245	0.45	1.5	60.0

* By wt. of concrete

Figure 3- 2. Concrete Constituents

Mixing procedure

Coarse aggregates are first added to a concrete mixer then sand is added. When mixed uniformly the cement is added and let to be mixed with the rest of the constituents for about 3 minutes. When the evenly mixed and consistent mixture of dry constituents is achieved, water is added gradually to the appropriate amount based on the designed w/c ratio to obtain a good workability. In the case of steel fiber reinforced concrete, the steel fibers are added (% by weight of concrete) before the addition of water into the mix to allow for proper distribution of the fibers in the matrix. See Figure 3-3 and Figure 3-4.

Figure 3- 3. On-site concrete mixer

constituents mixed uniformly, (d) Water added to the mixture

Figure 3- 4. Adding steel fiber to the mix

After the mixing it was essential to measure the slump value. The slump value demonstrates the workability of the concrete. There are different types of slumps as shown below in Figure 3-5.

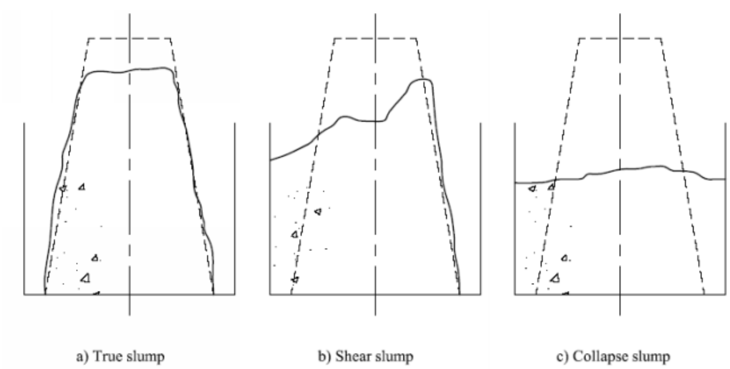


Figure 3- 5. Measuring slump

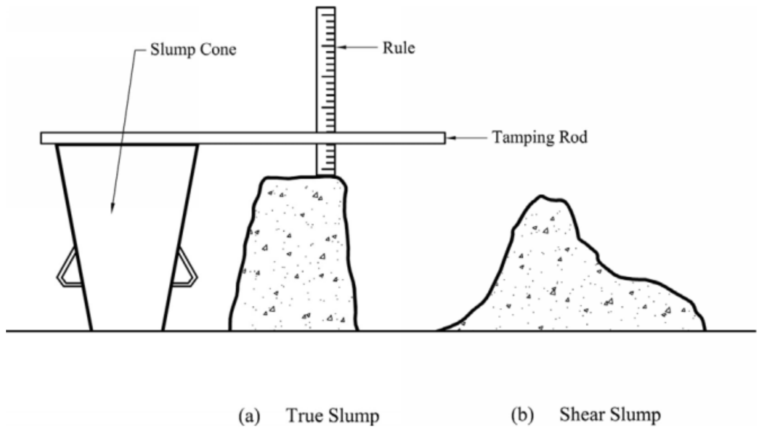


Figure 3- 6. Measuring slump

To measure the slump, a slump cone is used on a plate and concrete is poured inside the cone. When 1/3 of the cone is filled the concrete is tamped with tamping rod 24 times. This is repeated when 2/3 of the cone is filled. When the cone is filled with concrete the top surface is made to be smooth. Then the cone was lifted within 5 seconds and the distance from the top of the concrete to the top of the cone is the slump value. Figure 3-6 shows the method of measuring the slump and Table 3-3 shows the measurement after the mixing.

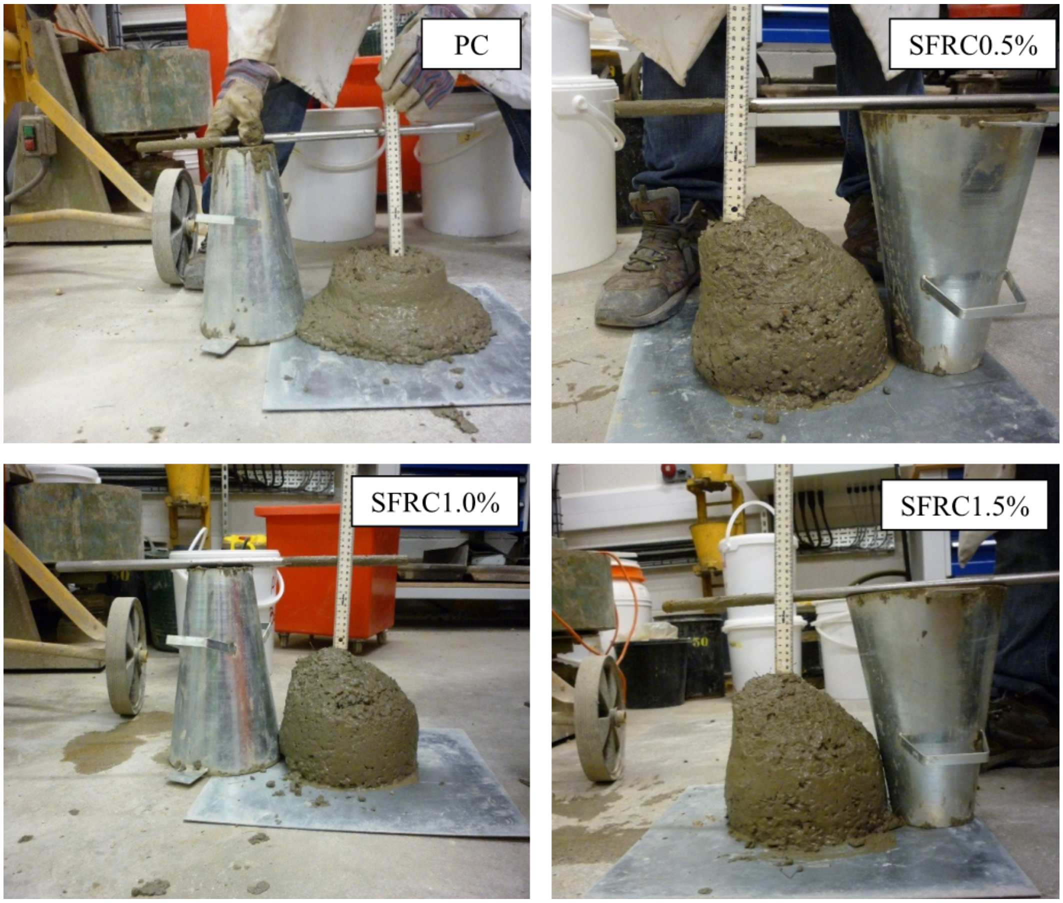


Figure 3- 7. Slump Test

Table 3- 3. Slump test results

Mixture name	% Fiber*	w/c	Slump Measurement (in)
PC 0%	0.0	0.45	8
SFRC 0.5%	0.5	0.45	5.5
SFRC 1.0%	1.0	0.45	5
SFRC 1.5%	1.5	0.45	4

Figure 3-7 shows that with the same water to cement ratio for all mixes the slump value is changing. With the addition of fibers, the consistency of the mix is influenced hence the slump value decreases. The surface area of the fiber is a factor to consider. In addition to the coarse aggregate, the sand and cement must also coat around the fibers. If the fraction of sand and cement is insufficient, then the effect on the slump and workability will be more, meaning that with the same amount of sand and cement ratio, increasing the fiber volume will require more sand and cement to coat the fibers and the consistency of the mix is less as well as higher air content in the mix. Overall, the workability of SFRC was less than plain concrete due to these reasons. This effect was more visible with the addition of a higher percentage of fibers. After the preparation of the concrete, the molds were covered with specific oil and concrete was poured in the molds and tamped with tamping rod, see Figure 3-8.

Figure 3- 8. Pouring concrete

The molds where then covered by a wet cloth as shown in Figure 3-9. After 24 hours

Figure 3- 9. Covering of the specimen after casting with wet cloth

the concrete specimen was de-molded and the specimens were labeled with the type of concrete and put in the curing room with room temperature to be cured until the test date. (Figure 3-10)

Figure 3- 10. Concrete Specimens Curing

3.4 Test set up

The tests for monitoring the performance of steel fiber reinforced concrete were conducted using UTA Civil Engineering Laboratory as below:

- 4” dia x 8” Cylinders Compression Test at 28 Day
- 6” dia x 12” Cylinders Split Tensile Test
- 6” x 6” x 20” Beams Flexural Test

3.4.1 Cylinder Compression Test

For each batch of concrete, numbers of Cylinders were casted and tested under a uniaxial compression load, a 500-kip compression machine is used to perform the ASTM C39 test on 4-inch diameter by 8-inch cylinder 12 cylindrical specimens. The test results are highly dependent on a proper setup. The maximum sustained load under a constant loading rate of 400 lb/sec (35 psi/sec) is recorded and used for determining the compressive strength of a tested specimen. Figure 3-11 contains images of test setup and instrumentation. The results of this compression test for all concrete types are summarized in Table 3-4.

Figure 3- 11. compression test set up

Table 3- 4. Compression Test Results

Concrete Mix	Specimen No.	Specimen	Max Load (lbs)	Stress (psi)	Average Stress (psi)
PC 0%	1	Cylinder 4”x8”	49120	3909	4017
	2		36270	2886	
	3		51830	4125	
SFRC 0.5%	1		71130	5660	4716
	2		53430	4252	
	3		53220	4235	
SFRC 1%	1		61230	4873	4961
	2		61730	4912	
	3		64070	5099	
SFRC 1.5%	1		48080	4818	5134
	2		69550	5535	
	3		63430	5048	

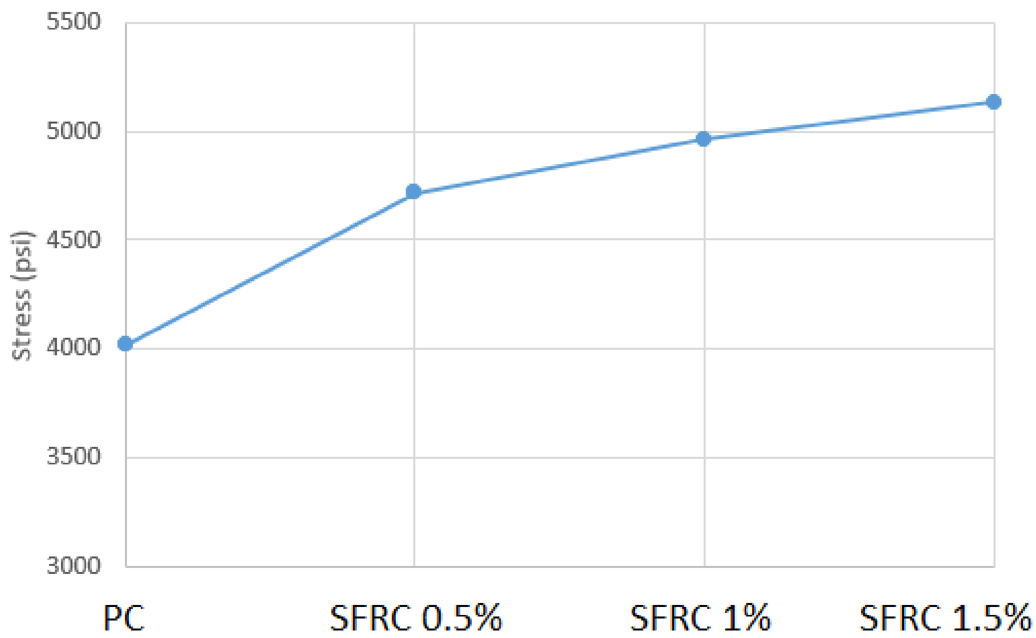


Figure 3- 12. Cylinder Compression Test Results

It can be seen that the strength has an increasing trend with the increase of fraction of fibers and the increase in strength from SFRC 0.0 % to SFRC 0.5 % is noticeable while increasing 0.5% of fibers to 1.5% have less effect on the compression strength (Figure 3-12). This could be attributed to the air content of the concrete, which previous researchers believe that the air content increases with the increase of steel fiber volume fraction, hence decreasing the compressive strength. However, the effect of more fibers is more pronounced in the damage that is visible on the cylinders as shown in Figures 3-13 to Figure 3-16. The increases in compressive strength from 0% to 0.5%, 0.5% to 1% and 1% to 1.5% was 17%, 5% and 4% respectively.

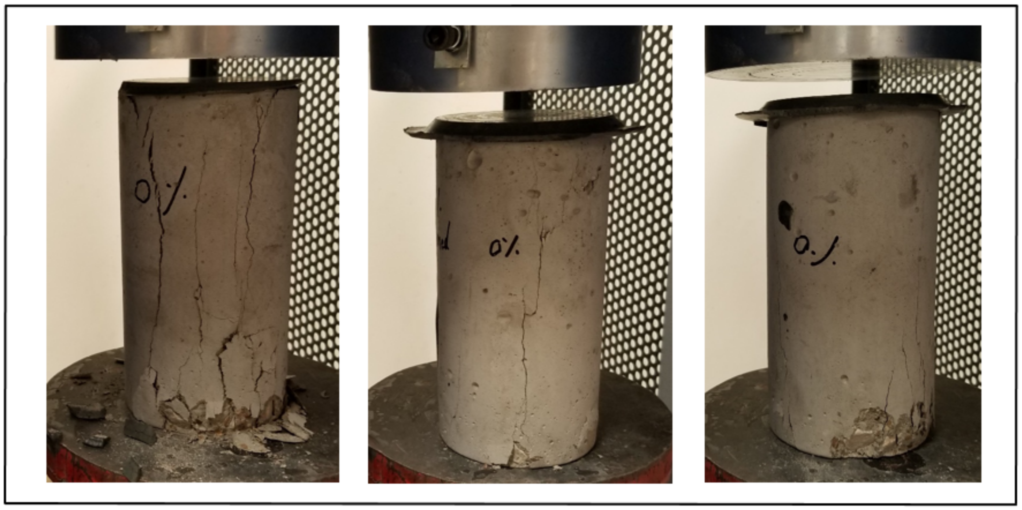


Figure 3- 13. Cylinder Compression Failure RC0%

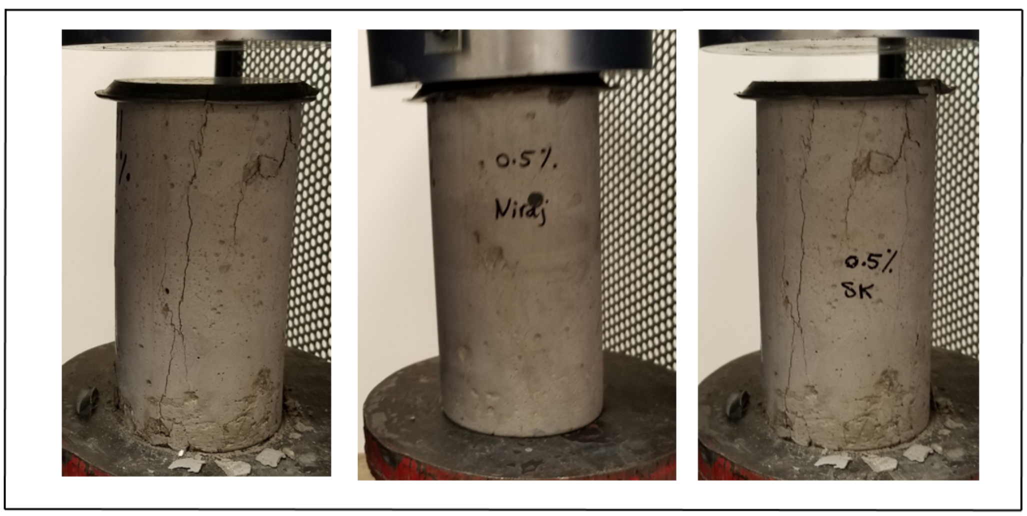


Figure 3- 14. Cylinder Compression Failure SFRC0.5%

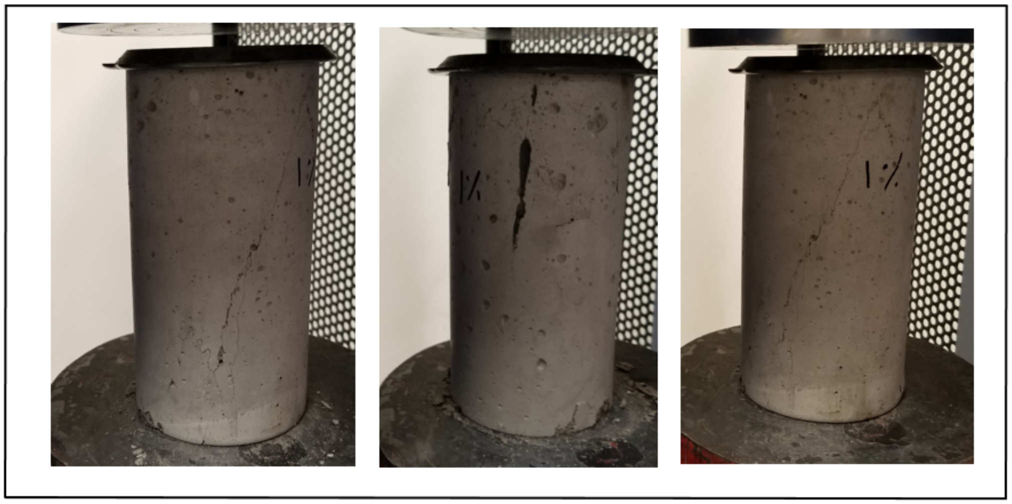


Figure 3- 15. Cylinder Compression Failure SFRC1%

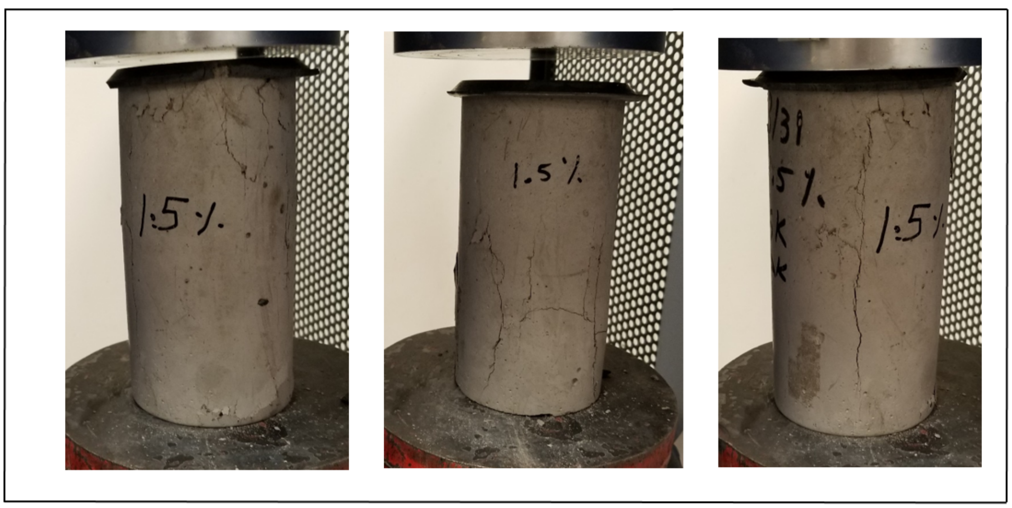


Figure 3- 16. Cylinder Compression Failure SFRC1.5%

3.4.2 Split Tensile Test

The 500-kips machine along with a typical test setup used for determining the tensile strength of the produced material is seen on Figure 3-17.

12 cylinders accompanying their respective large-scale slabs are used for performing a split-cylinder test according to ASTM C496 using the 500-kip compression machine seen in Figure 3-17. The results are valuable for assessing the shear strength of concrete. To perform this test, a 6-inch by 12-inch cylindrical specimen is placed flat on its long-axis, allowing a compressive diametric force to be applied its length. The test is performed using a constant rate of 100 to 200 lb/in^2 per minute until the specimen develops a tension crack along its diameter. The maximum sustained load due to the triaxle compression force is used in calculating the splitting tensile strength of the specimen. The results of the tensile test for all concrete types are summarized in Table 3-5.

Figure 3- 17. Tensile Test Machine

Table 3- 5. Tensile Test Results

Concrete Mix	Specimen No.	Specimen	Max Load (lbs)	Stress (psi)	Average Stress (psi)
PC 0%	1	Cylinder 6”x12”	48860	432	415
	2		48340	427	
	3		43600	386	
SFRC 0.5%	1		55560	491	504
	2		56780	502	
	3		58790	520	
SFRC 1%	1		60550	535	554
	2		64320	569	
	3		63210	559	
SFRC 1.5%	1		69870	618	642
	2		72340	640	
	3		75678	669	

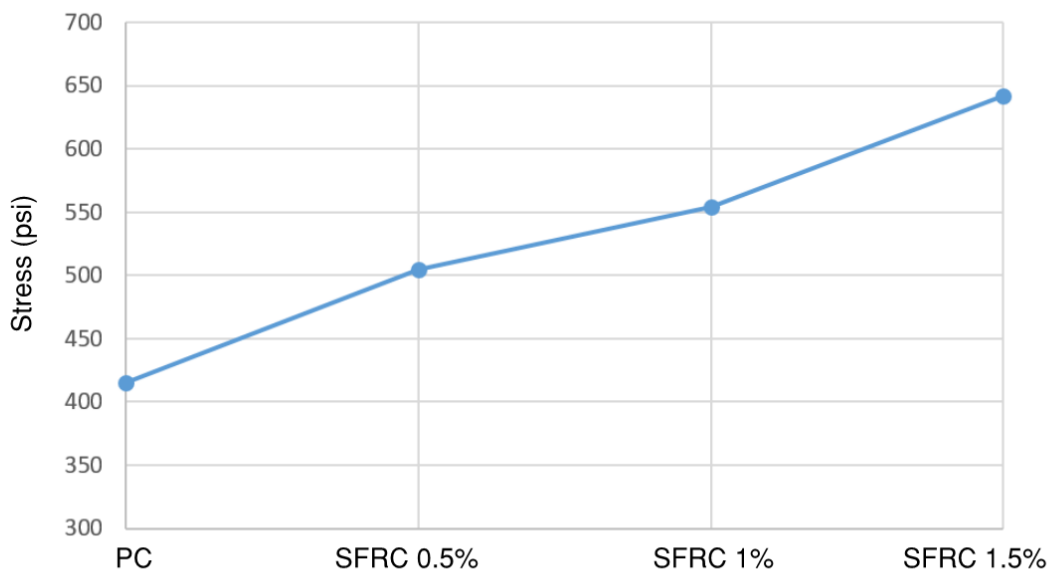


Figure 3- 18. Cylinder Tensile Test Results

From the strength values, it is evident that the split tensile strength of the concrete is increased with the same trend as concrete compressive strength (Figure 3-18). The increase for the strength from 0% to 0.5% has been more pronounced. The behavior of 1.0% and 1.5% is more similar in terms of strength. On the other hand, it is important how the fibers affect the failure of the specimens. Figures 3-19 to 3-22 below compare the specimens after failure. Results show that there is an increase of around 54.7% in splitting tensile strength of the tested specimens with an increase in steel fiber content from 0% to 1.5%. The increases in tensile strength from 0% to 0.5%, 0.5% to 1% and 1% to 1.5% was 21%, 10% and 16% respectively.

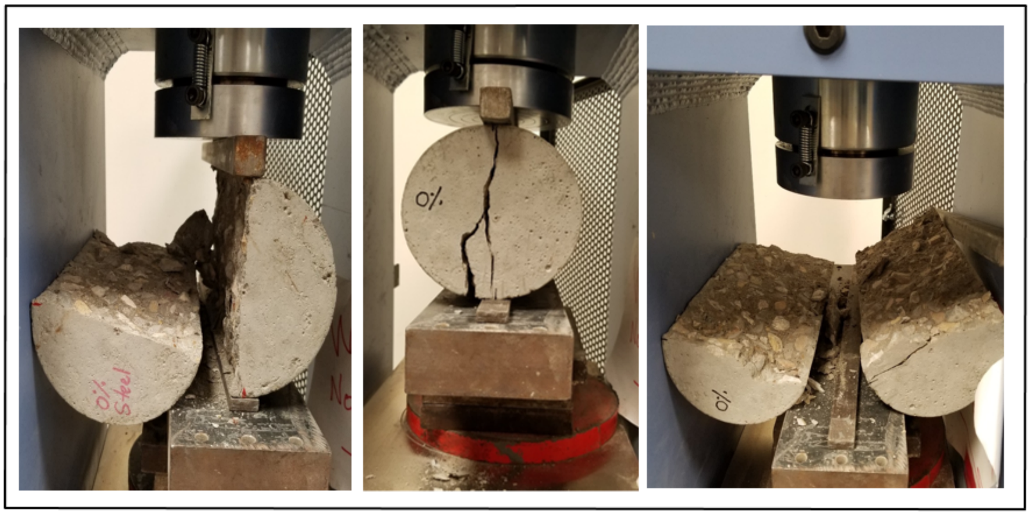


Figure 3- 19. Cylinder Tensile Failure RC0%

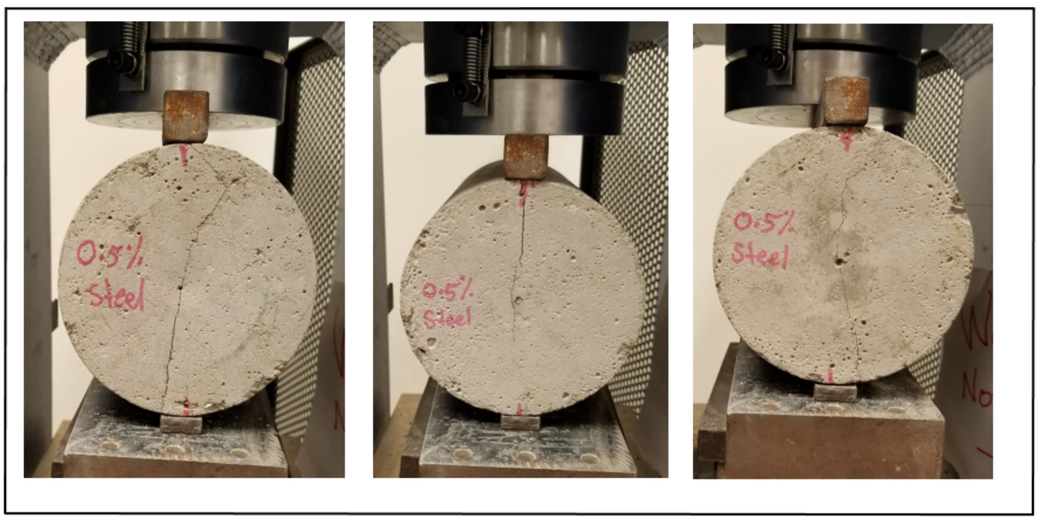


Figure 3- 20. Cylinder Tensile Failure SFRC0.5%

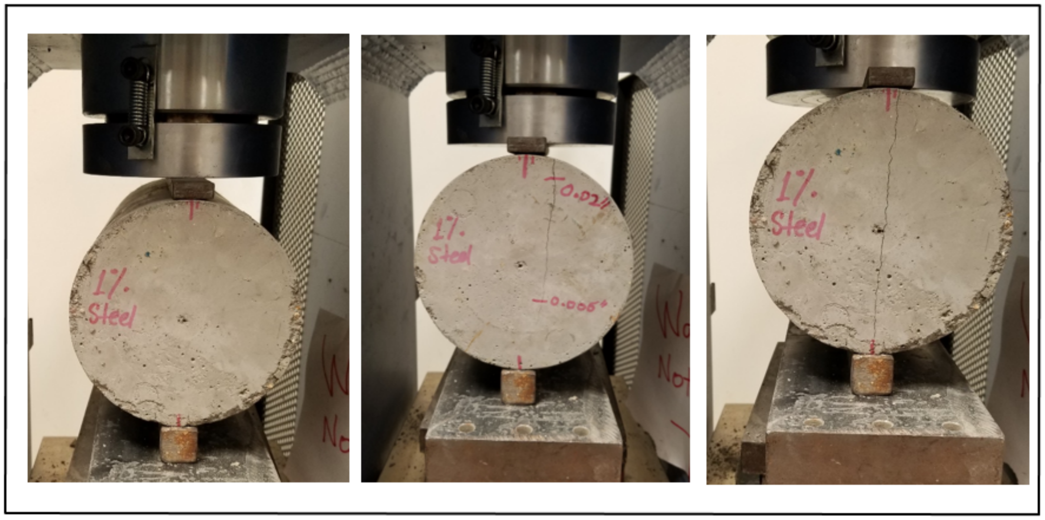


Figure 3- 21. Cylinder Tensile Failure SFRC1%

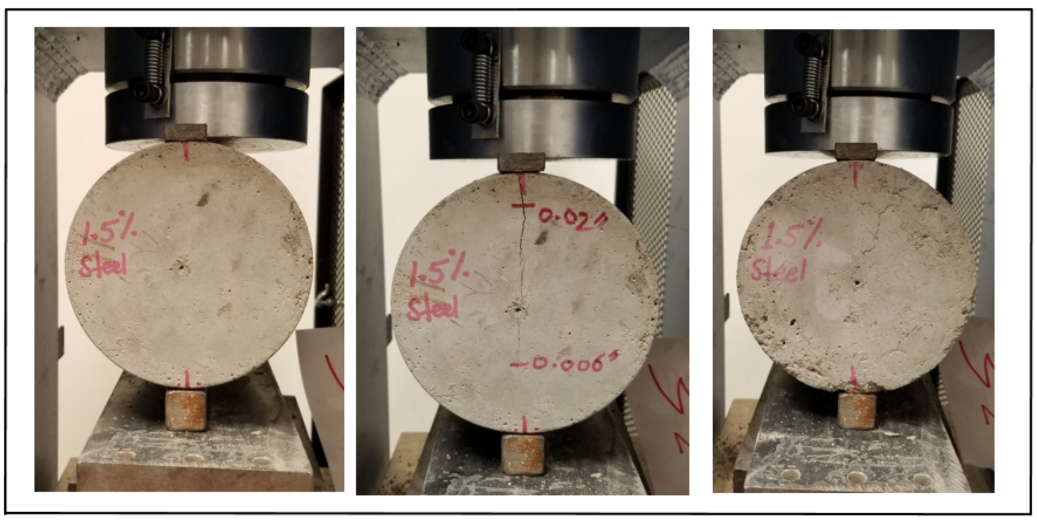


Figure 3- 22. Cylinder Tensile Failure SFRC1.5%

3.4.3 Flexural Beam Test

Flexural beam test is another indirect method of testing and evaluating the tensile strength of the concrete. For each batch numbers of beams were casted to be tested under compression load. The beams had the cross-section dimension of 6×6-inch and a length of 20-inch. The test was a 4-point bending test. the test was done according to ASTM C78, the clear span was set to 18-inch and the upper bearer distance was set to 6-inch (Figure 3-23).

The results of the Flexure test for all concrete types are summarized in Table 3-6.

Figure 3- 23. Flexure Test Machine

Table 3- 6. Flexure Test Results

Concrete Mix	Specimen No.	Specimen	Max Load (lbs)	Stress (psi)	Average Stress (psi)
PC 0%	1	6x6x20 inch	6482	540	561
	2		6767	564	
	3		6948	579	
SFRC 0.5%	1		6744	562	576
	2		7130	594	
	3		6843	570	
SFRC 1%	1		9265	772	668
	2		7671	639	
	3		7122	594	
SFRC 1.5%	1		7806	651	721
	2		9800	817	
	3		8333	694	

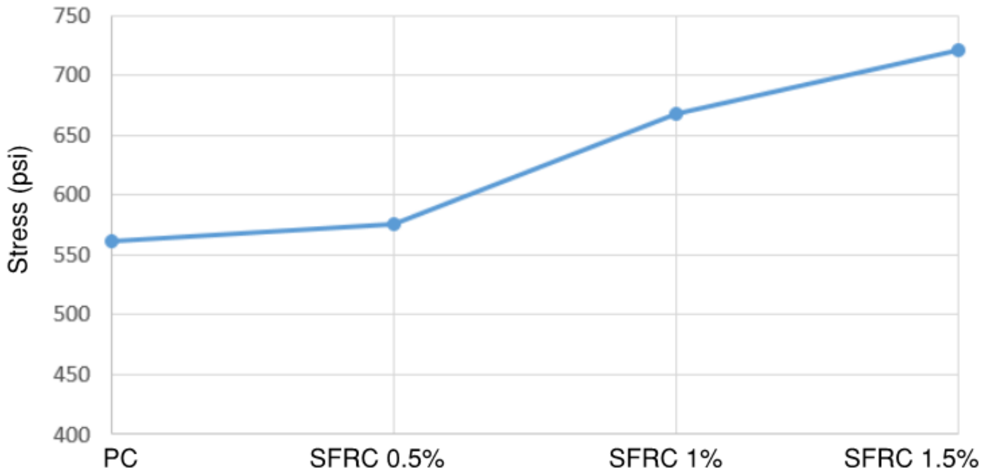
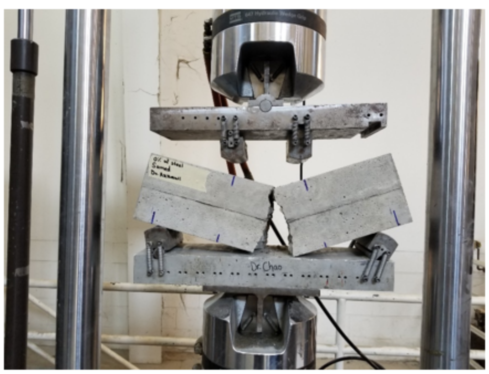
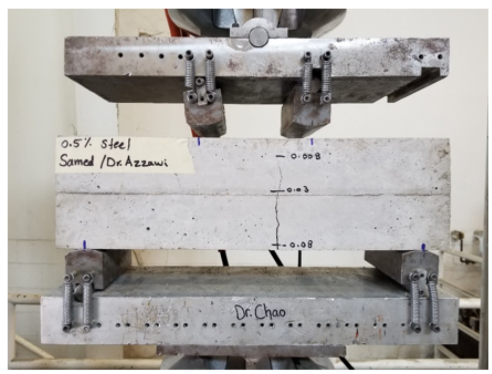


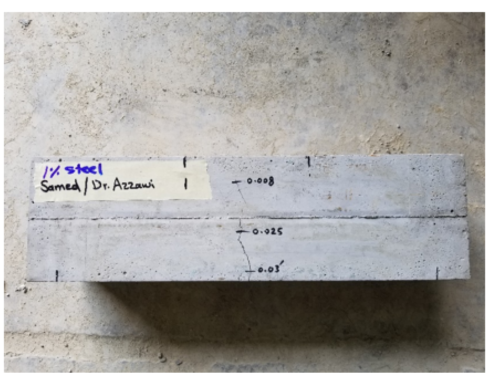
Figure 3- 24. Beams Flexure Test Results



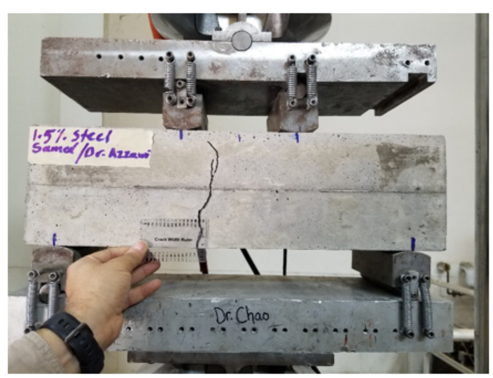
RC0%



SFRC0.5%



SFRC1%



SFRC1.5%

Figure 3- 25. Beams Flexure Failure

The Average stress results clearly show that the flexural strength of the test is increasing proportionally with the increase of the steel fiber. With the addition of steel fibers in a volume fraction of 0.5%, 1.0% and1.5% the flexural strength of concrete increased by 2.6%, 16%, and 7.8% respectively (Table 3-6), fibers had the highest effect on the flexural strength while 1.0% had an almost higher effect on the strength. Overall the literature suggested the increase of flexural strength by 1.5-3 times higher than plain concrete which in this study the flexural strength is also increased by 1.5 when 1.5% fibers is used (Figures 3-24 and 3-25). One of the most important factors that can be concluded from the flexural test is the tensile capacity of the beams. When the beam is loaded the bottom fiber of the beam is under tension. The higher the tensile strength of the beam the better the beam will perform especially after cracking.

3.5 The relation between split tensile strength and flexural strength

From Table 3-7 it can be seen that the ratio between flexural strength and the split tensile strength is almost the same for all mixes. Plain concrete has the highest ratio and SFRC0.5% has a similar ratio while SFRC1.5%. This reveals that the relation of the tensile strength and the flexural strength has the same value varying the fiber volume of the steel fibers in SFRC.

Table 3- 7. Relation between split tensile strength and flexural strength

	PC 0%	SFRC 0.5%	SFRC 1%	SFRC 1.5%
Split	414.9	504.3	554.3	642.2
Flexural	561	575.5	668.3	720.5
Flexural/Split ratio	1.35	1.14	1.21	1.12

3.6 Conclusion

From the material test it was evident that the use of fibers had a great effect on the performance of the plain concrete on all mechanical aspects of compressive strength, split tensile strength and flexural strength. The increase of the fibers from 0.5% to 1.5% showed better performance and amongst these volume fractions the SFRC 1.5% performed the best. Flexural strength increased by 28.4% with the addition of 1.5% fibers. Also, split tensile strength increased by 54.8% and Compressive strength increased by 19.6%. The effect of fiber was more evident and effective on the flexure and tensile strength since the fibers bridge the cracks, giving concrete more capacity under tensile loads.

The optimum value of steel fibers is suggested to be 1.5% as it affects mechanical performance greatly. Also, the literature and industry consider 1.5% to be a practicable and cost-effective amount. However higher steel fiber fractions also have been studied up to 3% and at some cases 5% for ultra-high performance concrete which is a very brittle material compared to conventional plain concrete. It should be noted that this amount of fibers decreases the consistency and workability of the concrete which can be undesirable, therefore the use of additives to enhance the workability would be essential. In conclusion, the use of 1.5% of fibers by the weight of concrete is considered to be satisfactory.

3.7 Concrete Slabs Specimens

3.7.1 Fabrication of Test Specimens

3.7.1.1 Design of Slab Specimens

The Slabs are designed to fracture and fail in applying concentrated load P, they have dimensions of 20”x45”x3.5” thick, three specimens of conventional concrete have (3) #3 bars three specimens have 0.5% of Steel fiber reinforcement concrete, three specimens have 1% of SFRC and the last three specimens have 1.5% of SFRC as shown in Figure 3-26.

3.7.1.2 Test Specimens

Timber formworks are constructed for 12 slabs and illustrated in Figure 3-27. To avoid any boding between the timber formworks and poured concrete, the interior panels of all formworks are oiled up. Furthermore, this significantly helped in demolding of casted specimens from the formworks in the next stage.

3.7.1.3 Concrete Pouring

Formworks are fabricated for 12 slabs, 12 beams, and 24 cylinders. Initially, the 3 RC slabs which had no fibers are casted. The 9 SFRC slabs with different fiber fractions are casted. Each slabs beam’s accompanying small-scale beams and cylinders are casted using their equivalent batch. In summary, after the steel skeleton of the slabs, they were placed into the formworks and ready for concrete pouring.

Concrete was made on lab by electrical concrete mixer. The concrete mix poured into the formworks. An internal vibrating device is used to vibrate the poured concrete to achieve proper consolidation of the concrete mix, as seen on figure 3-28.

Four concrete mix was done on Civil Engineering Building Laboratory (CELB) in University of Texas at Arlington (UTA). An on-site slump test is performed according to ASTM C143, which involves utilizing an 8 in. bottom diameter and 4-in. tope diameter 12-inch-high slump cone. Fresh concrete is poured into the cone up to one-third of the cone's height, the next one-third is poured after tamping the concrete 25 times. The procedure is repeated until the cone is completely filled with concrete and then struck flush from the top with a rod. The concrete subsides after carefully removing the cone vertically. The measured subsidence gives the slump of the concrete mix, as seen in Figure 3-7.

Fresh concrete pours, the first one being a plain concrete mixture which is used for 3 slabs of 0% SFRC with reinforcement, the second concrete mixture is 0.5% fraction concrete mix used for the 3 of 0.5% SFRC slabs and the third concrete mixture is 1% fraction concrete mix used for the 3 of 1% SFRC slabs, the forth concrete mixture is 1.5% fraction concrete mix used for the 3 of 1.5% SFRC slabs. Moisture loss of the casted specimens was prevented by covering the specimens with polyethylene tarps after the pour Figure 3-9. Finally, the specimens were demolded and coated with curing compound product as shown in Figure 3-29 and placed/ storage in provided place as shown in Figure 3-30.

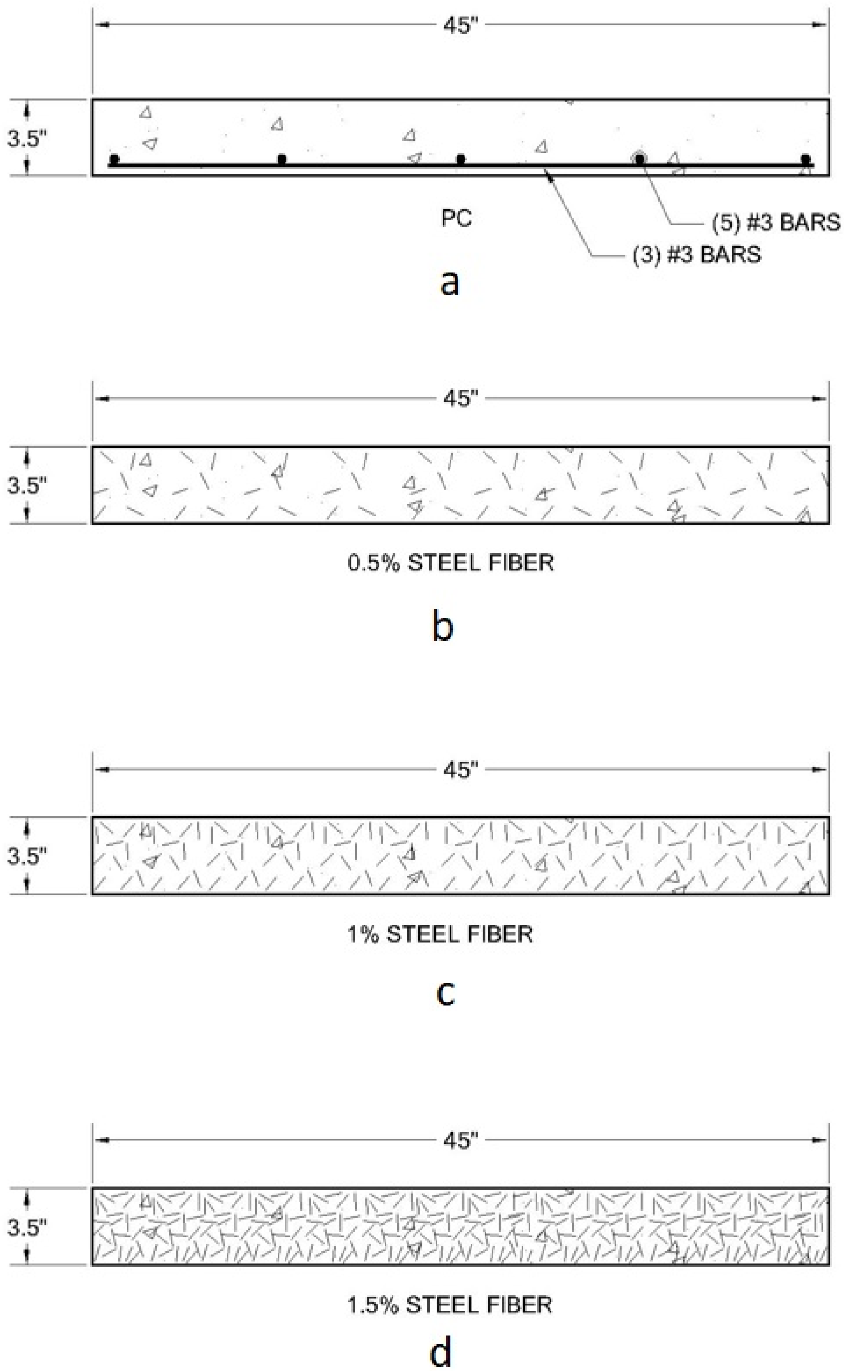


Figure 3- 26. Slabs Specimens

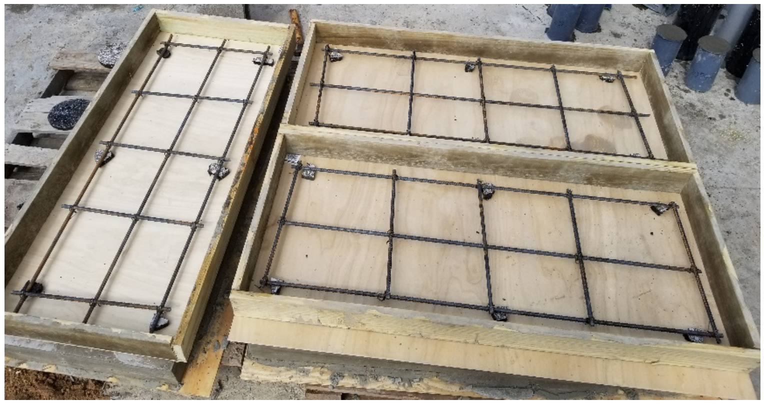


Figure 3- 27. Timber formworks

Figure 3- 28. Placing Concrete

Figure 3- 29. Applied Curing Compound

Figure 3- 30. Placing and storage the Specimens

3.7.1.4 Testing Machines

The 12 Concrete Slabs are tested using a 400-Kip load-controlled compression machine. This section elaborates the testing equipment and procedure utilized for performing each of the tests (Figure 3-31).

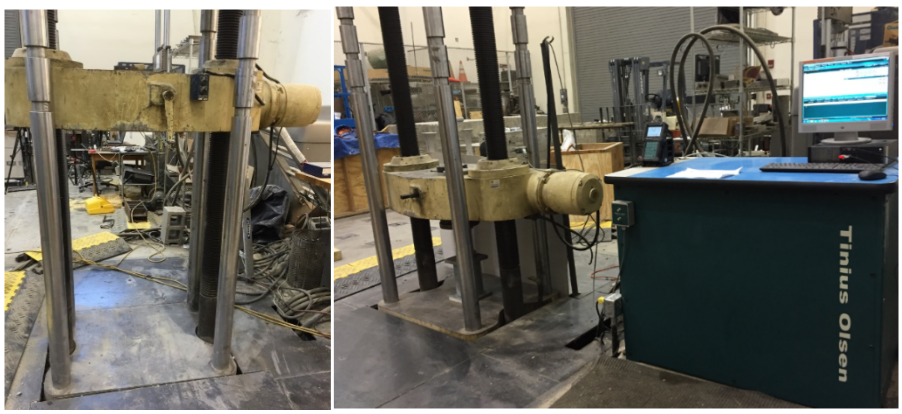


Figure 3- 31.400 Kip Compression Machine

Along with this machine “INTERFACE” load cell has been used to record the applied load on the specimens ash shown in Figure 3-32. This load cell placed on top of 5-inch x 5-inch steel plate located on the center of the slabs as shown in Figure 3-36.

Figure 3- 32. Load cell

In addition, Micro-measurements tool has been used to record the displacements in Inches along with the applied load as shown in Figure 3-33 and this Micro-measurements tool has been placed under the concrete slabs at the center area of the slab and the string of the tool connected to the bottom of the slab to start to measure the displacements.

Figure 3- 33. Micro-measurements tool

Both load cell and the micro- measurements tools connected to the data receiver as shown in Figure 3-34.

The data receiver connected to the computer and by running a special software, which is “Strain Smart Data System”, then collected the data, which is the Load-Deflection as shown in Figure 3-35.

Figure 3- 34. Load cell & Micro- measurements tool receiver

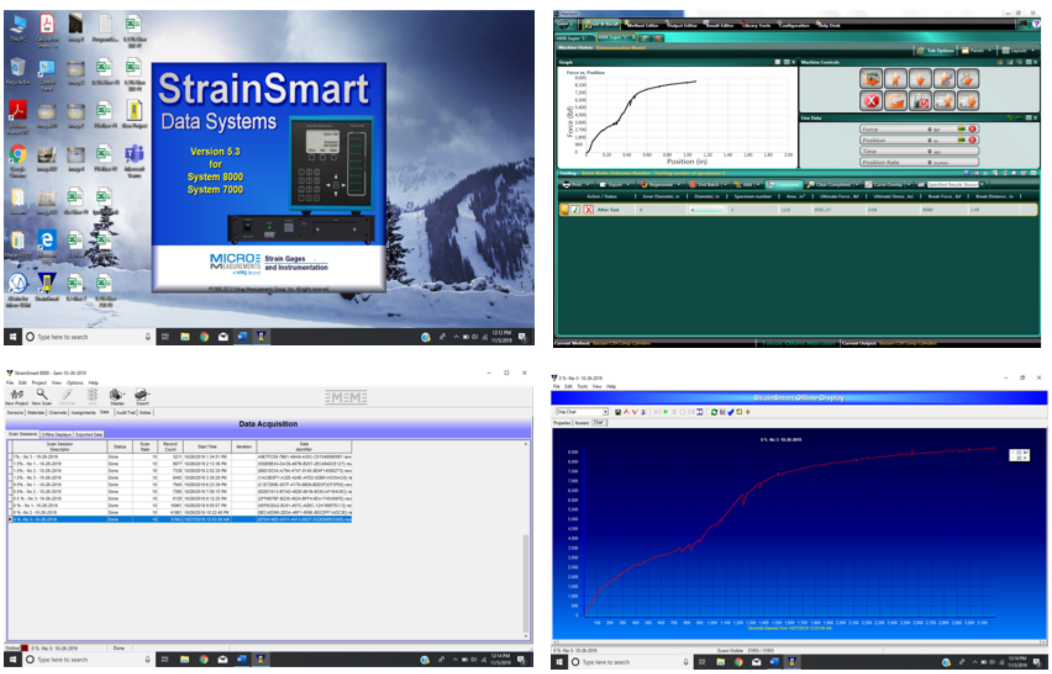


Figure 3- 35. Strain Smart Data System

A simply supported setup is used for testing of the 12 Concrete Slabs using the 400-kip compression machine. The machine has two cross-heads, one on the top and one on the bottom, as seen in Figure 3-31. The top cross-head stays fixed in place after initial adjustments are made to accommodate the supports, the beam, the load plates and the load cell. The lower cross-head moves upward in a steady manner and the machines load cell monitors the loading rate. 6 feet long wide-flange steel girders are aligned on the lower plate. The roller and pin support on the two ends are placed on the steel girder. A rollers support permitting lateral translation is used on the left end of the beam and pin support with no allowable lateral translation is setup on the right end of the beam as shown in Figure 3-37. Aligning and centering the girders the supports and specimen under the loading plate is fundamental to obtaining accurate results. The objective here is to make sure that the point load is applied exactly at the mid-span of the slab and that the supports are at their designated location in accordance with the slab design criteria of the study. Moreover, the load cell is placed on top of 3 plates that are placed on top of the slab. Once the setup is ready for testing, a monotonic load 2.2 kip/minute constant point load is applied. Simultaneously, the load cell records the instantaneous load applied and the Micro-Measurements records the mid-span deflection of the beams. The Micro-Measurements tool placed on the top of steel girder under the concrete slab and vertically intersects a thin aluminum plate attached under the concrete slab to take deflection measurements, as shown in Figure 3-36. It is noteworthy to mention that all the measuring devices used for testing were calibrated by their respective manufacturers before any test was carried out. All the recordings were transmitted to a network of data acquisition scanners. The scanner network comprised of 3 Micro-Measurements VPG scanners connected to each other using relay cables, this provided 60 available channels. Data is obtained at a 0.02 second time intervals. Furthermore, each load cell and Micro-Measurement tool are connected to the scanner network using wiring adaptors acquired from strain gauge manufacturing firm. The main scanner within the network is the connected to a windows based *StrainSmart* equipped computer using *PC5101B PCMCIA* interface adapter (as seen in figure 3-35). As a result, the assembly produces accurate and reliable test data which lays a concrete foundation for performing an accurate stress analysis study.

Figure 3- 36. Testing setup

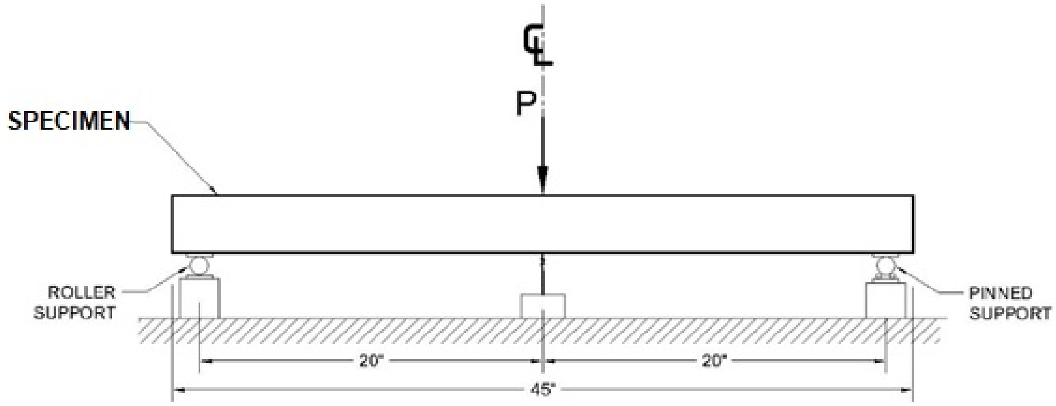


Figure 3- 37. Simply Supported Slab setup

CHAPTER FOUR

EXPERIMENTAL RESULTS AND ANALYSIS

Observing the cracking and failure mechanism during testing of concrete slab specimens shows that initial crack in all specimens prominently occurred within the middle span. Observing this result shows that cracking in all slabs initiated in the critical bending section. The cracking pattern and order of cracks were precisely monitored during testing. It was observed that in all slabs first crack, started at the mid-span and then started to spread out. As the load kept increasing, the crack width was increasing with the increase of the load. SFRC slabs failed with a single crack whereas RC 0% Slabs with minimum reinforcement failed with multiple cracks because the steel bars started carrying the load after the failure of the concrete. The difference in fiber reinforcement was clearly evident during testing, as SNFRC slabs the maximum load was increasing with The Average concentrated load results clearly show that it is increasing proportionally with the increase of the steel fiber. With the addition of steel fibers in fraction of 0.5% and 1.0% the maximum load applied on concrete slab increased by 15.3% while the increase in maximum load with the addition of steel fiber in fraction of 1% to 1.5% is 22.8%, fibers had the highest effect on the maximum load while 1.5% had almost higher effect on the strength.

Also the concrete slabs behaves as more ductile materials with the higher dose of steel fiber and this is clearly shown that the deflection before they fail with 0.5% of steel fiber (SFRC0.5%) was 0.023 inch and this goes up to 0.0313 inch with 1% of steel fiber (SFRC1%) and then goes to 0.036 inch with 1.5% of steel fiber (SFRC1.5%).

4.1 Reinforcement Concrete Slabs with no Steel Fibers (RC 0%)

The average maximum load of the 3 concrete slabs with 0% steel fiber and minimum steel reinforcement of # 3 bars at 8" center to center as shown in Figure 3-26 (a), was 9259 lbs before it fails, the first crack developed when the load was around 4500 lbs and that is very clear in Figures 4-1 To 4-5. Then the reinforcement started carrying the load up to 9259 lbs with very high deflection which is 1.053 in see Table 4-1, and the cracks width was around 0.15 inch.

Table 4- 1. Maximum Load- Deflection Test Results for Slabs

Concrete Mix	Specimen No.	Specimen	Max Load (lbs)	Max Deflection (in)	Average Load (lbs)	Average Deflection (in)
RC (0% Fiber)	1	Slab 45"x20"x3.5"	9169	0.94	9259	1.053
	2		9894	1.26		
	3		8715	0.96		
SFRC (0.5%)	1		4080	0.025	3958	0.023
	2		4283	0.026		
	3		3510	0.019		
SFRC (1%)	1		4586	0.034	4564	0.031
	2		4550	0.037		
	3		4555	0.023		
SFRC (1.5%)	1		5800	0.037	5606	0.036
	2		5477	0.030		
	3		5540	0.041		

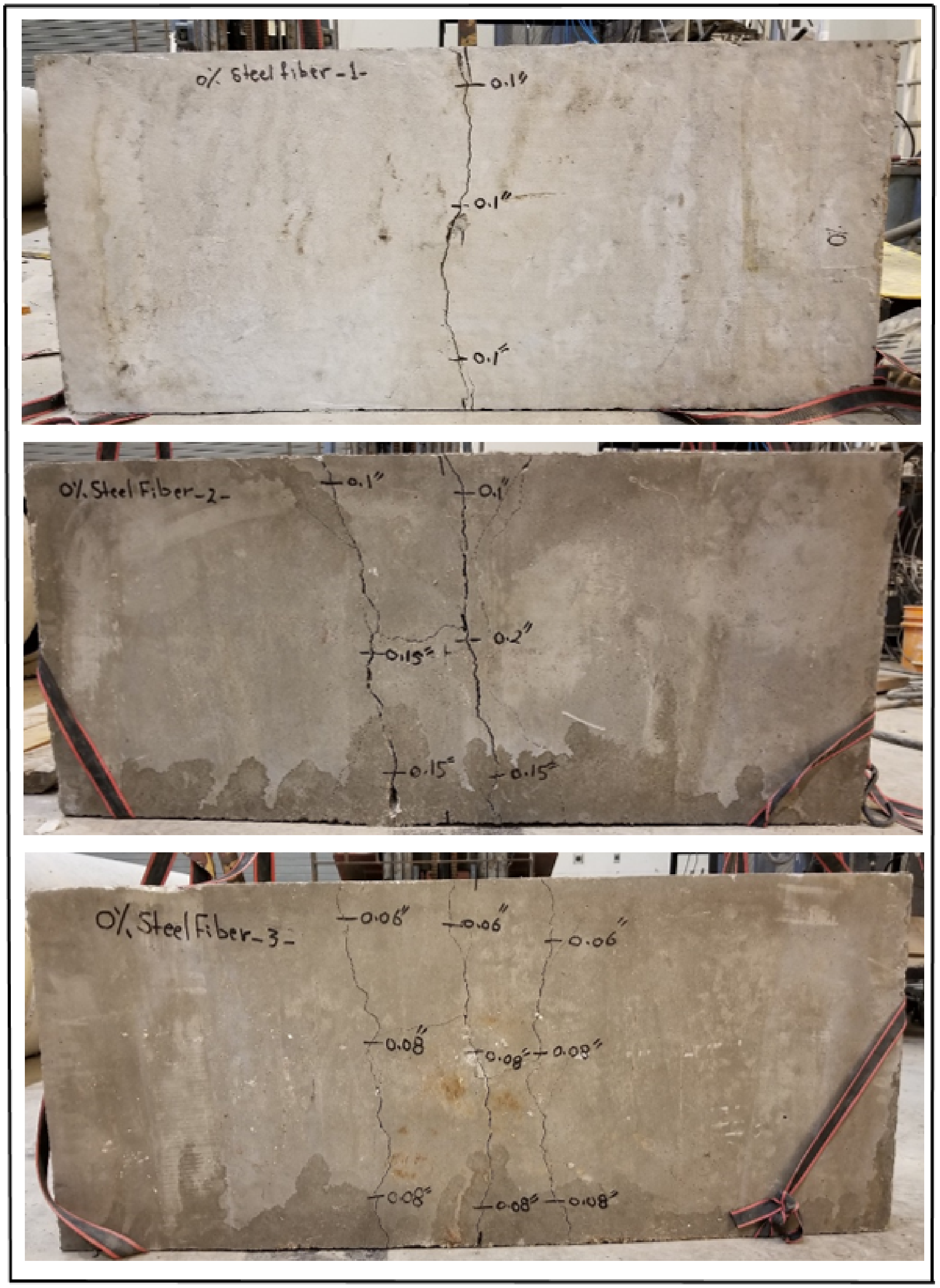


Figure 4- 1. Specimen Failure of RC 0%

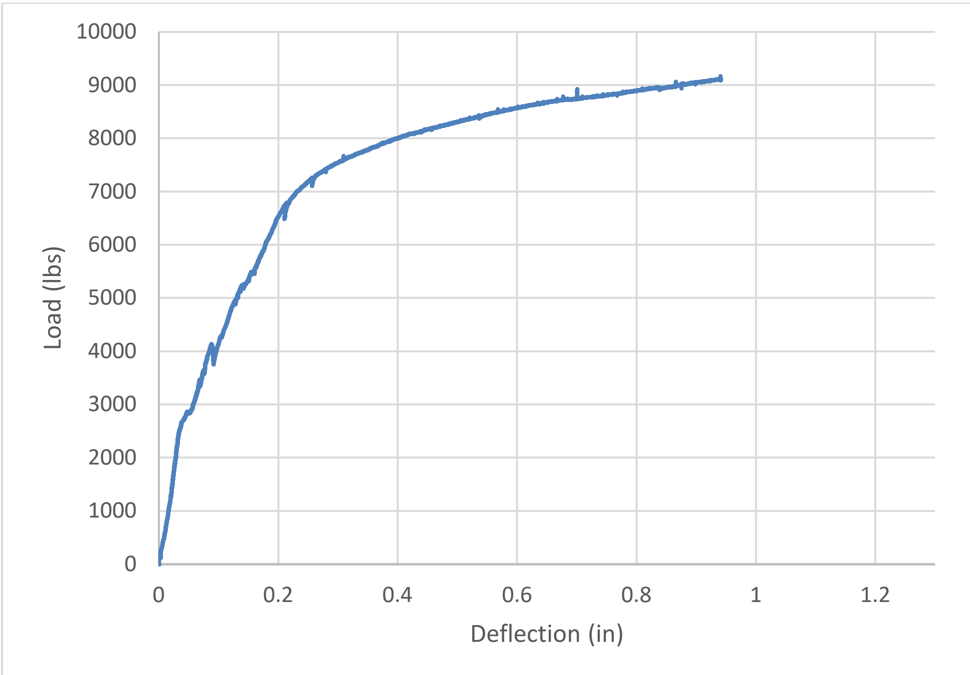


Figure 4- 2. Load-Deflection response for RC 0% Slab #1

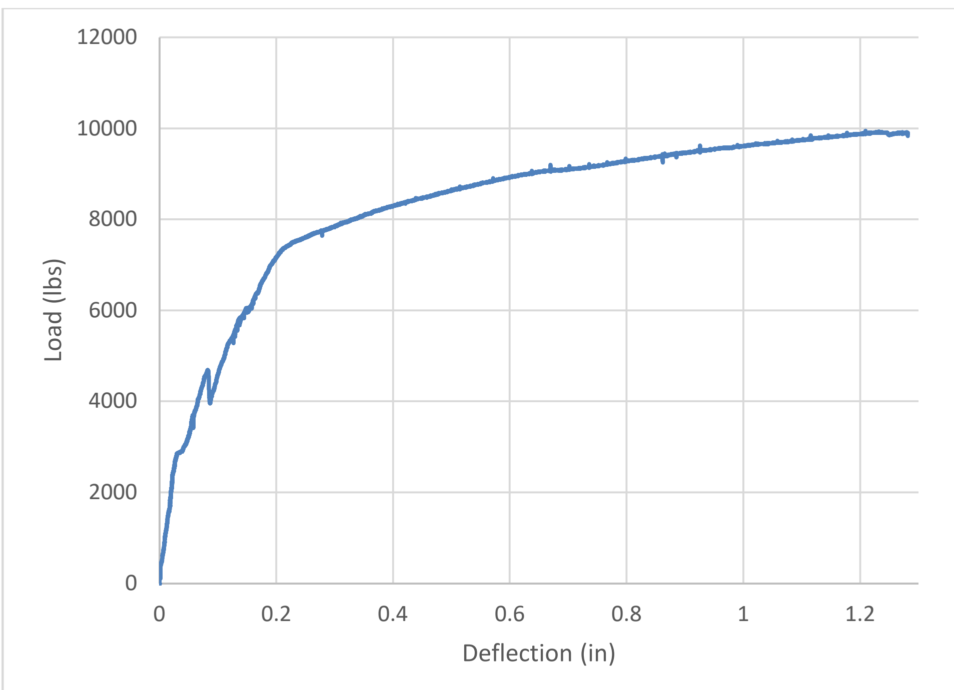


Figure 4- 3. Load-Deflection response for RC 0% Slab #2

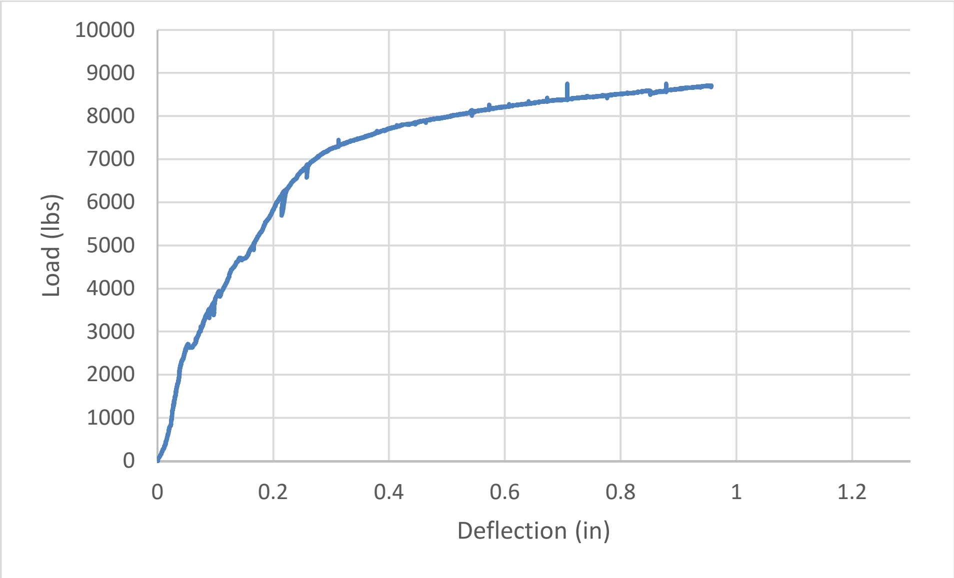


Figure 4- 4. Load-Deflection response for RC 0% Slab #3

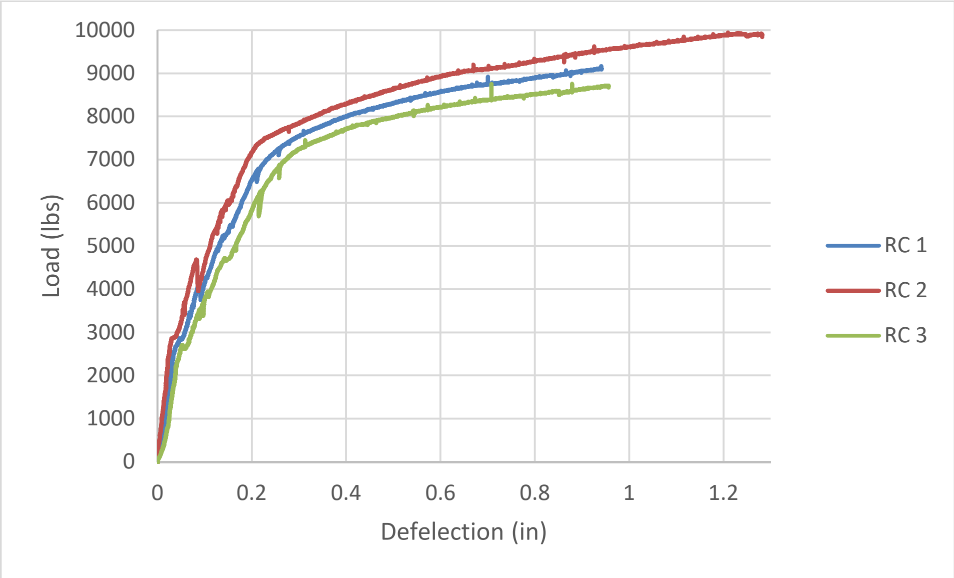


Figure 4- 5. Load-Deflection response for RC 0% Slab #1, 2 and 3

4.2 Concrete Slabs with 0.5% Steel Fiber SFRC (0.5%)

The average maximum load of the 3 concrete slabs with 0.5% steel fiber SFRC (0.5%) as shown in Figure 3-26 (b), was 3958 lbs before it fails, see Table 4-1, the cracks developed at the maximum load and the load started decreasing with increasing of the deflection to reach the maximum average deflection of 0.023 inch as shown in Figures 4-6 To 4-10, the average maximum deflection was 0.023 inch

Figure 4- 6. Specimen Failure of SFRC (0.5%)

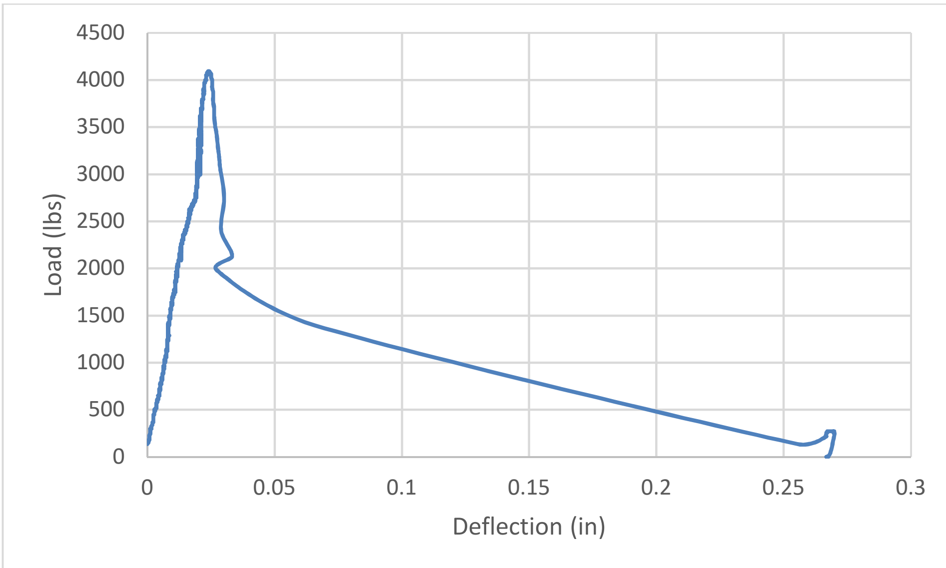


Figure 4- 7. Load-Deflection response for SFRC (0.5%) Slab #1

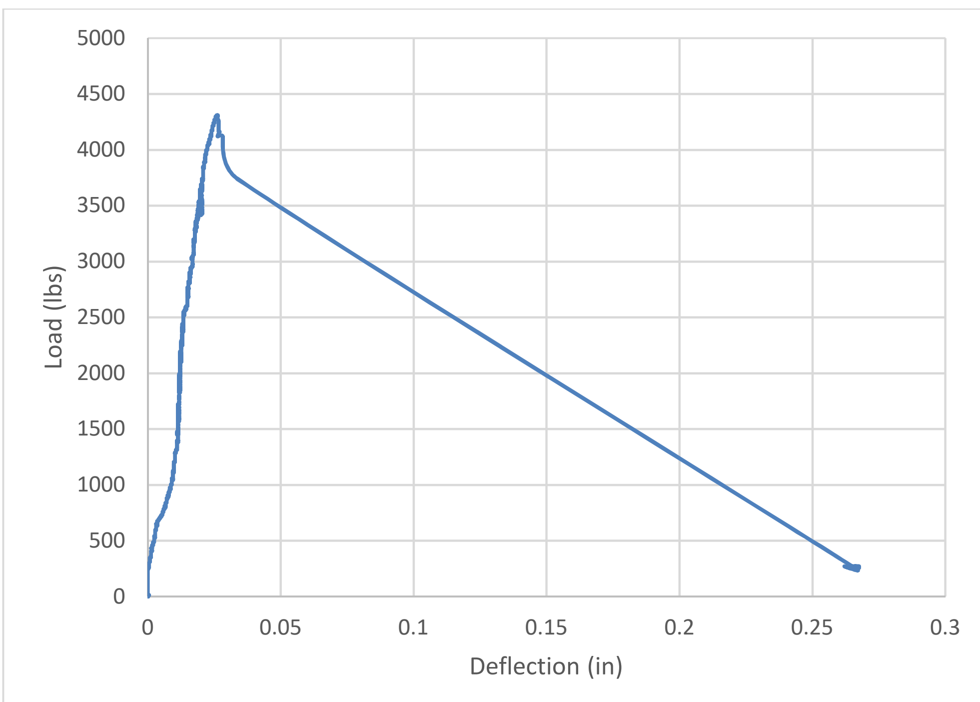


Figure 4- 8. Load-Deflection response for SFRC (0.5%) Slab #2

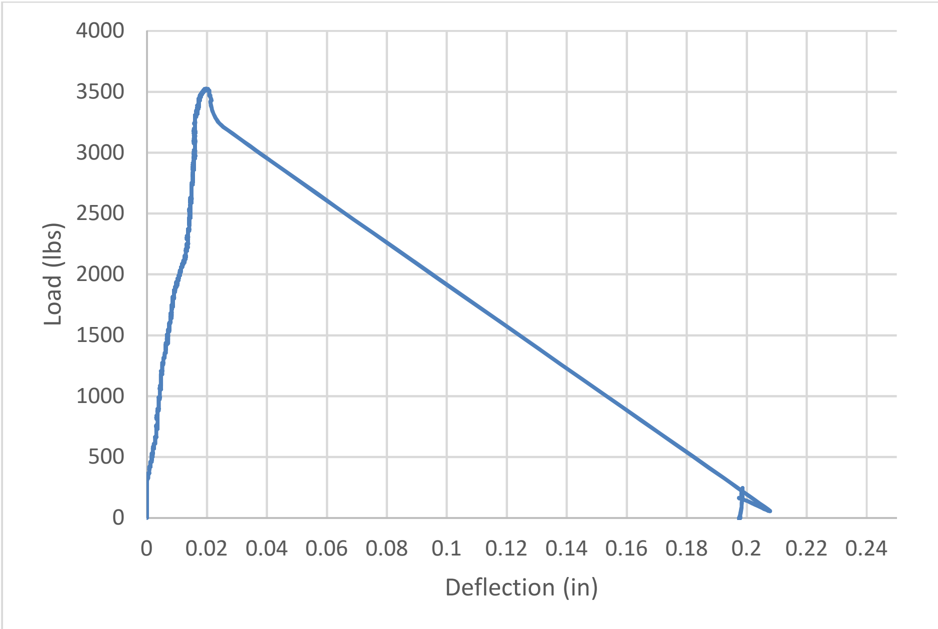


Figure 4- 9. Load-Deflection response for SFRC (0.5%) Slab #3

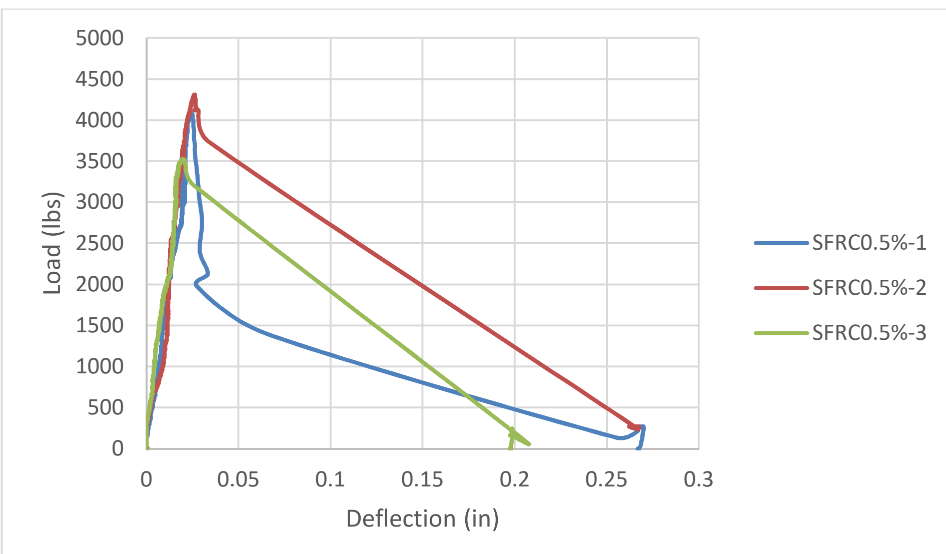


Figure 4- 10. Load-Deflection response for SFRC (0.5%) Slab #1, 2 & 3

4.3 Concrete Slabs with 1% Steel Fiber SFRC (1%)

The average maximum load of the 3 concrete slabs with 1% steel fiber SFRC (1%) as shown in Figure 3-26 (c), was 4564 Ibs before it fails see Table 4-1, the cracks developed at the maximum load and the load started decreasing with increasing in deflection as shown in Figures 4-11 To 4-15, the average cracks width was around 0.1 inch.

Figure 4- 11. Specimen Failure of SFRC (1%)

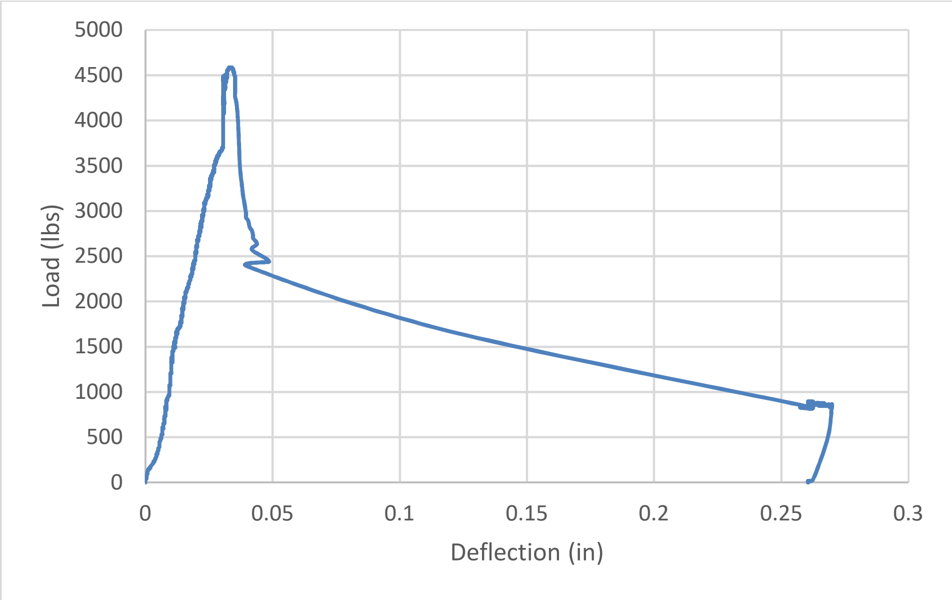


Figure 4- 12. Load-Deflection response for SFRC (1%) Slab #1

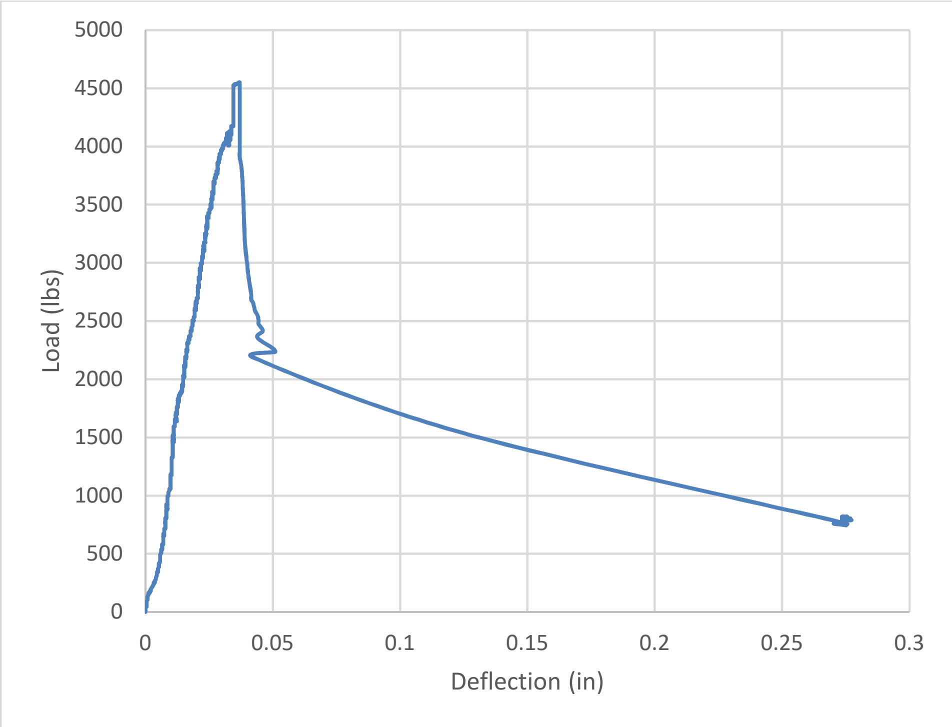


Figure 4- 13. Load-Deflection response for SFRC (1%) Slab #2

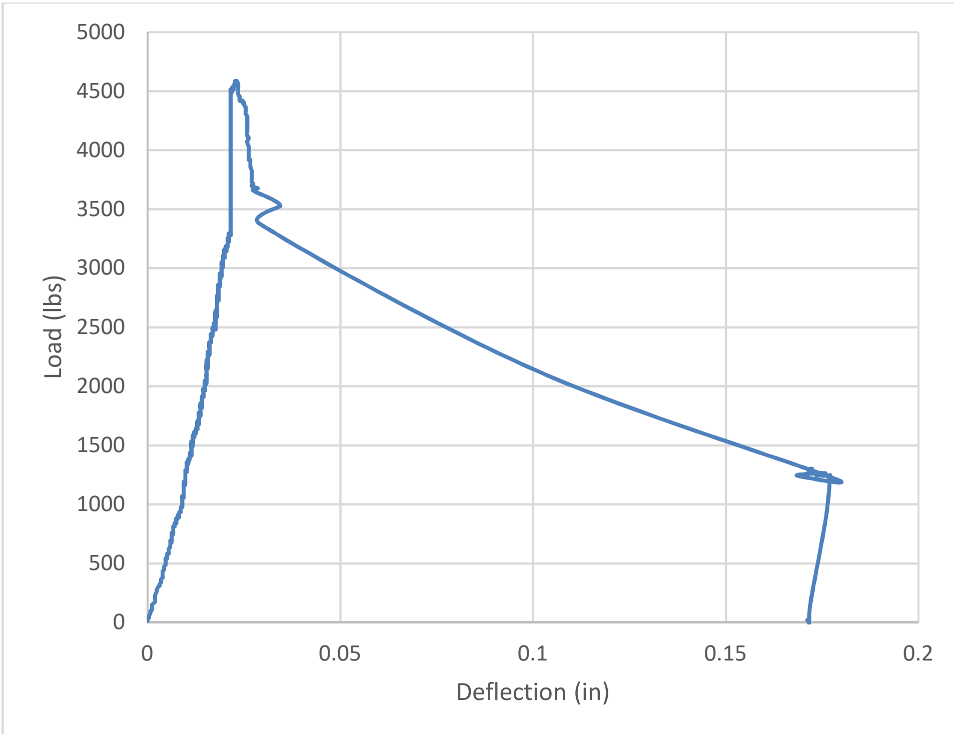


Figure 4- 14. Load-Deflection response for SFRC (1%) Slab #3

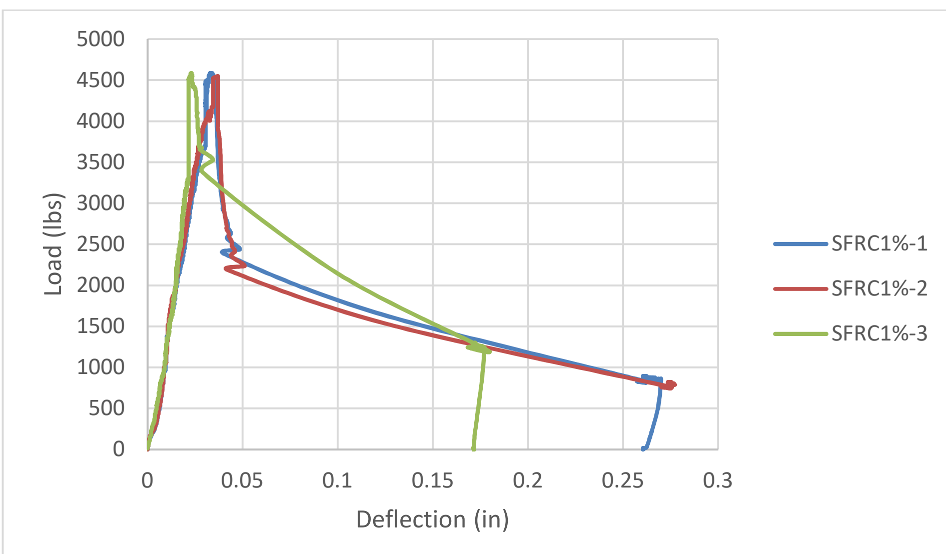


Figure 4- 15. Load-Deflection response for SFRC (1%) Slab #1, 2 & 3

4.4 Concrete Slabs with 1.5% Steel Fiber SFRC (1.5%)

The average maximum load of the 3 concrete slabs with 1.5% steel fiber SFRC (1.5%) as shown in Figure 3-26 (d), was 5606 lbs before it fails see Table 4-1, the cracks developed at the maximum load and the load started decreasing with increasing in deflection as shown in Figures 4-16 To 4-20, the average cracks width was around 0.08 inch.

Figure 4- 16. Specimen Failure of SFRC (1.5%)

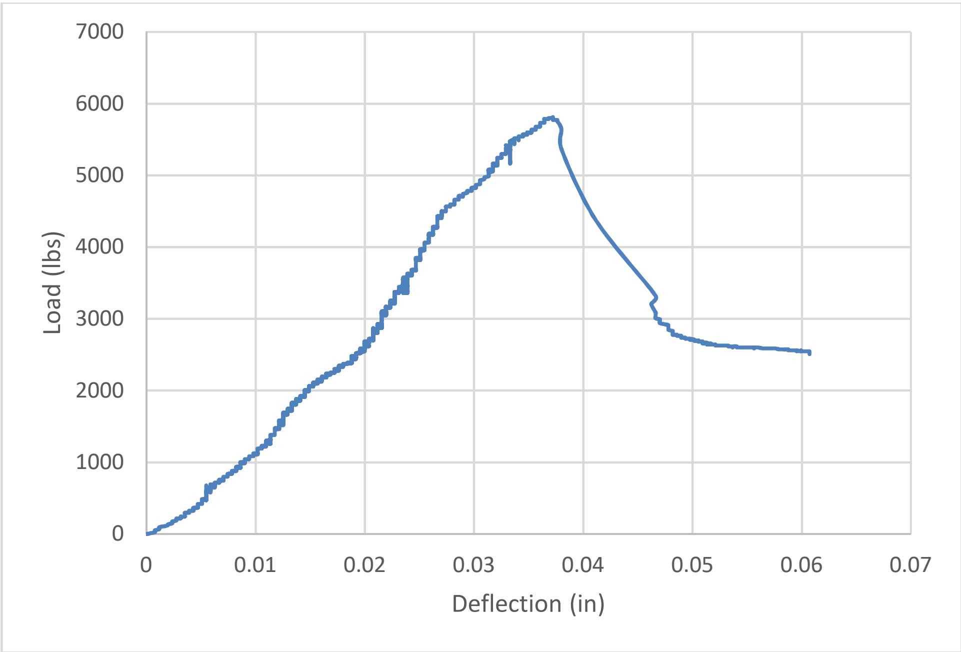


Figure 4- 17. Load-Deflection response for SFRC (1.5%) Slab #1

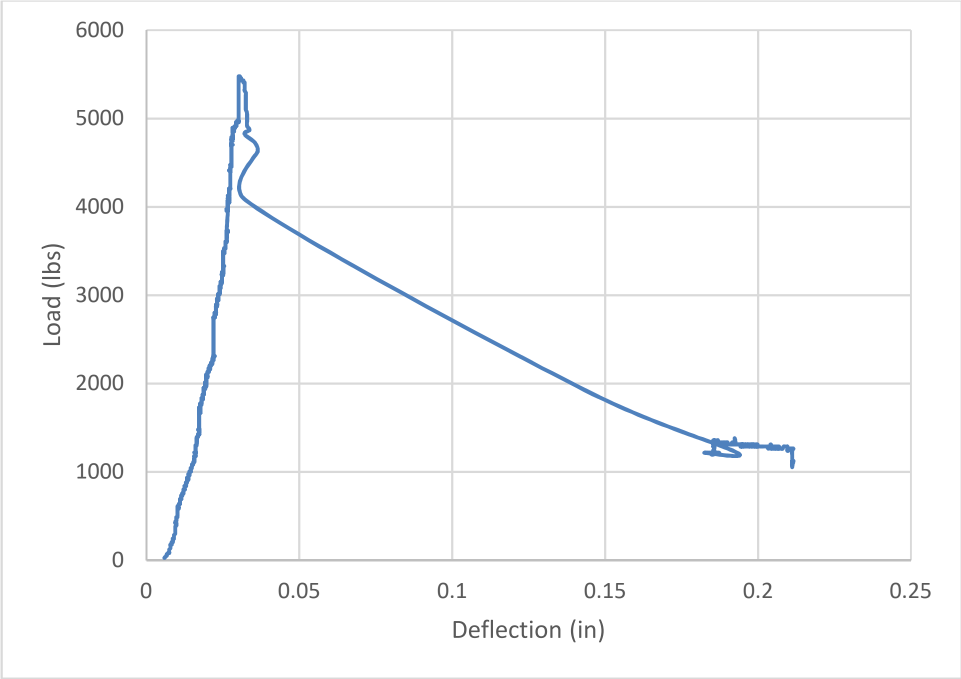


Figure 4- 18. Load-Deflection response for SFRC (1.5%) Slab #2

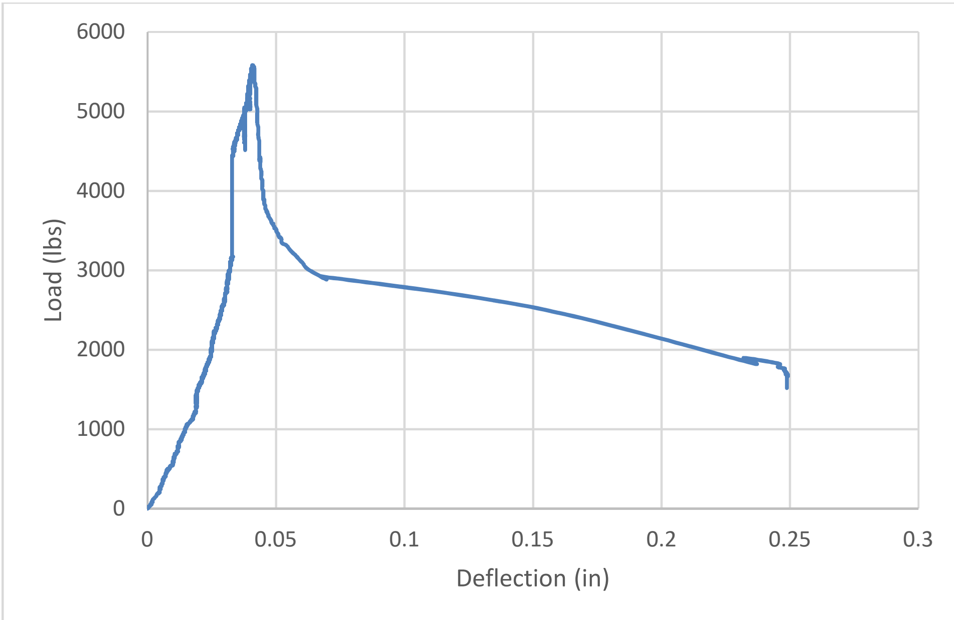


Figure 4- 19. Load-Deflection response for SFRC (1.5%) Slab #3

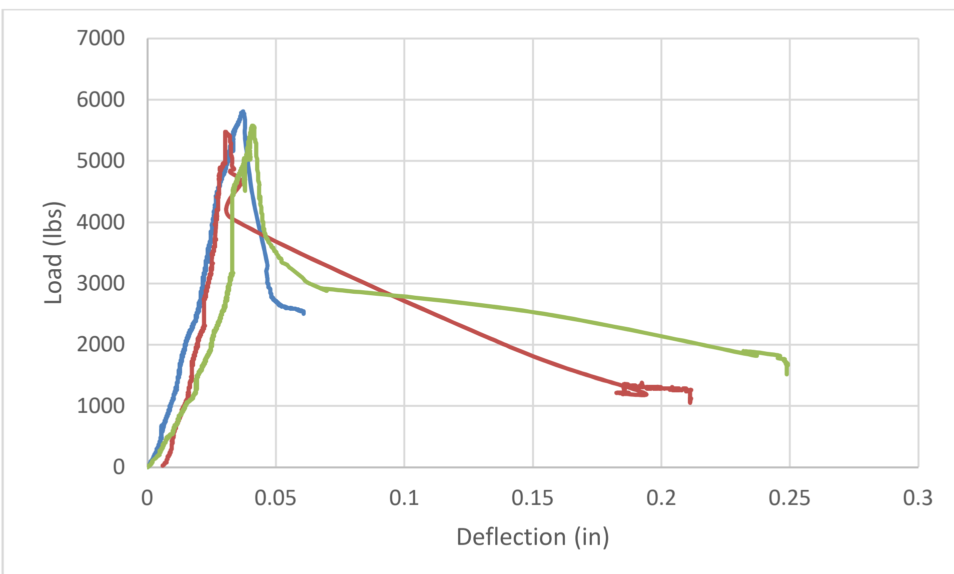


Figure 4- 20. Load-Deflection response for SFRC (1.5%) Slab #1, 2 & 3

CHAPTER FIVE

COST ANALYSIS

Working using steel fiber reinforcement in most cases is not more expensive than using traditional reinforcement concrete it is true that is the rebar per unit weight is indeed less expensive than steel fibers but in order to make correct price comparison, one is to consider the total cost of ownership, it means the total cost of the solution must be taken in to the account and not just the cost of the material per unit weight and doing the comparison indeed we should consider the amount of the materials steel and concrete, in this case to meet the desired requirements, the labor cost to apply the reinforcement and the other factors involved such as the construction time for what concerns the amount of the materials often steel fiber reinforcement require less steel and concrete to build resulting inconsequential in addition for what concerns the cost of labors steel fiber reinforced concrete is easier and quicker to apply, cutting the cost of construction and ensuring fast return of investment, therefore, the total cost of ownership analysis should be done in case by case

Steel fibers are now being produced domestically, which dramatically improves the opportunity for economical construction, the other main objects for this study to carry out a cost analysis when replacing the traditional reinforcing bars by Steel Fibers.

In order to have an idea and compare the cost of ordinary reinforcement concrete deck and steel fiber reinforced concrete deck, there are many aspects to consider, such as reinforcing bars installation time and cost, ready-mix concrete cost and workability.

5.1 Materials:

5.1.1 Concrete

The cost of the concrete is the same for both types of reinforcement, the ready mix concrete is widely used in the projects especially in bridges, as of today the cost per cubic yard delivered to the job site is about $115.

5.1.2 Reinforcement:

One of the differences in cost is the reinforcement, in this research using of # 3 bars at 8 inch center to center is the minimum reinforcement and the amount is 97 lbs per cubic yard while the amount of 1.5% of steel fiber is 61 lbs per cubic yard.

5.1.3 Tie wires and chairs:

Traditional reinforcement bars required tying by using tying wires to place the bars in the right place and also required spacers to chair up the bars and provide the clear cover, and this cost will vary based on the design and other factors while the steel fiber does not require any tying or spacers so the big saving in cost by using steel fiber is the cost of the materials and the time of installation.

5.2 Labors:

5.2.1 Fabrications:

Including all works of detailing the shop drawings cutting and bending the steel bars and even sometimes transport them to the job site and here also time and money involved while steel fiber does not require fabrication.

5.2.2 Formworks:

The process of creating a temporary mold into which concrete is poured and formed, It is easy to produce but time-consuming for larger projects and high cost sometimes which is required for a traditional reinforced concrete while it can be not used when using precast steel fiber decks.

5.2.3 Placing and positioning:

The main difference in cost and time between the traditional and steel fiber reinforced concrete is placing the steel bars because what it takes from cost and time of placing and keeping the steel bars in the right place all the time until the placing the concrete and these activities:

- Getting the reinforcing in the right place by laying the reinforcing bars and tying it together and chair up according to the design drawings.
- Apply and verify the clear cover of the reinforcing bars
- Keeping it there during concrete placement is critical to the structure's performance.
- Reinforcement should be placed as shown on the placing drawings such as the number of bars, bar lengths, bends, and positions
- What is important to remember is that the design of the structure is based on having the steel in the right place and that required reinforcing bar supports, which are made of steel wire, precast concrete, or plastic. Chairs and supports are available in various heights to support specific reinforcing bar sizes and positions. In general, plastic accessories are less expensive than metal supports.
- Simply placing the bars on supports is not enough. Reinforcing steel must be secured to prevent displacement during construction activities and concrete placement. This is usually accomplished with tie wire. Tie wire comes in 3- or 4-pound coils. Wires are placed in a wire holder or a reel is suspended from the worker's belt for accessibility. The wire is typically 16½- or 16-gauge black, soft, annealed wire, although heavier reinforcement may require 15- or 14-gauge wire to hold the proper position of the rebar. A variety of tie types (ties are basically wire

twists for connecting intersecting bars), from snap ties to saddle ties, are used in the concrete reinforcing industry.

5.2.4 Inspection:

This is the time spending on inspecting all reinforcement works to make sure it is done per the design drawings and it is in the right place and meet the codes requirements.

So the cost of engineering, design, fabrication, placing, and inspection of the reinforcement concrete is much higher than the cost of placing steel fiber concrete mixture.

5.3 Finishing the concrete

As the amount of fibers is increased, the workability of the concrete is influenced. Therefore, special techniques and concrete mixtures are used for steel fibers such as addition of super plasticizer. Finishing problem may arise if proper techniques and proportions are not used, with the fibers coming out of the concrete while this issue is not exist in the conventional concrete so in general the cost for placing and finishing the Steel Fiber concrete is relatively higher than the conventional concrete.

In order to have a clear idea about the differences in cost of the traditional reinforcement and the steel fiber reinforcement in bridge decks a cost analysis has been made in Table 5-1 shows the cost of each item and activity in both types of concrete reinforcement between traditional reinforcement without steel fiber (RC 0%) and having # 3 bars @ 8 inch center to center in 3.5 inch thickness and steel fibers reinforced concrete with steel fiber fraction of 1.5% (SFRC 1.5%) considering the cost of 1 cubic yard of concrete including cost of all materials and labors.

Table 5- 1. Cost & Time Comparison between Traditional reinforced concrete and Steel fiber concrete

		Traditional Reinforced Concrete With 0% of steel fiber	Steel Fiber Concrete With 1.5% Steel fiber
Materials	1	Concrete: The cost and time of ready mix delivered to the job site will be the same for both types of reinforcement.	Concrete: The cost and time of ready mix delivered to the job site will be the same for both types of reinforcement.
	2	Reinforcement bars: The cost of reinforcement steel bars is less than the cost of the using the steel fiber reinforcement	Steel Fiber: As it’s known the steel fiber is costly but to address the total cost is to consider the total cost of ownership.
	3	Tie wires and chairs: Traditional reinforcement bars required tying by using tying wires to place the bars in the right place and also required spacers to chair up the bars and provide the clear cover, and this cost will vary from based on the design also this will required time to apply it.	No ties wire and chairs required

Labors	1	Fabrication: Including all works of detailing the shop drawings cutting and bending the steel bars and even sometimes transport them to the job site in addition to this cost the fabrication processes will required time also.	Fabrication: No fabrication is required No time required
	2	Formworks : Which is the cost of all processes of creating a temporary mold into which concrete is poured and formed, also the formworks will take time for installation, inspection and demolishing	Formwork : The main goal of this research is to speed up the construction so the recommendation is to use precast steel fiber concrete bridge decks so the cost will negligible also there is no time to spend for the formworks
	3	Labors: It is the cost of all activities of placing, tying and chair up the reinforcement bars and inspect the reinforcement and the formworks also placing the concrete and finishing it.	Labors: No placing of reinforcement required in using of steel fiber and the only cost will be the placing and finishing the concrete.

5.4 Conclusion

From the Comparison in Table 5-1 we can address some important things:

5.4.1 Cost;

As shown in the table of the differences between the two types of reinforcement, it is clear that the total cost of the ownership of using steel fiber in concrete bridge decks is less than the traditional reinforced concrete.

5.4.2 Time:

The steel fiber also won when it comes to the time of construction, the steel fiber reduced the time of construction significantly and cutting the cost of construction and ensuring fast return of investment of the project.

5.4.3 Flexure Strength:

Per the experimental in chapter four, the maximum load before failure was 9259 lbs and 5606 lbs for traditional reinforced concrete slab and 1.5% steel fiber concrete slab respectively, the reason of this difference is because the steel reinforcement bars is not equivalent to the steel fibers, so by adding more steel fibers to get the same maximum load that will increase the cost of the concrete mix a little bit and the overall cost will be less than the traditional reinforced concrete with same strength.

CHAPTER SEVEN

SUMMARY AND CONCLUSIONS

6.1 Summary

In summary, the flexure strength performance and failure mechanism of 12 concrete slabs with/without Steel Fiber are studied and discussed in this research study. 45 x 20 x 3.5 inch slabs with various fiber dosage were produced and tested at Civil Engineering Laboratory Building (CELB) at the University of Texas at Arlington. This includes longitudinally reinforced concrete slabs (RC), reinforced concrete slabs with 0.5% steel fiber reinforced concrete (SFRC 0.5%), 1% steel fiber reinforced concrete slabs (SFRC 1%) and 1.5% steel fiber reinforced concrete slabs (SFRC 1.5%). Concrete slabs are tested using a 400-kips compression testing machine using a simply supported setup. The resulting load-deflection curves for each specimen are obtained and discussed. The results showed the improved overall performance of concrete slabs reinforced using steel fibers. Furthermore, a total of 12 cylindrical specimens, 4-inch diameter, and 8-inch height, were tested after 28 days curing using a 500-kips compression testing machine per ASTM C39 and ASTM C496 standards, total of 12 cylindrical specimens and 6-inch diameter and 12-inch height, were tested after 28 days curing using a 500-kips tensile testing machine per ASTM C496, the resulting of maximum curves obtained from these tests demonstrate improved compression capacity of Steel fiber reinforced concrete cylinders. Likewise, the splitting-tensile tests not only showed improved tensile capacity but also considerable improvement in the failure mechanism of steel fiber reinforced cylinders relative to plain concrete specimens. In addition, a total of 12 beam specimens, 6 in by 6 in. by 20 in. were produced and tested per ASTM C1609. The results showed improved flexural crack resistance and higher tensile load capacity of steel fiber reinforced concrete beams. This study reports on the increased concentrated load performance of concrete slabs due to the application of 0.5%, 1% and 1.5% Steel fibers into the concrete matrix.

In conclusion, the results obtained through experimental testing of steel fiber-reinforced concrete specimens showed relative improvement in shear strength, tensile strength and compressive strength. Testing of concrete slabs specimens showed that slabs with Steel fiber reinforcement improving overall performance and the improvement directly proportional to the increase of steel fiber.

The Average concentrated load results clearly showed that it is increasing proportionally with the increase of the steel fiber. With the addition of steel fibers in fraction of 0.5% and 1.0% the maximum load applied on concrete slab increased by 15.3% while the increase in maximum load with the addition of steel fiber in fraction of 1% to 1.5% is 22.8%, fibers had the highest effect on the maximum load while 1.5% had almost higher effect on the strength.

Also the concrete slabs behaves as more ductile materials with the higher dose of steel fiber and this is clearly shown that the deflection before they fail with 0.5% of steel fiber (SFRC0.5%) was 0.023 inch and this goes up to 0.0313 inch with 1% of steel fiber (SFRC1%) and then goes to 0.036 inch with 1.5% of steel fiber (SFRC1.5%).

6.2 Conclusion

1. In general, the performance of the concrete slabs was increasing with the increase of steel fiber.
2. The increase in compressive strength was relatively low, the high dosage of steel fiber may increase the air content and reduce the compressive strength.
3. The tensile strength of the concrete slabs increased proportionally with the increase of steel fiber.
4. The flexure strength of the concrete slabs increased proportionally with the increase of steel fiber.
5. The behavior of the concrete slabs with steel reinforcement was better than the concrete slabs with steel fiber because the steel reinforcement was carrying the load right after the cracks occurred.
6. The area under the Load-Deflection curve increased with the increased of the steel fiber so its mean the concrete slabs with steel fibers were gaining strength with the increase of the steel fiber and this is clearly shown on the Load-Deflection figures.
7. With the increase of steel fiber dosage the width of the crack of the concrete slabs decreased and turned from sudden cracks to gradually cracks so that's mean the concrete behaved as a ductile material with a high dosage of steel fiber.
8. The deflection right before the failure happened of the concrete slabs increased with the increase of the steel fiber dosage.
9. The total cost of steel fiber reinforced concrete is less than the cost of steel bars reinforced concrete.

10. The construction time by using the steel fiber reinforced concrete is much less than the steel bars reinforced concrete and this will speed up the construction time of the projects and fast return of project incensement.
11. The steel fiber have more corrosion resistant options over the conventional reinforcing bars as corrosion of reinforcing steel in the most common path to failure of the bridge deck

6.3 Recommendations

1. In order to get high performance of using steel fiber reinforced concrete decks the research recommend adding wire mesh to steel fiber reinforced concrete matrix.
2. Use high fraction of steel fiber (1.5% or higher) to obtain high flexural strength.
3. Investigate the Conduct a parametric study on the behavior of SFRC slabs under concentrated load and investigate the following parameters:
    - Aspect ratio of steel fiber
    - Type of steel fiber
    - Slab thickness
    - support type
    - coarse aggregate size compare with steel fiber length
4. Investigate the behavior of the concrete slabs with another steel fiber dosage.
5. Using FE analysis and material models to predict the behavior of SFRC slabs under concentrated load with the best structural performance.
6. Complete experiments including:
    - The uniaxial tension,
    - The biaxial failure in plane state of stress
    - The triaxle test of concrete

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