# Properties of Concretes Produced by Single and Combined Hooked End Discontinous Discrete Steel Fibers

**Kamran Keikhaei**

Submitted to the
Institute of Graduate Studies and Research
in partial fulfillment of the requirements for the Degree of

Master of Science
in
Civil Engineering

Eastern Mediterranean University
September 2012
Gazimağusa, North Cyprus

Approval of the Institute of Graduate Studies and Research

Prof. Dr. Elvan Yılmaz
Director

I certify that this thesis satisfies the requirements as a thesis for the degree of Master of Science in Civil Engineering.

Assist. Prof. Dr. Murude Çelikağ
Chair, Department of Civil Engineering

We certify that we have read this thesis and that in our opinion it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Civil Engineering.

Assoc. Prof. Dr. Özgür Eren
Supervisor

Examining Committee

1. Assoc. Prof. Dr. Özgür Eren
2. Assist. Prof. Dr. AlirezaRezaei
3. Assist. Prof. Dr. Serhan Şensoy

# ABSTRACT

Steel fibers are widely used in concrete as additional industrial materials for concrete products. Because of its huge application areas it keeps its popularity to be an academic research on developing the usage of them. As concrete is naturally weak in tension, steel fibers added will improve tensile strength of concrete. Producing steel fiber reinforced concrete is not a very new technology in but these concretes are generally produced by using only one type of steel fiber (aspect ratio, diameter or length) due to economical and practical reasons and concretes having various types of these fibers are not generally produced. Finding an optimum combination of fibers that are added to concrete which develop the SFRC properties in both, fresh and hardened states would bring many benefits.

This study investigates the effect of adding combined steel fibers with two different aspect ratio(80, 60) and three different length (60, 50, 30) on concrete properties in fresh and hardened states. These concretes are produced by combining these different fibers with varying volume percentages. At the end of the study, optimum combination obtained by comparing the effects of the mixes with the plain concrete, on fresh properties such as workability and hardened properties such as compressive strength, flexural strength, rebound number, ultrasonic pulse velocity and drying shrinkage. The results have shown that the adding combined fibers to the concrete, increase the compressive strength, flexural strength and rebound number, on the other hand adding fibers enhances the ultrasonic pulse velocity and drying shrinkage of concrete as well.

**Keywords:** Steel fibers, concrete, aspect ratio, strength, shrinkage, Vebe time, pundit.

# ÖZ

Günümüzde çelik elyaf endüstriyel ürünlerde yaygın olarak kullanılmaktadır. Yaygın kullanımından dolayı ise akademik araştırmalarda hala daha önemli bir yer tutmaktadır. Betonun çekme dayanımının zayıf olmasından dolayı çelik elyaf betona karıştırılmaktadır. Genelde betona karıştırılan çelik elyaf tek bir narinlik oranı veya boyda olmaktadır. Bunun esas nedeni ekonomi ve uygulamadaki pratikliktir. Diğer taraftan betona farklı narinlik be boda olan çelik elyafın karıştırılması betonun taze ve kuru özelliklerini geliştirebileceği düşünülmektedir.

Bu çalışmada esas olarak narinlik oranı 80 ve 60 olan çelik elyafın farklı karışım oranlarında birleştirilerek kullanılması ile elyaflı beton üretilmesi ve üretilen betonların taze ve kuru özelliklerinin ölçülmesi hedeflenmektedir. Burada kullanılacak olan çelik elyaf üç değişik boyda kullanılacaktır (60, 50, 30 mm). Ölçülecek olan özellikler ise VeBe zamanı, basınç dayanımı, çekme dayanımı, beton çelici, pundit ve kuruma büzülmesi olarak belirlenmiştir. Bu çalışma sonucunda ise en iyi sonucu veren optimum karışım oranları ve boyutu ortaya çıkacaktır.



**Anahtar Kelimeler:** çelik elyaf, beton, narinlik oranı, mukavemet, büzülme, VeBe zamanı, pundit.

To my dear parents for their everlasting support and love

# ACKNOWLEDGMENT

The special thank goes to my helpful supervisor, Assoc. Prof. Dr. Özgür Eren. The progression of this study was impossible without his supervision, guidance and support that he gave.

My grateful thanks also go to Materials Of Construction Laboratory staff at EMU, Mr. Ogün Kılıç for his effort during experimental part of this study.

I would like to thank all the staff in Civil Engineering department in EMU for their help and support for completing this study.

Lastly, I would also like to disclose my special thanks to my parents, my elder brother, my two elder sisters and my best friends. They were always supporting me and encouraging me with their useful opinions.

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# LIST OF SYMBOLS

| | |
|---|---|
| ACI | American Concrete Institute |
| ASTM | American Society for Testing and Materials |
| BS EN | British European Standards |
| SFRC | Steel Fiber Reinforced Concrete |
| l/d | Length/diameter ratio, fiber aspect ratio |
| UPV | Ultrasonic Pulse velocity |

# Chapter 1

# INTRODUCTION

## 1.1 Common information

Since ancient times, brittle materials have been reinforced by using fiber. For instance, horse hair was used for reinforcing masonry mortar and plaster. Nowadays, a wide range of engineering materials include fibers to improve their properties such as tensile strength, crack resistance, crack control, shrinkage and elastic modulus.

From 1910, some experimental examinations that were using discontinuous steel reinforcing elements such as nails, to develop the properties of concrete were carried out. The first major investigation on steel fiber in United States was performed to estimate the ability of steel fibers for a reinforcement for concrete during the early 1960s. Since then, a large amount of investigation, development and research on steel fiber reinforced concrete has done (Zollo R, 1996).

Application of steel fiber reinforced concrete since mid-1960s have included a few subjects of construction works. Other new developments in concrete field were also aided the usefulness of SFRC. Superplasticizers enhance the workability of insensitive SFRC mixes (ACI 544.1, 2002).

Adding steel fibers to the concrete enhance concrete properties such as tensile compressive and shear strength. The amount and type of fibers affect the properties of steel fiber reinforced concrete significantly(Dvorkin & Zhitkovsky, 2011).

Using fibers instead of conventional concrete will have impact on construction process. The cost of construction has affected by using reinforcement bars in concrete structure construction sections ( Cunha etal., 2008).

Improving the properties of concrete by steel fibers made the researchers to work on it and also this fact has been contributing to an increasing number of structural application of SFRC. Nonetheless, there is a long way to go on the development of methods and design procedure to improve the reliability of this material (Laranjeira & Grunewald, 2010).

## 1.2 Problem statement

Concrete is an inseparable material from construction works. Although it has a lot of advantages, there are many ways to develop its properties in order to use it in special cases. Adding steel fibers to the concrete is not a very new technology but the methods of producing SFRC is one the important topics that researchers are working on it. Therefore, it was necessary to examine a different model of adding steel fibers to the concrete in order to improve SFRC's properties.

## .1.3 Scope of the study

The aims of this investigation are:

1. To provide a brief literature survey about steel fiber reinforced concrete such as characteristics, physical properties and mechanical properties.

2. To design SFRC with the acceptable workability by using available material on N.Cyprus.

3. Gathering data about how effective is the amount of steel fibers with different length and aspect ratio on SFRC in fresh state such as consistency and workability, and in hardened state such as compressive strength, flexural strength, rebound number, ultrasonic pulse velocity and drying shrinkage tests.

4. To study the effect of the combination of steel fibers with different length and aspect ratio on fresh properties of SFRC such as workability and consistency, and hardened properties such as compressive strength, flexural strength, rebound number, UPV and drying shrinkage tests.

## 1.4 Works carried out

The following works were done in order to achieve the objectives of the study which explained above:

1. A survey of the publications on this subject was done in order to evaluate the previous works.

2. BS EN and ASTM standards were used in order to carry out the experiments in its correct way in this study.

4. Sieve analysis for fin and coarse aggregates was done.

5. Trial mixes were designed and tested in order to find out the proper water/cement ratio that satisfy the workability of SFRC mixes.

6. Experiments in order to examine the fresh properties of SFRCs such as workability and consistency were done.

7. Laboratory tests for evaluating the hardened properties of SFRCs such as compressive strength, flexural strength, rebound number, UPV and drying shrinkage tests were carried out.

## 1.5 Achievement

The followings were achieved from this study:

1. The proper mix design with acceptable workability for SFRCs.

2. Aggregates were tested in order to estimate their physical properties and mechanical properties.

3.The effect of different amount of steel fibers on fresh properties of SFRC was evaluated.

4. The effect of the combination of two or three different sizes of steel fibers on fresh properties of SFRC was assessed.

5. The effect of various amount of steel fibers on concrete in hardened state such as compressive strength, flexural strength, rebound number, UPV and drying shrinkage were evaluated.

6. The effect of the combination of two or three different sizes of steel fibers on the properties of concrete in hardened state such as compressive strength, flexural strength, rebound number, UPV and drying shrinkage were evaluated.

## 1.6 Thesis guideline

Chapter 2 deals with a review of the works that have been done before on steel fiber reinforced concrete.

Chapter 3 contains the properties of the material used in this study and the experiments details. The methods for mixing process, casting of specimens, curing procedure and tests procedure are clarified. The details of evaluation of fresh steel fiber reinforced concrete in fresh and hardened state are esplained.

Chapter 4 contains  the results and discussions about the results.

Chapter 5 is the conclusions and the recommendations for further studies.

References are prepared at the end.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Steel Fiber Reinforced Concrete (SFRC)

### 2.1.1 Description of Steel Fiber Reinforced Concrete

Steel fiber reinforced concrete is kind of a concrete which is containing cement with fine aggregate or both fine and coarse aggregate with the addition of discontinuous separate steel fibers (ACI 544.1, p.7).

Steel fibers are strings of wire, that are cut into small pieces with various lengths. They are useful for reinforcing concrete and other composite materials . Hooked end steel fibers are made from low carbon steel wire with high quality. This is a kind of fibers that have good tensile strength, good toughness and they are more economical. This product is used to improve the strength of concrete.

It has been recognized that adding steel fibers to the concrete develops the mechanical properties of it (Chalioris & Sfiri, 2011).

### 2.1.2 Narration of Steel Fiber Reinforced Concrete (SFRC)

In the past 25 years, using of steel fiber reinforced concrete sharply increased. Bentur and Mindess reported that many efforts were done to develop the performance of steel fiber reinforced concrete significantly (Nataraja & Dhang & Gupta, 1999).

Fiber reinforcement was investigated by The Portland Cement Association (PCA) in the late 1950s. These tests showed that adding fibers increases the toughness and the first crack strength (ACI 544.1, p7).

Applications of SFRC embraced road and floor slabs and concrete products until the mid-1960s (ACI 544.1, p.9).

### 2.1.3 Classification and types of steel Fiber

There are different types of steel fibers which are classified according to their shape and production process.

Round, straight steel fibers are produced with wire. Mostly wire having a diameter between 0.25 to 1.00 mm, this kind of fibers are produced by cutting the wire into small pieces.

Flat, straight steel fibers usually have cross sections value from 0.15 to 0.64 mm thickness by 0.25 to 2.03 mm width are shaped by shearing sheet or devastation wire.

Folded steel fibers have been created with both full length folding, or enlarged at the end.

Bending fibers or flattering fibers have been done in order to increase mechanical bonding,

The fibers that are specially designed for the reinforcement of concrete and cementitous mixes. These are cold drawn wire fiber and they are deformed with hooked end to provide most favorable anchorage within the concrete mix (ACI 544.1, p.9)

The investigation shows that the crimped and hooked fibers performed better under the tests(Z. Xu, 2011).

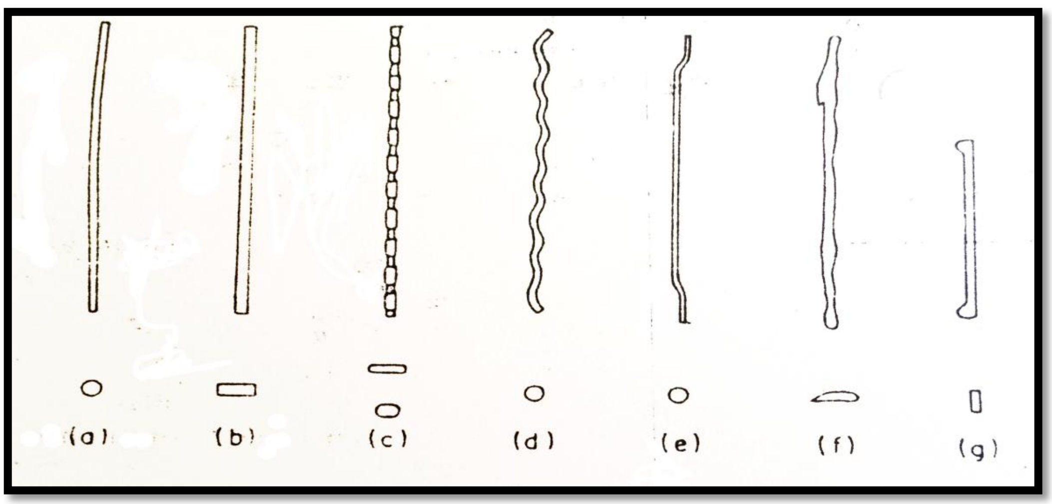


Figure 1: shape of steel fibers, (a) Round, (b) rectangular, (c) indented, (d) Crimped, (e) Hooked ends, (f) Melt extract process, (g) Enlarged ends

### 2.1.4 Benefits of Steel Fiber Reinforced Concrete

Concrete  is a major construction material and its use have been increased nowadays, but it has such problems preventing its usage in concrete structures. The problems of the concrete contain low tensile/compressive strength, low flexural strength, low fracture toughness, high brittleness and shrinkage.

Some properties of concrete can be improved sharply by adding steel fibers to the concrete. for instance, steel fibers improve tensile/compressive ratio, crack resistance and fracture toughness (Jianming Gao, 1997).

### 2.1.5 Physical  properties of SFRC

The important  properties of fibers are stiffness, strength and how good they are to bond with the matrix.

Alkaline environment of the cementitious matrix protect fibers from corrosion, and mechanical anchorage or surface roughness can improve fibers bonding to the matrix. Mechanical properties of steel fibers do not affected by being under load for a long time.

The use of stainless steel fibers is required in particular environments. There are various types of steel fibers but they do not have the same exposure in different situations such as corrosive environment, so the user should consider all of the parameters before designing with steel fibers for specific applications.

### 2.1.6 Fresh properties of SFRC

The length and the aspect ratio of the fibers, affect the steel fiber reinforced concrete in fresh state. Other parameters such as amount of fiber and the characteristics of fiber-matrix interfacial bond also affects that.

For placing SFRC, sufficient workability should be assumed in order to allow placement, consolidation, and finishing in an easier way while having an acceptable uniformity of fibers and having the lowest amount of segregation.

For a given mixture and also for plain concrete, the consolidation degree influences the strength and other hardened material properties ( ACI 544.1, p.10 ).

#### 2.1.6.1 Effect of fiber parameters on workability of SFRC

The balling of fibers must be avoided. If the aspect ratio of long thin steel fibers goes higher than 100 and shaken together, the tendency to form a ball will occur and it is hard to separate only by vibration. Although shorter fibers which their aspect ratio is below 50 have their own problem because they are not able to attach together and during vibration they become dispersed ( Hannant, 1978).

#### 2.1.6.2 Effect of aggregate size on workability of SFRC

The effect of the aggregate size become more obscured when fibers are not introduced into a mortar mix and they are introduced into a concrete instead. This can be avoid by fine grained materials which separate them and move among them. If the fibers distributed uniformly, there are particles in concrete that have larger size than the average fiber spacing ( Hannant, 1978). Figure 2 shows the effects of aggregate size on fiber distribution.

The maximum size of the aggregates and the final gradation of them effect the tendency of a SFRC mixture for create balling of fibers in the freshly mixed state. The aspect ratio of the fibers, the amount of fibers, the shape of fibers, and the method of adding fibers into the mixture also effect it. When larger maximum size of aggregates used, lesser amount of fibers should be added in order not to have a tendency to ball (ACI 544.1, p.10).

**2.1.6.3 Testing fresh SFRC**

SFRC should be tested for fulfilling the workability due to the effects of fibers before producing.

However, when the amount of fibers is increased, the workability of the concrete is decreased (Tayfun, 2010).

**2.1.6.4 VeBe test**

In typical range amount of fibers for SFRC (0.25 to 1.5 volume percent), adding steel fibers to the concrete may decrease the slump in comparison with normal concrete in the range of 25 to 102 mm. British Standards Institution (BS 1881) recommended using Vebe consistometer for assessing the workability of steel fiber reinforced concrete rather than the conventional slump measurement.

Fig 2 shows a relationship between slump and Vebe time.

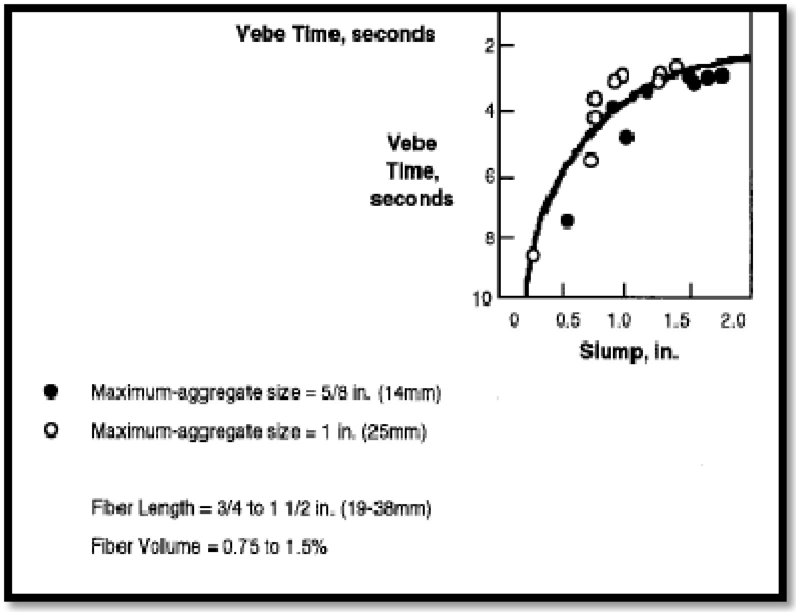


Figure 2: relationship between slump and Vebe time
Source: (ACI 544.1)

### 2.1.7 Properties of SFRC in the hardened state

The bond strength between the fiber and the concrete is one of the major factors which determines the properties of the hardened concrete (Hannant, 1978).

#### 2.1.7.1 Compressive strength

In compression, the presence of fiber had a slightly effect on the ultimate strength. 1.5 percent fibers increased the strength from 0 to 15 percent (ACI 544, p.10).

#### 2.1.7.2 Flexural Tensile Strength of SFRC

All the researchers agreed that the important parameters which affect the flexural strength are the amount of fiber and the aspect ratio of the fibers (Hannant, 1978).

An increase in both, volume and aspect ratio of the fibers will increase the flexural strength linearly (Eren, 1999).

Flexural strength of SFRC increases more than tension or compression and it is because of ductile behavior of the SFRC on the tension side of a beam that alters the normal elastic distribution of stress and strain over the member depth.

Although it is observed that flexural strength can be increased up to two times by using four percent amount of fibers in a sand-cement mortar, it is recently found out that using coarse aggregates in the mix and by considering normal mix and placing procedure, limit the fiber amount from 1.5 to 2.0 percent (ACI 544.1, p.11).

#### 2.1.7.3 Toughness and ductility of SFRC

Toughness is a very important parameter for distinguishing steel fiber reinforced concrete from normal concrete.

The primary parameters which affecting toughness of SFRC are the form, length/diameter ratio, amount of fiber and orientation of the fiber itself (ACI 544.1, 1996).

Flexural loading is the technique that researchers prefer to use for evaluating toughness.

JSCE SF-4 and ASTM C 1018 which are the standardized slow flexure methods, by analysis of the load-deflection curve, the toughness can be observe. Fig. 3 shows the procedure.

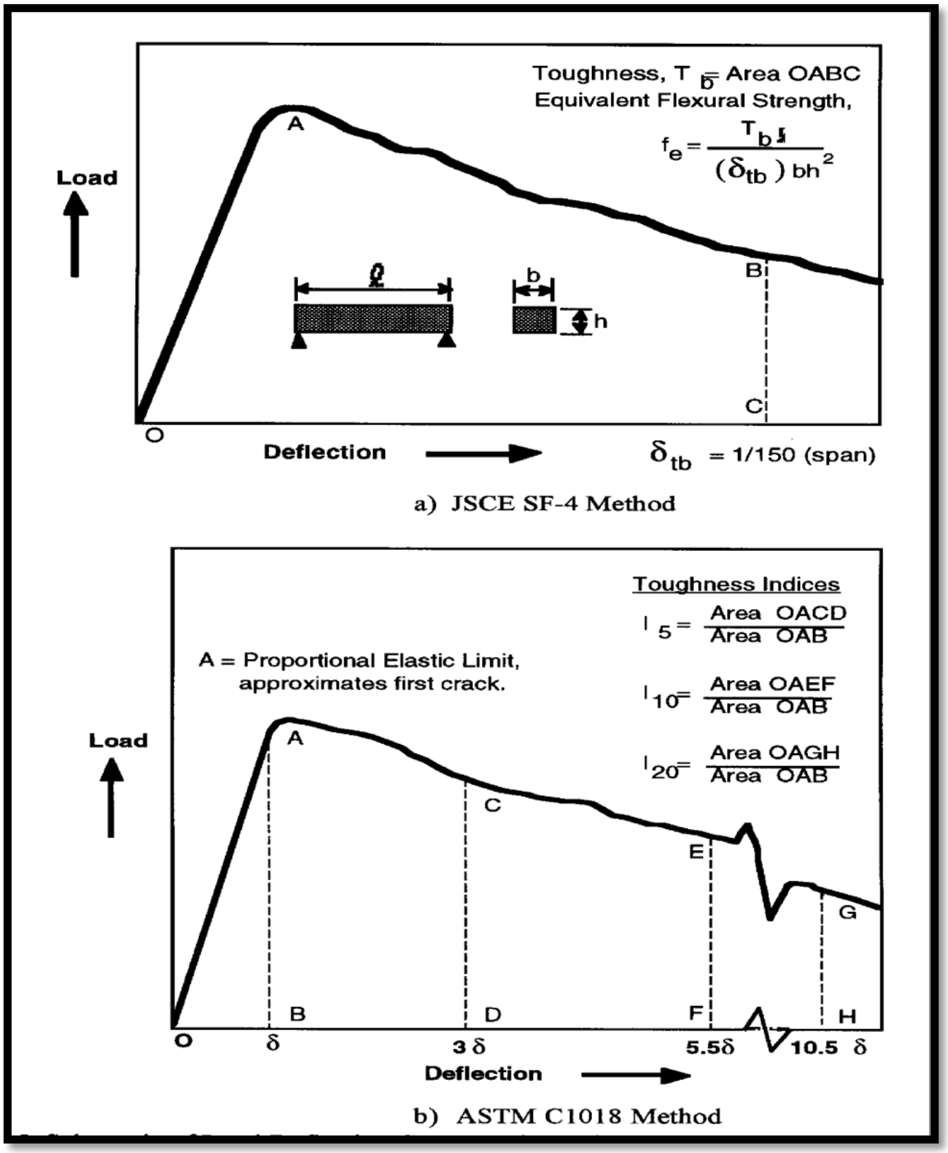


Figure 3: Load-deflection curve and toughness parameters
source: (ACI 544.1, p.12)

### 2.1.7.4 Shrinkage of SFRC

Limited test data indicates that steel fiber reinforcement having steel fiber less than one percent do not affect the creep and shrinkage of portland cement mortar and concrete significantly.

# Chapter 3

# EXPERIMENTAL WORKS

## 3.1 Introduction

Steel Fiber Reinforced Concrete (SFRC) mixes were made of portland cement, crushed lime stone aggregates (fine and coarse aggregates), superplasticizer and steel fiber with different aspect ratio in laboratory environment. The test that was performed just after mixing on fresh concrete was VeBe time test. Other tests such as, compressive strength, flexural strength, UPV test, schmidt hammer test and drying shrinkage test were done on hardened concrete.

## 3.2 Mixes and material details

### 3.2.1 Information of the cement

In this investigation, CEM II/B-M (S-L) 32,5 R was used which was kept in dry place. The cement that is used in this study is produced in North Cyprus. The cement used was CEM II/B-M (S-L) 32,5 R according to EN 197-1. The details of the compositions of the cement are given in Table 1.

Table1: The compositions of the CEM II/B-M (S-L)

| | |
|---|---|
| Composition | The Portland composite cement CEM II / BM (S-L) 32.5 R is produced from the grinding of<br>- + - 66% PORTLAND CEMENT BRICK<br>- + - 17% BLAST FURNACE SLAG GRANULATED<br>- + - 11% LIMESTONE low TOC<br>- + - 6% natural anhydrite |
| Principal properties | The cement quality CEM II/B-M (S-L) 32,5 R is ground to a moderate fineness which allows to use it in the manufacture of normal quality concrete |
| Fields of application | The cement quality CEM II/B-M (S-L) 32,5 R is recommended in the manufacture of lean concrete and ordinary concrete used on site. |
| **Setting time (min)** | |
| Initial | 225 |
| Final | 345 |
| **Le chatelier (mm)** | 0.64 |
| Specific weight (gr/cm3) | 3.23 |

### 3.2.2 Information of aggregates

All the aggregates used in this study were crushed limestone from Beşparmak Mountains, Cyprus. 20mm aggregates were used as maximum size of aggregates. Table 2 shows the aggregate properties. The coarse and fine aggregate grading was fulfilling the ASTM standard ( ASTM C 33, 2008). The details of the sieve analysis for fine and coarse aggregates are also shown in Table 3 and Table 4 respectively. The grading curve for fine aggregates is drawn in Figure 4 according to the standard (ASTM C 33, 2008). Figure 5 shows the grading curve for coarse aggregates.

Table 2: The properties of fine aggregates and coarse aggregates

| **Properties** | **Relevant Standards** | **Fine Aggregate** | **Coarse Aggregate** |
|---|---|---|---|
| Relative Density | (ASTM C 127, 2007)<br>(ASTM C 128, 2007) | 2.65 | 2.69 |
| Water absorption (% of dry mass) | | 2.57 | 0.7 |
| Dust content (%) | (ASTM C 117, 2004) | 16.5 | 4.2 |

Table 3: Sieve analysis data for fine aggregate

| **Sieve size (mm)** | **Percentage passing of fine aggregate (by weight)** |
|---|---|
| 9.5 | 100 |
| 4.75 | 100 |
| 2.36 | 85 |
| 1.18 | 69 |
| 0.600 | 34 |
| 0.300 | 26 |
| 0.150 | 6 |
| 0.075 | 1 |

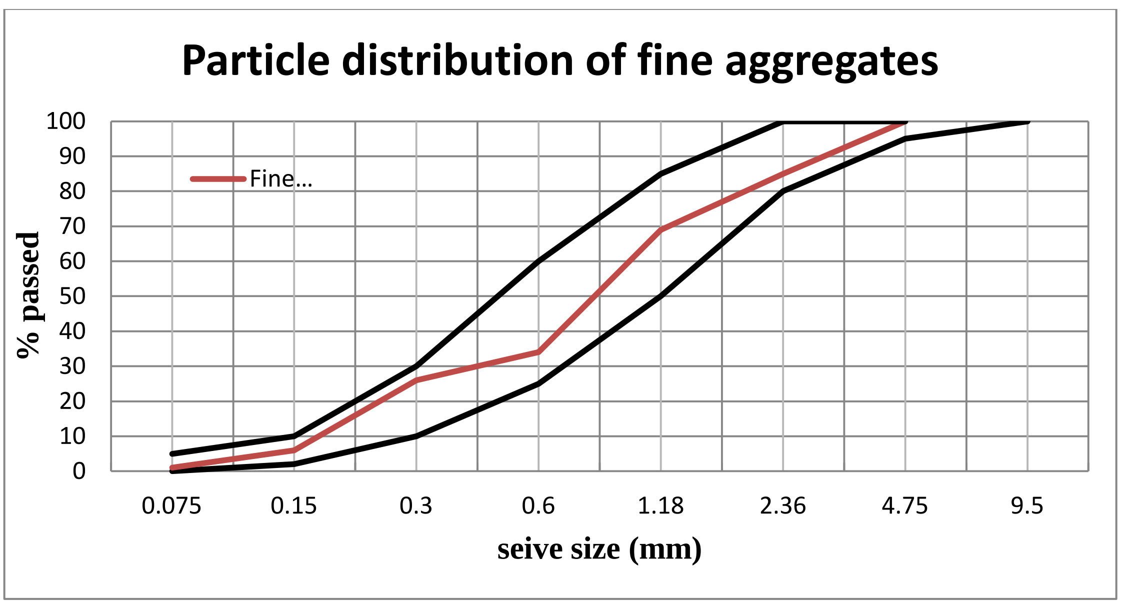


Figure 4: Particle size distribution of fine aggregates

Table 4: Sieve analysis data for coarse aggregates

| Sieve size (mm) | Percentage passing (by weight) of coarse aggregate |
|---|---|
| 37.5 | 100 |
| 25 | 100 |
| 19 | 94 |
| 9.5 | 48 |
| 4.75 | 8 |
| 2.36 | 4 |

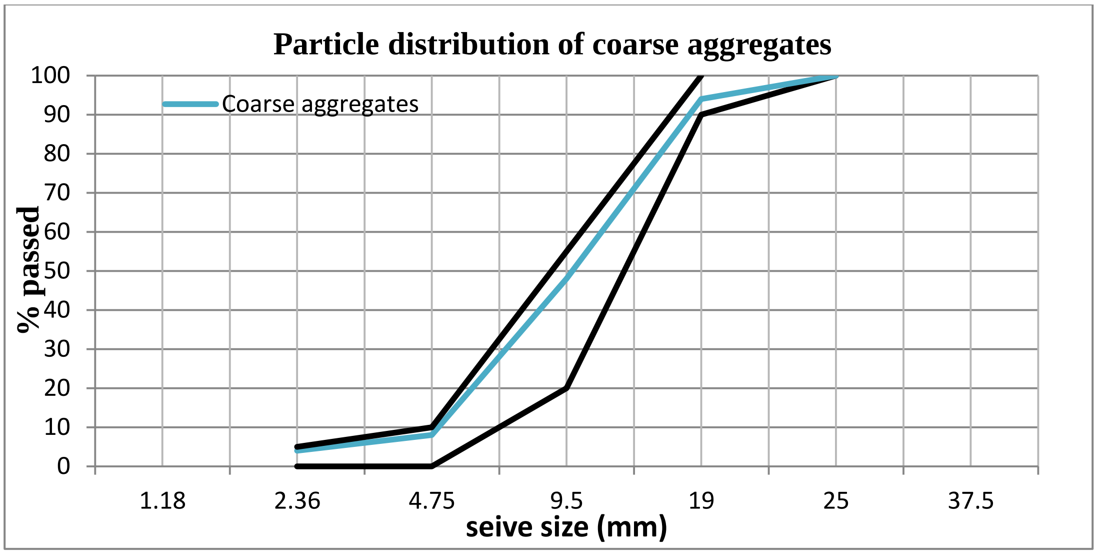


Figure 5 : Particle size distribution of coarse aggregates

### 3.2.3 Mixing water

The mixing water that was used for mixing process was drinking-quality. For curing process, the same water was used.

### 3.2.4 High range water reducer(superplasticizer)

As using the fiber in concrete mix reduces the workability, using water reducing admixture is essential. A high range water reducing admixture (superplasticizer) (Glenium 27) is used in order to increase the maintain the workability of concrete in fresh state. The properties of Glenium 27 are shown in Table 5.

Table 5: The properties of Glenium 27

| | |
|---|---|
| **Product Information** | |
| Color/appearance | Brown liquid |
| Storage condition/ shelf life | Store in reasonable temperature above +5°C in closed packs. Recommended to store in unopened containers up to 12 months under manufacturer's instructions. |
| Packing | available in 200 liter drums, 1000 liter pallecons and bulk |
| **Product technical information** | |
| Chemical base | based on a unique carboxylic ether polymer with long lateral chains |
| **Application information** | |
| Dosage | 0.4-1.6 liters per 100kg of cement is recommended. The dosage rate also depends on mix design and other requirements. |
| Application notes | Should be added to the concrete mix after 50-70% of water is added.<br>It should add carefully for a complete dispersion during the mix.<br>Should not be added to the dry aggregates. |
| Features and Benefit | • Having concrete with good workability and no segregation with the lowest w/c ratio.<br>• Excellent slump retention without retardation<br>• Reduces the curing cycles<br>• Reducing the vibration time even in case of congested steel reinforcement<br>• Less workman is required<br>• Developing the surface and quality of finished concrete<br>• GLENIUM 27 has more benefits than old superplasticisers, adding it to the mix will improve concrete durability and physical properties of it.<br>•Decreases Risk of shrinkage |

### 3.2.5 Information of steel fiber

The fiber that used in this investigation were hooked end steel fibers with three different aspect ( length over diameter) ratio/length. The aspect ratio/length of the fibers were 80/50, 80/60 and 60/30.

## 3.3 Mixes details

In this study, the concrete mix was designed according to the standard (BRE 331, 1988). The net water cement ratio used for the concrete mix was 35%. All the mixes were the same and only the percentage and types of the fiber were different. The details of the mixes and fiber percentage for each mix are shown in Table 6 and 7, respectively.

Table 6: The amount of the mixes ingredients

| | **Cement** | **Water** | **Fine aggregate** | **Coarse aggregate** | **Super Plasticizer** |
|---|---|---|---|---|---|
| For plain and SFRCs mixes | 640 | 225 | 650 | 861 | 3.2 |

Table 7: The amount of the fibers for each mix

| Concrete type | Fiber 80/50 | Fiber 80/60 | Fiber 60/30 |
|---|---|---|---|
| **Plain** | 0 | 0 | 0 |
| **F1 (0.5%)** | 39.50 | 0 | 0 |
| **F1 (1%)** | 78.50 | 0 | 0 |
| **F1 (1.5%)** | 117.75 | 0 | 0 |
| **F2 (0.5%)** | 0 | 39.50 | 0 |
| **F2 (1%)** | 0 | 78.50 | 0 |
| **F2 (1.5%)** | 0 | 117.75 | 0 |
| **F3 (0.5%)** | 0 | 0 | 39.50 |
| **F3 (1%)** | 0 | 0 | 78.50 |
| **F3 (1.5%)** | 0 | 0 | 117.75 |
| **F1(0.25%), F2(0.75%)** | 16.12 | 55.37 | 0 |
| **F1(0.5%), F2(0.5%)** | 39.50 | 39.50 | 0 |
| **F1(0.75%), F2(0.25%)** | 55.37 | 16.12 | 0 |
| **F1(0.25%), F3(0.75%)** | 16.12 | 0 | 55.37 |
| **F1(0.5%), F3(0.5%)** | 39.50 | 0 | 39.50 |
| **F1(0.75%), F3(0.25%)** | 55.37 | 0 | 16.12 |
| **F2(0.25%), F3(0.75%)** | 0 | 16.12 | 55.37 |
| **F2(0.5%), F3(0.5%)** | 0 | 39.50 | 39.50 |
| **F2(0.75%), F3(0.25%)** | 0 | 55.37 | 16.12 |
| **F1(0.25%), F2(0.25%), F3(0.5%)** | 16.12 | 16.12 | 39.50 |
| **F1(0.5%), F2(0.25%), F3(0.25%)** | 39.50 | 16.12 | 16.12 |
| **F1(0.25%), F2(0.5%), F3(0.25%)** | 16.12 | 39.50 | 16.12 |
| **F1(0.33%), F2(0.33%), F3(0.33%)** | 21.27 | 21.27 | 21.27 |

## 3.4 Mixing process

For each concrete mixes, the coarse aggregate, fine aggregate, cement, steel fibers, water and superplasticizer were put in the laboratory mixer. This procedure was used for all the mixes in order to have a homogenous mixes and decrease the risk of possible inequality of each mix.

Steel fibers were added to the mix during dry mixing process and after that the water and superplasticizer were added . The mixing process time was about 4 minutes in order to have a uniform composite. Photo 1 and 2 show the mixing procedure and concrete mix obtained.

Photo 1: The mixer and the materials ready for mixing

Photo 2: A typical concrete mix

## 3.5 Casting of the specimens

### 3.5.1 Casting the specimens for compressive strength test

For compressive strength test of steel fiber reinforced concrete, cubic molds were used. Size of the cubic specimens was 150 mm. Nine samples were casted for each mix according to the standards (BS EN 12390-2, 2009). The samples were cured in water tank for 3,7 and 28 days until testing. Photo 3 shows the samples for compressive strength test casting.

Photo 3: The compressive strength test samples

### 3.5.2 Casting the specimens for flexural strength test

Three beams were casted for flexural strength test. The size of each beam was 100 × 100 × 500 mm. All the specimens were cured in water for 28 days. Photo 4 shows the casting of flexural test beams.

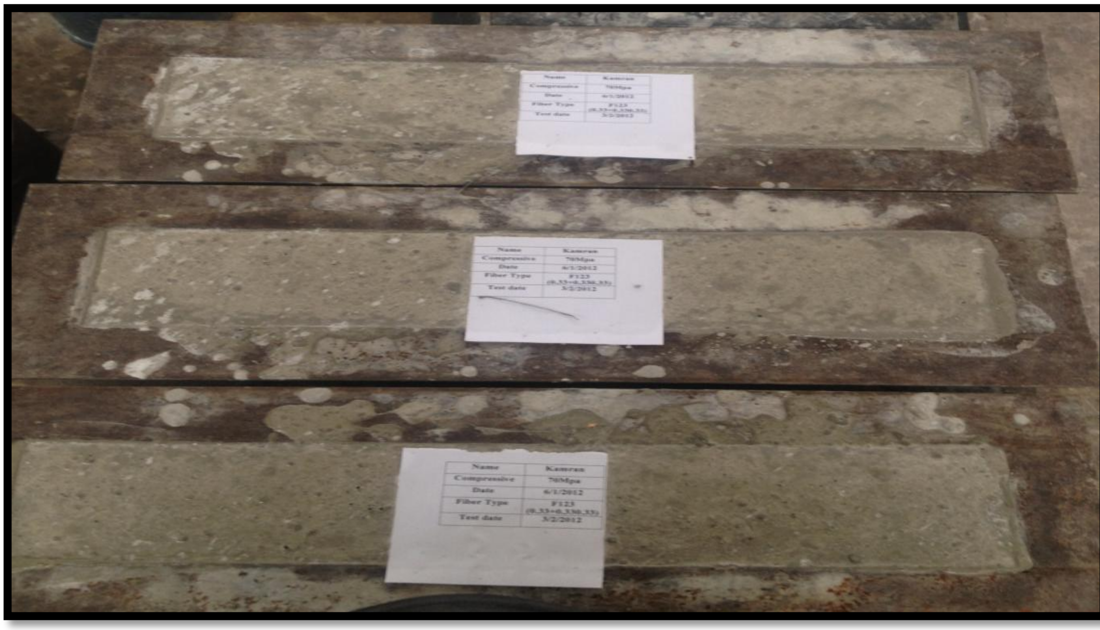

Photo 4: Flexural strength test beams

### 3.5.3 Casting the specimens for drying shrinkage test

One specimen was casted for drying shrinkage test. Test beam size was 100 × 100 × 300 mm. The specimens were cured in water tank for 28 days and after that, they were placed in laboratory room for reading the length change periodically. Photo 5 shows the shrinkage beam test mold.

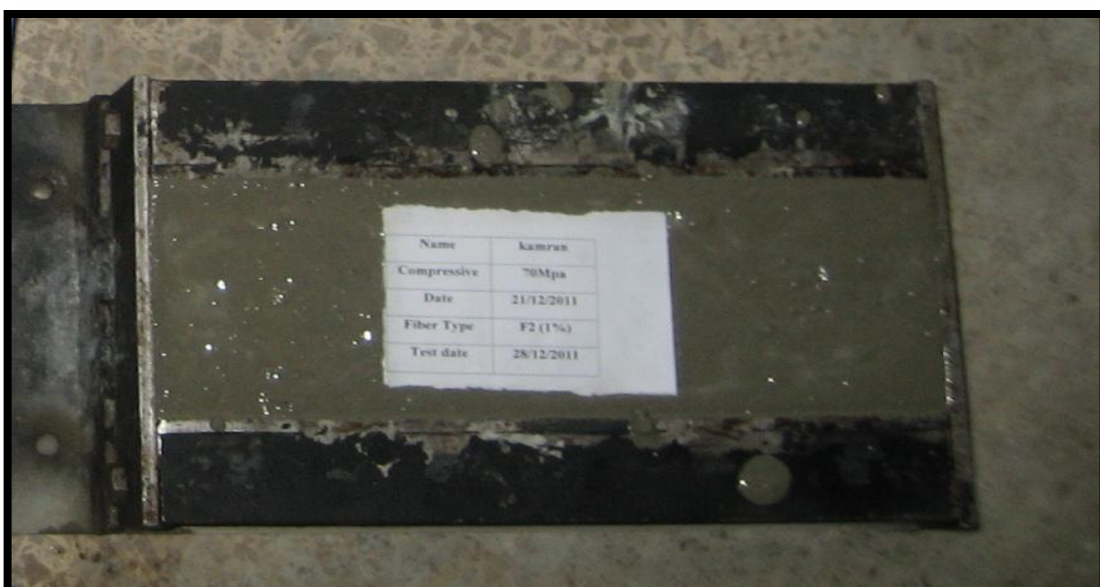


Photo 5: Shrinkage test specimen

## 3.6 Curing process

The specimens molds were opened after one day that the specimens stored in curing room. After about 24 hours the specimens used for testing in hardened state of FSRC were brought out from the molds and moved to a water curing tank and kept there throughout the curing period for 28-day according to the standards(BS EN 12390-2, 2000). Photo 6 shows the specimens in water tank.

Photo 6: Curing of the specimens in water tank

## 3.7 Testing of fresh properties of SFRC

For all the mixes, VeBe test were done for testing consistency/workability of SFRC. The test were done according to the standard (BS EN 12350-3, 2009). Figure 6 shows the typical VeBe consistometer. Photo 7 and 8 shows the VeBe test apparatus.

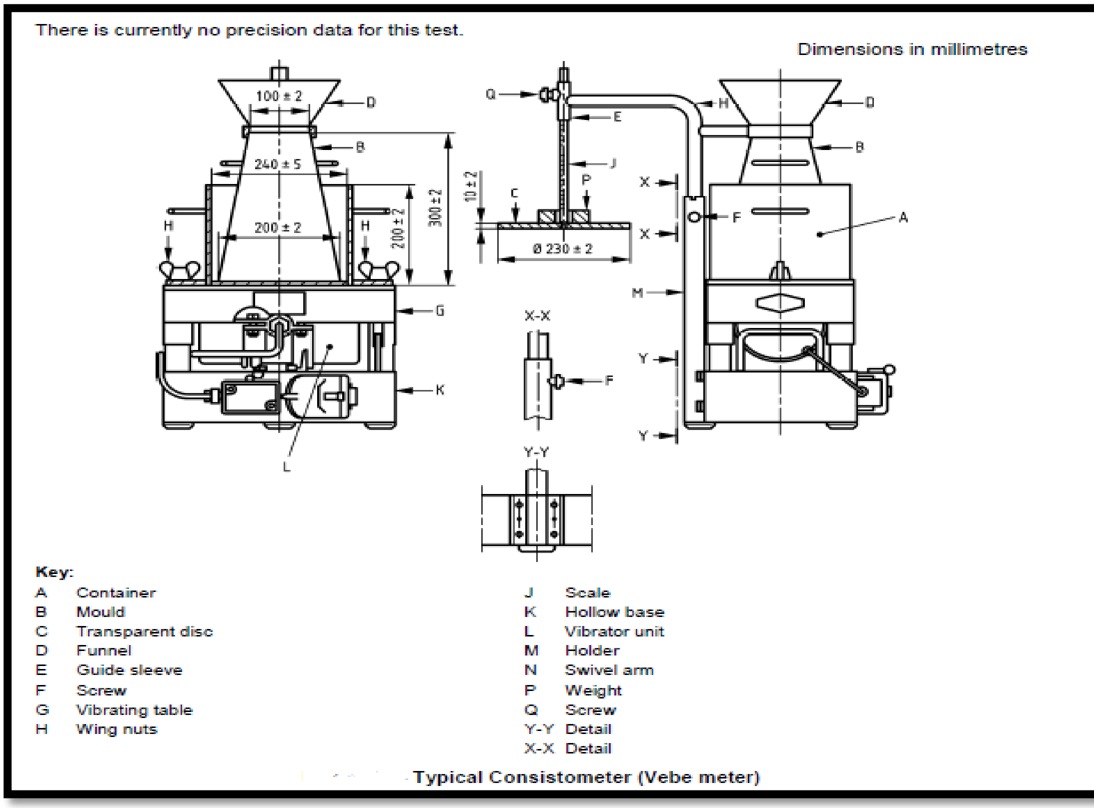


Figure 6: Typical Vebe consistometer

Photo 7: Fresh SFRC in VeBe test pan


Photo 8: VeBe test completed

## 3.8 Testing of the mechanical properties of SFRC

### 3.8.1 Compressive strength test

The tests for compressive strength were done on 150 mm cubes in accordance to the standard ( BS EN 12390-3, 2009). The tests were performed for three, seven and twenty eight day ages on  samples by the machine which if for compressive strength testing. The crushed specimen after compression test  is shown in photo 9 .

Photo 9 : Crushed specimen after compression test

### 3.8.2 Flexural strength test

The flexural strength test was done on 100 × 100 × 150 mm test beams. This test was performed on specimens, one with LVDT in order to have load-deformation curve and one without LVDT. The specimens were tested with a third-point load test machine at a 0.05 mm/min constant deformation rate, according to the standard (ASTM C 1609, 2010). Two LVDTs were used for measuring the mid-span deflections of the test beams. There was a yoke that is used for eliminating the subsidiary settlements of the supports in order to record the net beam deflection. Photo 10 shows the testing arrangements and photos 11 shows the specimen at the end of the test.

Photo 10: Flexural test apparatus

Photo 11: Crack in flexural test beam

### 3.8.3 Ultrasonic pulse velocity test

Three specimens were tested for each mix for ultrasonic pulse velocity test and the average of these test were used for determining the pulse velocity. The specimens were cubes with the size of 150 mm according to the standard ( ASTM C 597, 2009). Photo 12 shows the test procedure.

UPV was evaluated by dividing the pulse time to the length of path. The equation below was used for determining the velocity.

$$V=\frac{l}{t}$$

V= Pulse Velocity (km/sec)

l= length of the specimen (km)

t= time (second)


Photo 12: UPV test

### 3.8.4 Schmidt hammer test (Rebound Number of Hardened Concrete)

This test method shows the evaluation of rebound number of a spring-driven steel hammer of hardened concrete.

In this test cubic specimens with the size of 150 mm were used. The specimens were subjected to the constant compressive load (100 kN) with the compressive testing machine. Rebound hammer which was consisting of a spring-loaded steel
hammer that when released strikes a steel plunger in contact with the concrete surface used. The rebound distance of the steel hammer from the steel plunger is measured on a linear scale attached to the frame of the instrument. For each specimens ten rebound number was read and the average of these numbers considered as the rebound number according to the standard (ASTM C 805, 2008). Photo 13 shows the rebound hammer.

Photo 13: Rebound hammer

### 3.8.5 Drying shrinkage test

For this test, one 100 × 100 × 300 test beam was used for each mixture. After 28 days curing in water the specimens transferred to a laboratory room. Two pins were attached to the specimens in order to read the length between them. The length change between the pins was recorded periodically. This should have done until the length change became constant for a few days. The calculation of the length change is shown above. Photo 14 shows the comparator reading procedure.

$$\Delta L_x = \frac{\mathrm{CRD} - \mathrm{initial\ CRD}}{\mathrm{G}} \times 100$$

$\Delta L_x$ = Length change, %

CRD = Final reading

G = the gage length

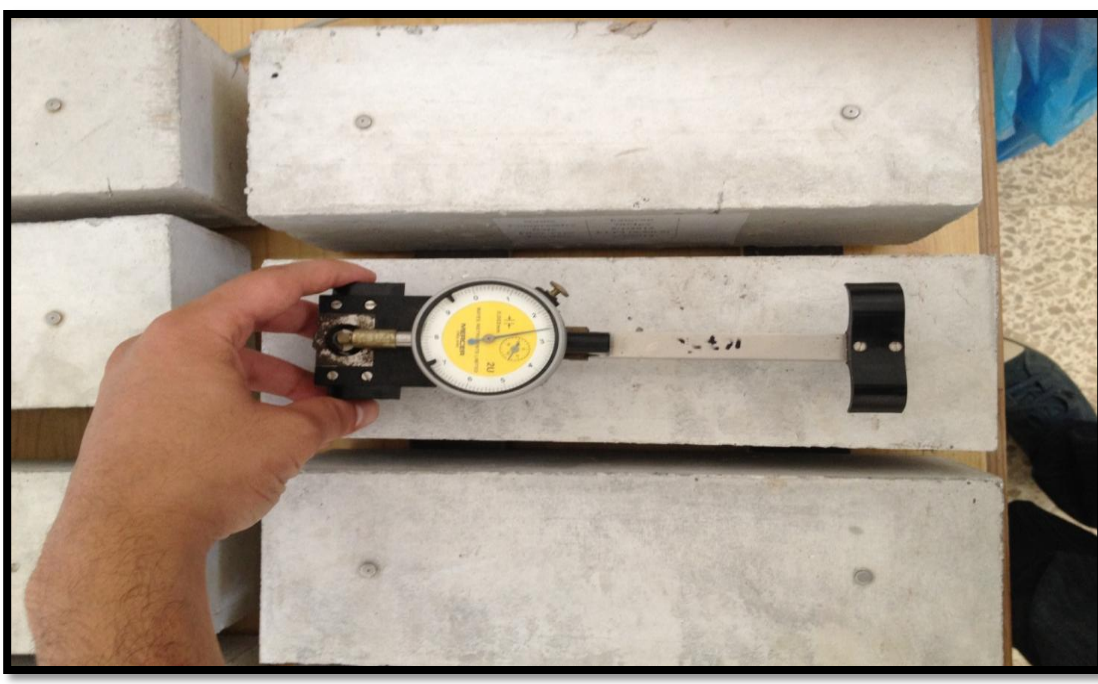

Photo 14: Shrinkage comparator reading

# Chapter 4

# RESULT AND DISSCUSION

## 4.1 Fresh properties

The workability and consistency of SFRC mixes were investigated in fresh state of concrete by VeBe test. Addition of steel fibers to the concrete has a significant effect on the workability of concrete. In order to maintain the consistency and workability of the mixes high range water reducer was added to the mixes to modify the fresh properties of the mixes. The results are shown in Table 8 and Figure 7.

It was impossible to measure the Vebe time for plain concrete because in order to reach a workable concrete with the highest amount of fiber (1.5%), high range water reducer was used and it made the plain concrete to behave like a self compacted concrete.

The results show that when the fiber amount and the length of fibers increased, the Vebe time also increased. This is due to the effects of long fibers on the workability. Using longer fibers in the concrete, made concrete insensitive. As expected, fibers with aspect ratio/length (80/60) which is the longest fiber used, with 1.5% by volume, gave the highest Vebe time among all other mixes. For F1 which is the mix having fibers with aspect ratio/length of 80/50, it was observed that by increasing the amount of fiber, the Vebe time increased. This also occurred for F2 with aspect ratio/length of 80/60 and F3 with aspect ratio/length of 60/30. For the combination of two types of steel fibers, F1 and F2 gave the maximum Vebe time [F1(0.75%), F2(0.25%)]. For F1 and F3 combination, the maximum Vebe time was for [F1(0.75%, F3(0.25%)] and for F2 and F3 the maximum Vebe time was for [F2(0.75%), F3(0.25%)]. The results of the combination of three type of steel fibers showed that mixture of [F1(0.25%), F2( 0.5%), F3(0.25%)] had the maximum Vebe time 4.9 sec. It is obvious that combining fibers with different aspect ratio/length had the same effect on concrete workability as that of concretes having single type of fibers.

Table 8: Vebe time

| **Concrete type** | **Vebe time (sec)** |
|---|---|
| **Plain** | - |
| **F1 (0.5%)** | 1.7 |
| **F1 (1%)** | 4.5 |
| **F1 (1.5%)** | 6.8 |
| **F2 (0.5%)** | 2.16 |
| **F2 (1%)** | 4.8 |
| **F2 (1.5%)** | 7.6 |
| **F3 (0.5%)** | 1.2 |
| **F3 (1%)** | 4.18 |
| **F3 (1.5%)** | 5.9 |
| **F1(0.25%), F2(0.75%)** | 4.3 |
| **F1(0.5%), F2(0.5%)** | 3.5 |
| **F1(0.75%), F2(0.25%)** | 5.4 |
| **F1(0.25%), F3(0.75%)** | 2.9 |
| **F1(0.5%), F3(0.5%)** | 3.7 |
| **F1(0.75%), F3(0.25%)** | 5.1 |
| **F2(0.25%), F3(0.75%)** | 3.1 |
| **F2(0.5%), F3(0.5%)** | 4.2 |
| **F2(0.75%), F3(0.25%)** | 5.2 |
| **F1(0.25%), F2(0.25%), F3(0.5%)** | 3.9 |
| **F1(0.5%), F2(0.25%), F3(0.25%)** | 4.3 |
| **F1(0.25%), F2(0.5%), F3(0.25%)** | 4.9 |
| **F1(0.33%), F2(0.33%), F3(0.33%)** | 4.5 |

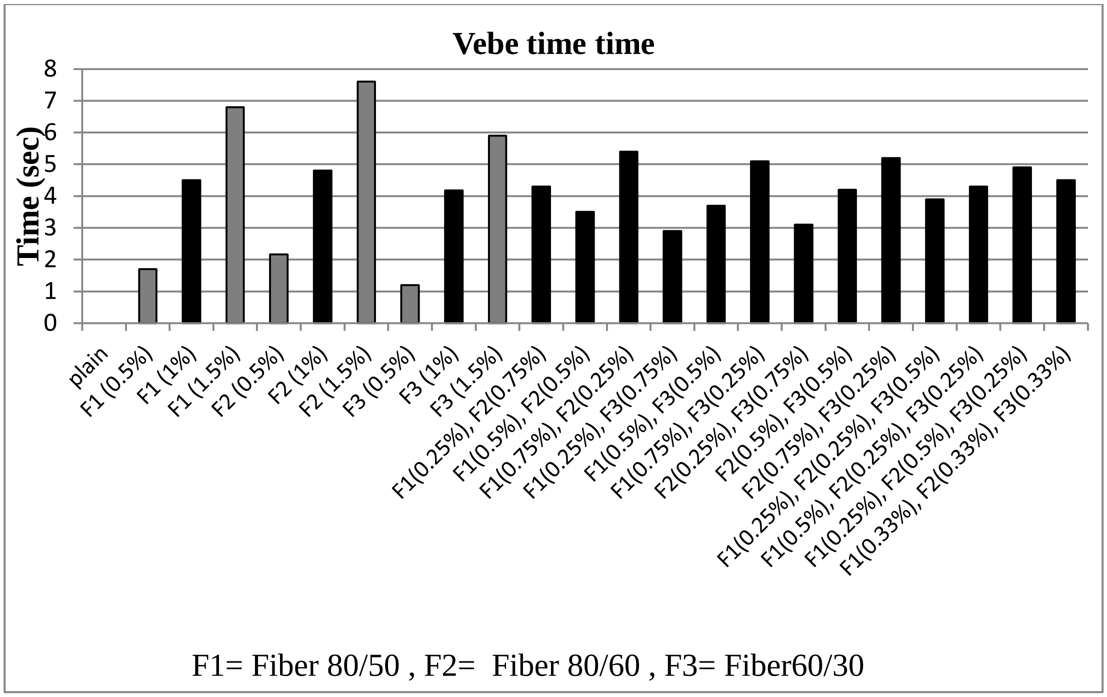


Figure 7: Vebe time test results

## 4.2 Compressive strength

In this study, two hundred and seven cubic samples were tested for compressive strength of steel fiber reinforced concretes. The tests were done on samples for 3, 7 and 28 days. For each mix three samples were tested and the average of those results was taken into account for compressive strength. The results are shown in Table 9, and the percentage change for the compressive strength in comparison with plain concrete is shown in Table 10. Figures 7, 8 and 9 show the compressive strength and Figure 10, 11 and 12 show the percentage changes among results compared to plain concrete for 3, 7 and 28 days, respectively.

It is determined for 3 and 7 days test that, most of the mixes had the compressive strength lower than that of the plain concrete. This might be due to the chemical properties of cement which is related to strength development and also the entrapped air voids due to steel fibers. For 28 days results, all of the mixes except [F1(0.75%), F2(0.25%)] had the compressive strength higher than that of the plain concrete.

The results that obtained at the age of 28 days show that adding fibers into the mix did not have a significant effect on the compressive strength, but it is obvious that the length of the fibers and the amount of fibers have significant positive effect for increasing compressive strength. The results of the mixes with combined steel fibers also confirms this, as in [F1(0.25%), F2(0.5%), F3(0.25%)] mix, the compressive strength is higher than the other fiber combined mixes. The results illustrate that F2(1.5%) had the highest compressive strength of 59.83 MPa.

The results shows that at the age of 3 days the compressive strength increased by increasing the amount of fiber in F1, F2 and F3 which are the mixes with one type of fiber. The chart shows that among these mixes, F2 has the highest compressive strength for each fiber amount. The combination of two fibers shows that [F1(0.25%), F2(0.75%)] has the compressive strength of 26.74MPa which is the largest among all of these mixes. The results of combination of three type fiber mixes also show that [F1(0.25%), F2(0.5%), F3(0.25%)] has the highest among 3 days compressive strength.

At the age of 7 days, the effect of the length and amount of fibers were the same as 3 days for F1, F2 and F3. For combination of two type fiber mixes, [F1(0.75%), F3(0.25%)] there was a significant increase in comparison to 3 days compressive strength, but [F1(0.25%), F2(0.75%)] had the highest compressive strength among all these mixes. For mixes of three type fibers combination [F1(0.25%), F2(0.5%), F3(0.25%)] had the biggest compressive strength.

At the age of 28 days, all of the SFRC mixes had compressive strength more than plain concrete. For one type of fiber F2(1.5%) had the highest compressive strength. The percentage change in these mixes increased for each type of fiber by increasing the amount of fiber. For mixes having two types of fibers, [F1(0.75%), F1(0.25%)] had the biggest compressive strength. [F1(0.25%), F2(0.5%), F3(0.25%)] had a compressive strength of 59.00 MPa among all of the mixes produced by combination of three fiber types.

Table 9: Compressive test results

| Concrete type | 3 days (MPa) | 7 days (MPa) | 28 days (MPa) |
|---|---|---|---|
| **plain** | 27.76 | 42.30 | 56.20 |
| **F1 (0.5%)** | 25.63 | 39.10 | 58.43 |
| **F1 (1%)** | 27.70 | 40.40 | 58.80 |
| **F1 (1.5%)** | 27.96 | 40.92 | 59.11 |
| **F2 (0.5%)** | 26.46 | 40.84 | 58.54 |
| **F2 (1%)** | 28.20 | 41.52 | 59.00 |
| **F2 (1.5%)** | 29.17 | 42.20 | 59.83 |
| **F3 (0.5%)** | 24.91 | 38.75 | 57.12 |
| **F3 (1%)** | 26.31 | 39.41 | 59.44 |
| **F3 (1.5%)** | 26.74 | 40.22 | 59.71 |
| **F1(0.25%), F2(0.75%)** | 26.45 | 41.12 | 56.81 |
| **F1(0.5%), F2(0.5%)** | 25.94 | 40.74 | 56.48 |
| **F1(0.75%), F2(0.25%)** | 25.92 | 40.78 | 56.43 |
| **F1(0.25%), F3(0.75%)** | 24.82 | 39.47 | 55.90 |
| **F1(0.5%), F3(0.5%)** | 25.52 | 40.31 | 56.49 |
| **F1(0.75%), F3(0.25%)** | 25.47 | 41.65 | 57.29 |
| **F2(0.25%), F3(0.75%)** | 25.20 | 39.64 | 56.31 |
| **F2(0.5%), F3(0.5%)** | 25.84 | 40.53 | 57.92 |
| **F2(0.75%), F3(0.25%)** | 27.12 | 41.76 | 59.14 |
| **F1(0.25%), F2(0.25%), F3(0.5%)** | 26.28 | 40.61 | 58.49 |
| **F1(0.5%), F2(0.25%), F3(0.25%)** | 26.85 | 41.25 | 58.84 |
| **F1(0.25%), F2(0.5%), F3(0.25%)** | 27.33 | 41.71 | 59.00 |
| **F1(0.33%), F2(0.33%), F3(0.33%)** | 27.23 | 41.47 | 58.89 |

Table 10: percentage change for compressive strength results

| | Percentage change | | |
|---|---|---|---|
| **Concrete type** | **3 days** | **7 days** | **28 days** |
| **plain** | - | - | - |
| **F1 (0.5%)** | -7.60 | -7.56 | 3.96 |
| **F1 (1%)** | -0.21 | -4.49 | 4.62 |
| **F1 (1.5%)** | 0.72 | -3.30 | 5.17 |
| **F2 (0.5%)** | -4.68 | -3.54 | 4.16 |
| **F2 (1%)** | 1.58 | -1.89 | 4.98 |
| **F2 (1.5%)** | 4.82 | -0.23 | 6.45 |
| **F3 (0.5%)** | -10.30 | -8.51 | 1.63 |
| **F3 (1%)** | -5.25 | -6.85 | 5.76 |
| **F3 (1.5%)** | -3.81 | -4.96 | 6.24 |
| **F1(0.25%), F2(0.75%)** | -4.89 | -2.83 | 1.08 |
| **F1(0.5%), F2(0.5%)** | -6.70 | -3.78 | 0.49 |
| **F1(0.75%), F2(0.25%)** | -6.70 | -6.14 | 0.40 |
| **F1(0.25%), F3(0.75%)** | -10.66 | -6.85 | -0.53 |
| **F1(0.5%), F3(0.5%)** | -8.14 | -4.72 | 0.51 |
| **F1(0.75%), F3(0.25%)** | -8.50 | -1.65 | 1.93 |
| **F2(0.25%), F3(0.75%)** | -9.22 | -6.38 | 0.19 |
| **F2(0.5%), F3(0.5%)** | -7.06 | -4.25 | 3.06 |
| **F2(0.75%), F3(0.25%)** | -2.37 | -1.41 | 5.23 |
| **F1(0.25%), F2(0.25%), F3(0.5%)** | -5.61 | -4.01 | 4.07 |
| **F1(0.5%), F2(0.25%), F3(0.25%)** | -3.45 | -2.60 | 4.69 |
| **F1(0.25%), F2(0.5%), F3(0.25%)** | -1.65 | -1.41 | 4.98 |
| **F1(0.33%), F2(0.33%), F3(0.33%)** | -2.01 | -2.12 | 4.78 |

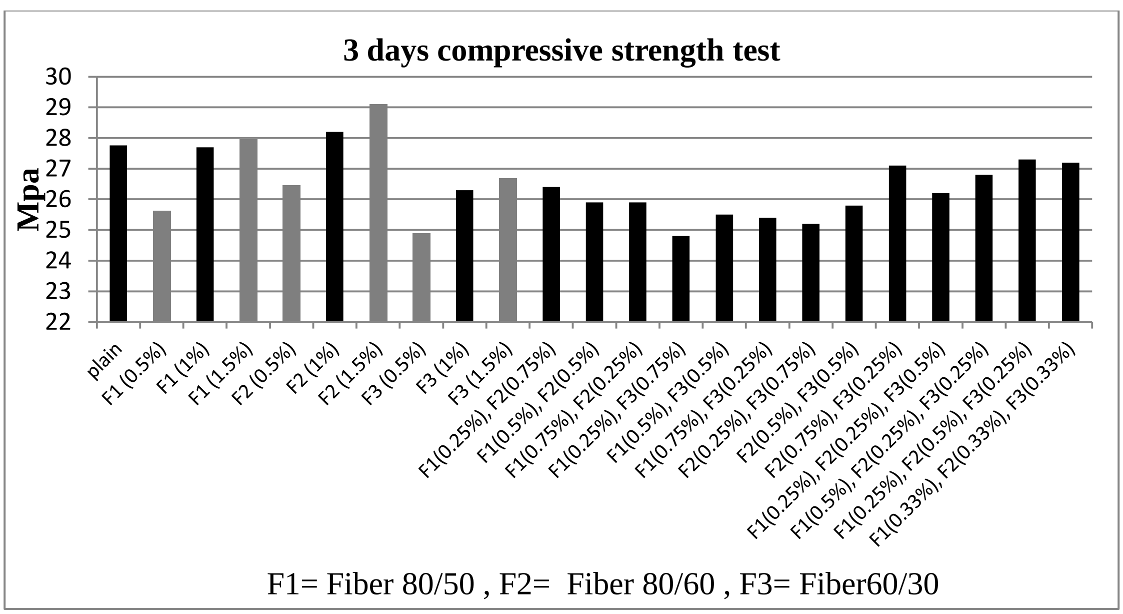


Figure 8: Compressive test results at 3 days age

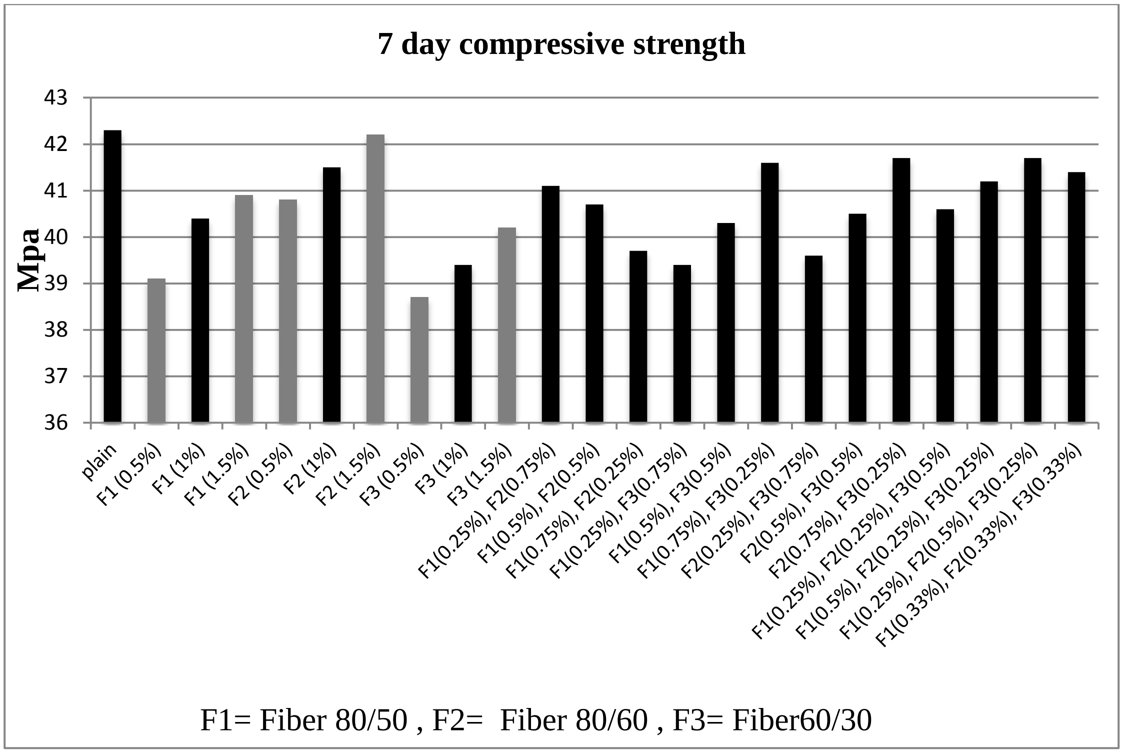


Figure 9: Compressive test results at 7 days age

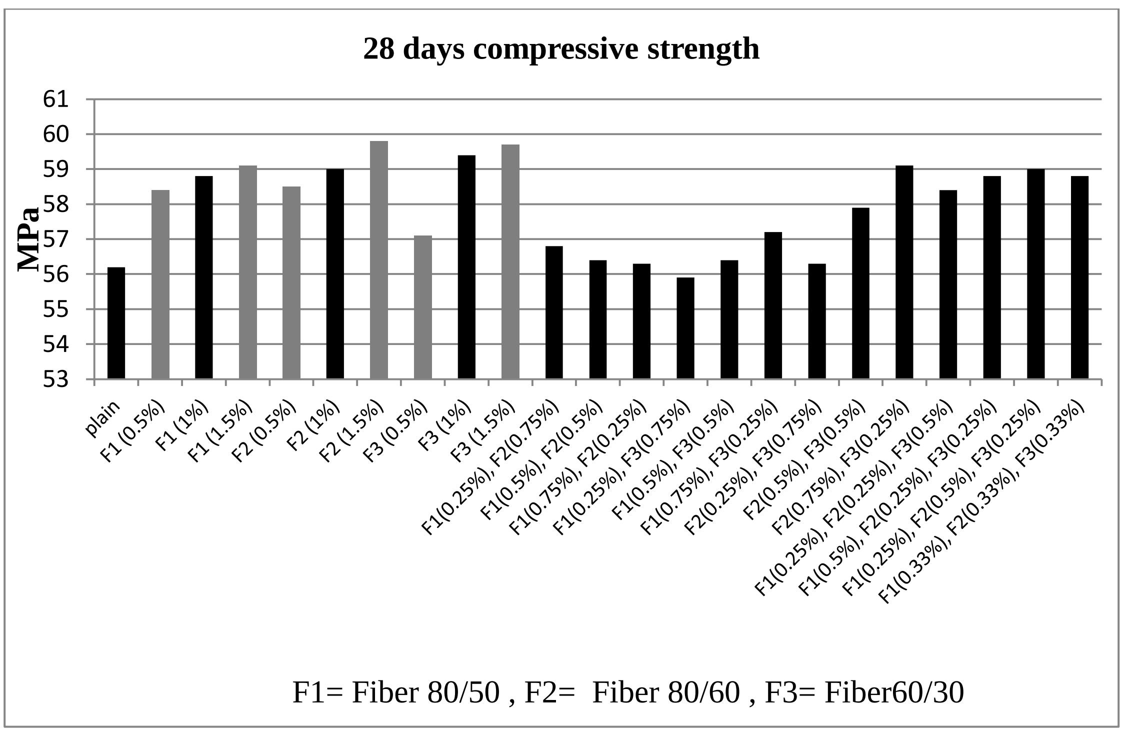


Figure 10: Compressive test results at 28 days age

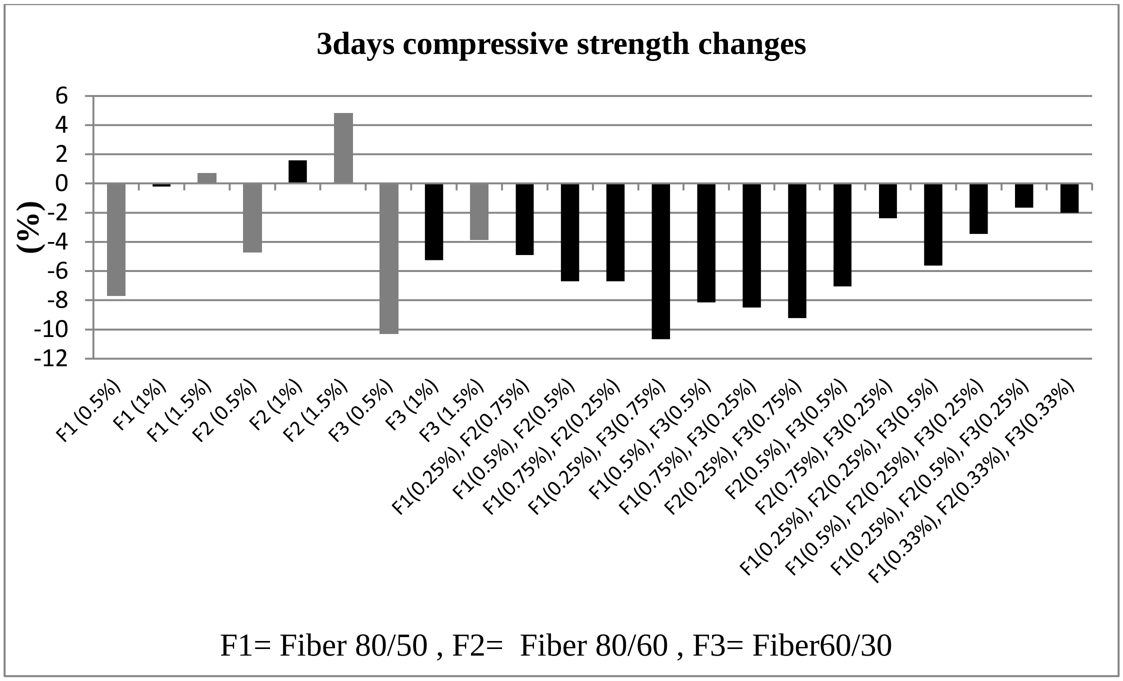


Figure 11: percentage changes for 3days compressive strength

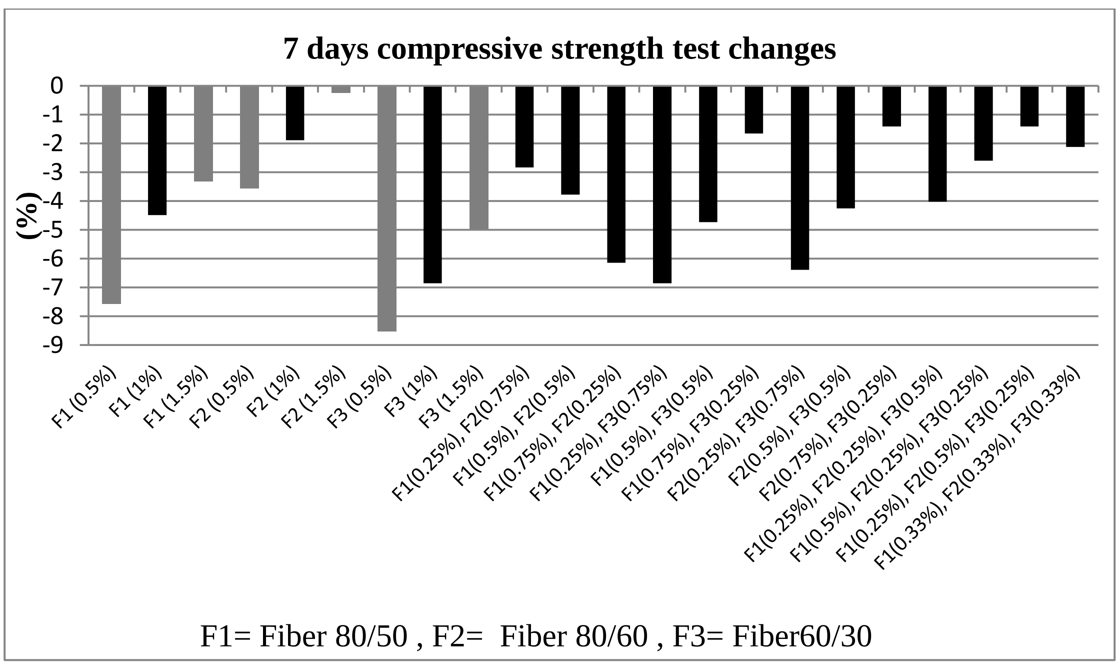


Figure 12: percentage changes for 7days compressive strength

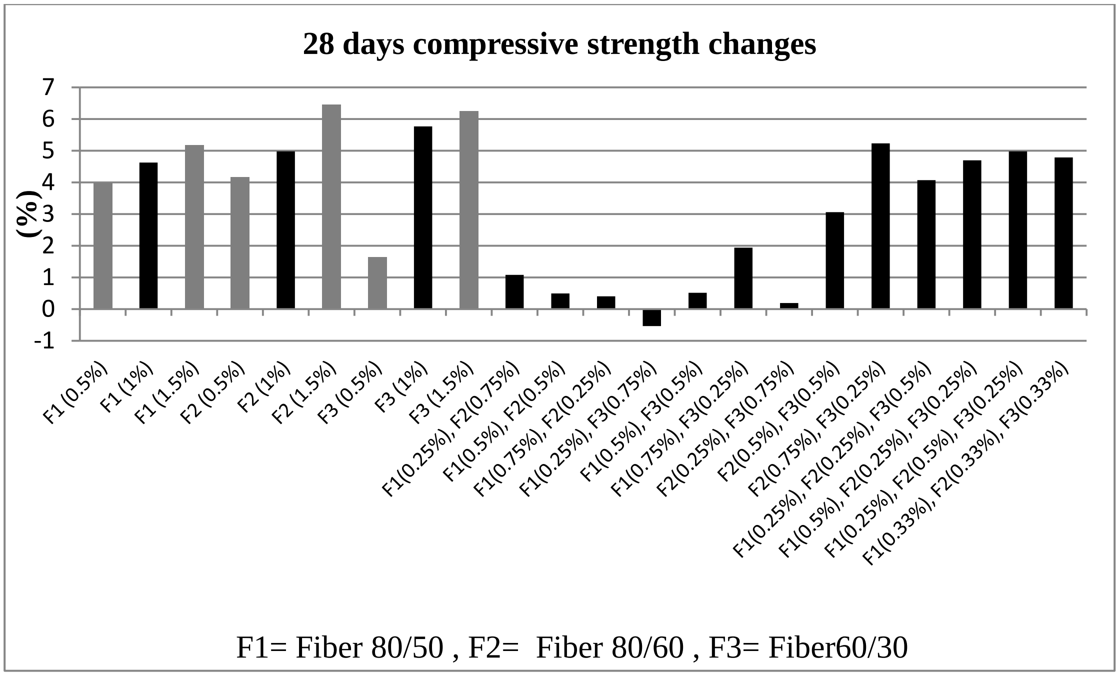


Figure 13: percentage changes for 28days compressive strength

## 4.3 Flexural strength

In this study, sixty nine flexural test beams were tested(3 beams for each mix). The results of the flexural strength tests and the percentage changes is given in Table 11. Figure 13 and Figure 14 show the percentage changes of SFRC among flexural strength results with respect to plain concrete.

It is clear from the results that for all of the mixes having steel fibers(alone or combined), the flexural strength values obtained are higher than the flexural strength values of plain concrete. It is due to the presence of fibers in the mix which made the matrix more resistant to tension forces and increased the resistance of failure. As it is shown in tables, the mixes with longer fibers and higher amount of fibers gave the highest flexural strength among all other mixes. It was observed that F2(1.5%) with 8.74

MPa flexural strength was the biggest value among all results. It is shown that this mix increased the flexural strength up to 57.55% compared to plain concrete. The results show that for all combination of the fibers with different percentages, flexural strength increased compared to plain concrete and the biggest change was obtained for [F1(0.33%), F2(0.33%, F3(0.33%)] by 33.81% increase.

For concretes having only one type of fiber, the mixes with 1.5% amount of fiber gave the maximum flexural strength values among all of the mixes. F1, mix gave 54.49% higher, F2 gave, 57.55% higher and F3 gave, 20.32% % higher flexural strengths compared to plain concrete. For two type combined fiber mixes, it was monitored that [F1(0.25%,F2(0.75%)] gave the highest increase of flexural strength with a percentage of 33.09 compared to plain concrete. In these mixes a clear relation was viewed that using higher amount of long fibers improved the flexural strength. The mixes with three types combination of fibers show that the equal combination of each fiber had better impact on flexural strength as in [F1(0.33%), F2(0.33%, F3(0.33%)] which gave 7.44MPa flexural strength.

Table 11: Flexural strength test results

| Concrete type | Flexural strength (MPa) | Flexural strength change (%) |
|---|---|---|
| **plain** | 5.56 | |
| **F1 (0.5%)** | 5.33 | 2.50 |
| **F1 (1%)** | 4.36 | 12.23 |
| **F1 (1.5%)** | 8.74 | 54.49 |
| **F2 (0.5%)** | 7.29 | 31.11 |
| **F2 (1%)** | 6.13 | 42.98 |
| **F2 (1.5%)** | 8.76 | 57.55 |
| **F3 (0.5%)** | 4.43 | 5.03 |
| **F3 (1%)** | 6.46 | 16.18 |
| **F3 (1.5%)** | 6.69 | 20.32 |
| **F1(0.25%), F2(0.75%)** | 5.70 | 33.09 |
| **F1(0.5%), F2(0.5%)** | 6.84 | 23.02 |
| **F1(0.75%), F2(0.25%)** | 7.06 | 16.36 |
| **F1(0.25%), F3(0.75%)** | 4.53 | 6.83 |
| **F1(0.5%), F3(0.5%)** | 4.79 | 13.66 |
| **F1(0.75%), F3(0.25%)** | 5.23 | 25.35 |
| **F2(0.25%), F3(0.75%)** | 4.71 | 12.05 |
| **F2(0.5%), F3(0.5%)** | 6.28 | 21.40 |
| **F2(0.75%), F3(0.25%)** | 7.25 | 30.39 |
| **F1(0.25%), F2(0.25%), F3(0.5%)** | 5.95 | 7.01 |
| **F1(0.5%), F2(0.25%), F3(0.25%)** | 5.93 | 6.65 |
| **F1(0.25%), F2(0.5%), F3(0.25%)** | 6.05 | 8.81 |
| **F1(0.33%), F2(0.33%), F3(0.33%)** | 7.44 | 33.81 |

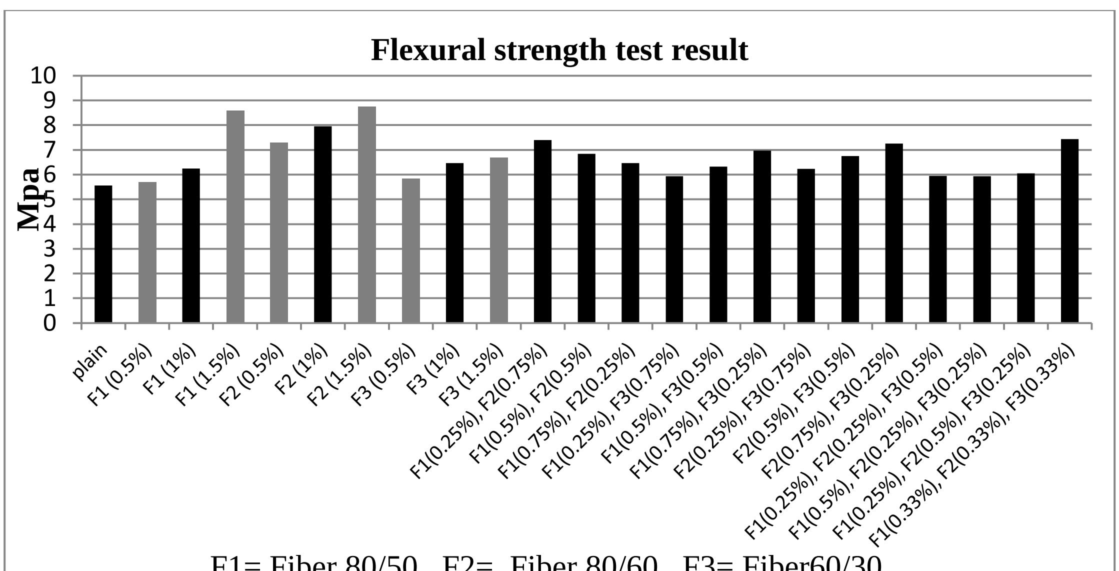


Figure 14: Flexural strength test results

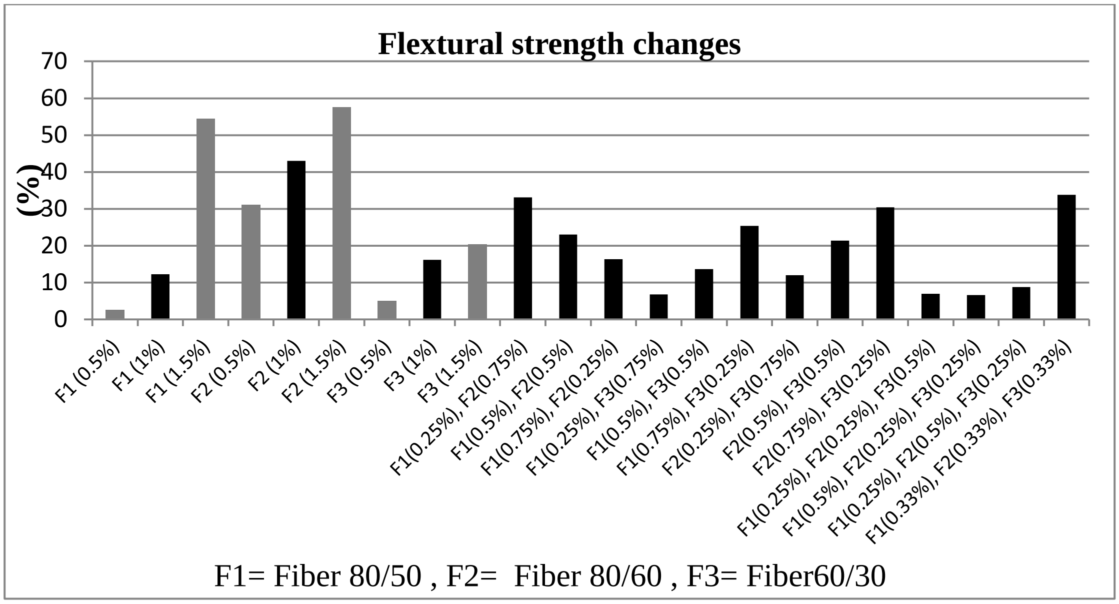


Figure 15: percentage changes for Flexural strength

## 4.4 Rebound number

This test was done on sixty nine cubic samples. Three samples were tested for each mix and their average was considered as rebound number. This test was carried out in order to see the uniformity of concrete mixes produced(ASTM C 805, 2008).

Table 12 shows the results of rebound number tests and the percentage changes among all the results. Figure 15 and Figure 16 show the rebound number and percentage changes of rebound number, respectively.

From the results it can be said that using fibers in the concrete increased the rebound number for all the mixes in comparison with plain concrete. The combination of different fibers also increased the rebound number but using three type of fibers had better effects on concrete rebound number compared to two types combination mixes.

The reason should be because of the better uniformity of concrete that short, medium and long fibers provide rather than using two of them only.

The results show that using one type of fibers in the mix, made it more uniform than the combination of different fibers. It also shows that concretes containing longer fibers have more rebound number than concretes containing shorter fibers. This might be due to the effects that longer fibers have on increasing the strength of concrete as observed in compressive strength test. In this study, F2(1.5%) had the maximum rebound number. This increase was measured to be 15.1% compared to plain concrete.

There is a relation between the rebound number and the quality of concrete which says that for rebound numbers more than 40, the quality of the concrete is very good. For the rebound number between 30-40, the quality is good. For the rebound numbers between 20-30, concrete quality is fair. If the rebound number is less than 20, the concrete is poor or delaminated and if the rebound number is 0, the concrete is very poor and delaminated(Mishra, 2012). According to this, the rebound number of the mixes with one type of fiber had a significant increase in comparison with plain concrete. For F1 the maximum rebound number was for F1(1.5%) which contained the highest amount of fiber. For F2 and F3 similar results were also obtained.

For the mixes having two types of fiber combination, the maximum rebound number was for [F1(0.75%), F3(0.25%)] and  an increase of 7.68% was obtained in comparison with the plain concrete.

For the combination of three types of fibers, all of the mixes have the rebound number more than plain concrete. [F1(0.25%), F2(0.5%), F3(0.25%)] had the maximum rebound number and the increase obtained was 7.01% compared to plain concrete.

Table 12 : Rebound number test results

| Concrete type | Rebound number | Rebound number change (%) |
|---|---|---|
| **plain** | 33.21 | - |
| **F1 (0.5%)** | 35.40 | 6.59 |
| **F1 (1%)** | 35.61 | 7.22 |
| **F1 (1.5%)** | 36.12 | 8.76 |
| **F2 (0.5%)** | 35.67 | 7.40 |
| **F2 (1%)** | 36.84 | 10.93 |
| **F2 (1.5%)** | 38.24 | 15.14 |
| **F3 (0.5%)** | 34.52 | 3.94 |
| **F3 (1%)** | 35.64 | 7.31 |
| **F3 (1.5%)** | 36.10 | 8.70 |
| **F1(0.25%), F2(0.75%)** | 34.31 | 3.31 |
| **F1(0.5%), F2(0.5%)** | 34.23 | 3.07 |
| **F1(0.75%), F2(0.25%)** | 34.06 | 2.55 |
| **F1(0.25%), F3(0.75%)** | 33.81 | 1.80 |
| **F1(0.5%), F3(0.5%)** | 35.13 | 5.78 |
| **F1(0.75%), F3(0.25%)** | 35.75 | 7.64 |
| **F2(0.25%), F3(0.75%)** | 34.72 | 4.54 |
| **F2(0.5%), F3(0.5%)** | 35.12 | 5.75 |
| **F2(0.75%), F3(0.25%)** | 35.42 | 6.65 |
| **F1(0.25%), F2(0.25%), F3(0.5%)** | 34.96 | 5.26 |
| **F1(0.5%), F2(0.25%), F3(0.25%)** | 35.29 | 6.26 |
| **F1(0.25%), F2(0.5%), F3(0.25%)** | 35.54 | 7.01 |
| **F1(0.33%), F2(0.33%), F3(0.33%)** | 35.39 | 6.56 |

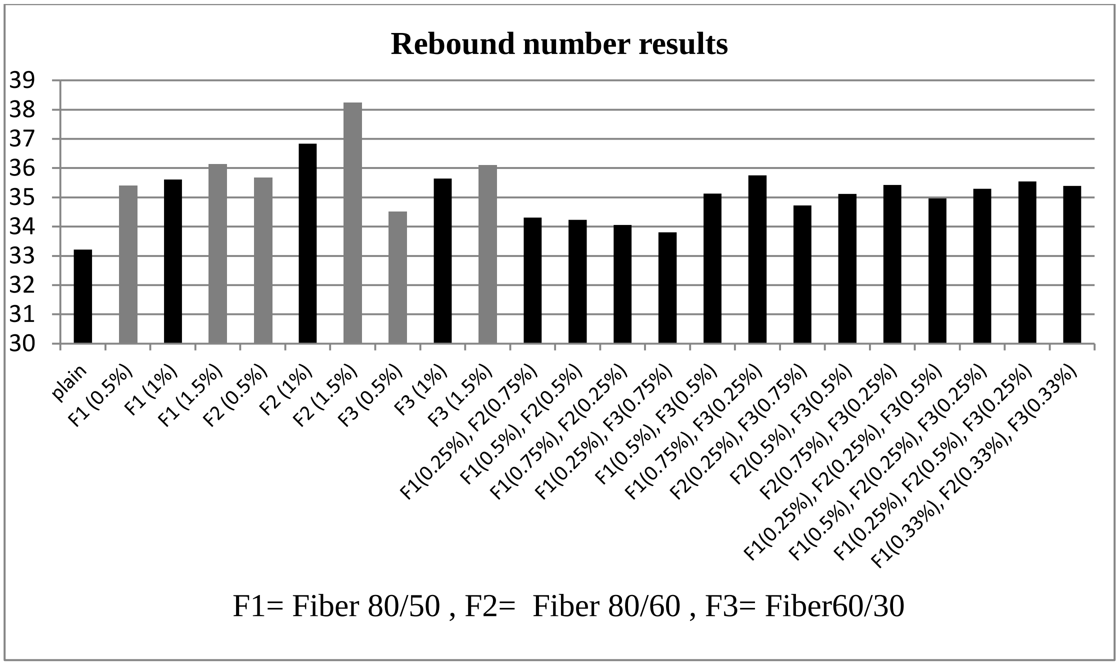


Figure 16: Rebound number results

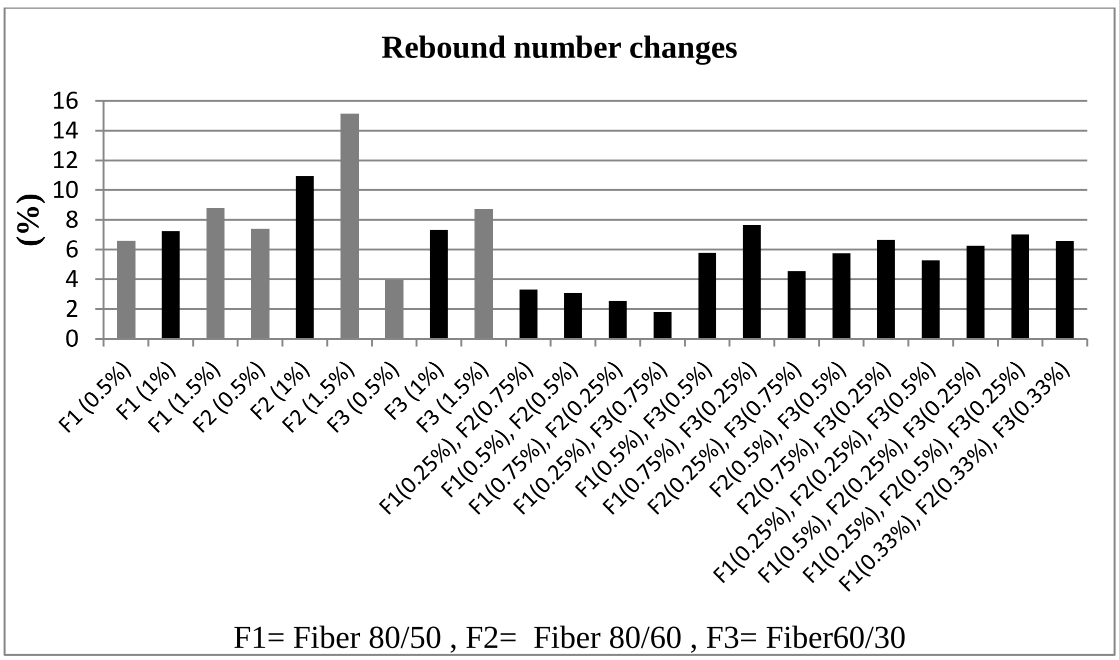


Figure 17: Percentage changes for rebound number

## 4.5 Ultrasonic pulse velocity

This test was done on the mixes in order to assess the homogeneity and integrity of concrete. The, higher the elastic modulus, density and integrity of concrete, the higher is the pulse velocity.

Sixty nine samples were tested for ultrasonic pulse velocity and, the results of the tests are given in Table 13 . The percentage change of ultrasonic pulse velocity results in comparison with the plain concrete for each mix is also shown in this table. Figure 17 and Figure 18 show the pulse velocity figures and the percentage of pulse velocity change among all results compared to plain concrete, respectively. The results illustrate that all the mixes containing fiber(alone or combined), have the pulse velocities higher than the plain concrete.

In one type of fiber mixes, such as F1, when the amount of fibers increased, the pulse velocity decreased. For F1(1.5%) the pulse velocity decreased about 1.62% in comparison to the plain concrete and it had the highest reduction among F1 mixes. For F2 mixes, the largest decrease was about 3.5% for F2(1%). Among F3 mixes, F3(1%) had the largest decrease which was about 7.07% less than the plain concrete.

Two types fiber combinations also had effect on pulse velocity in such a way that [F1(0.75%), F2(0.25%)] had the maximum decrease for the mixes which contained F1 and F2 reduction was about 5.32% in comparison with plain concrete. The maximum decrease of pulse velocity occurred for [F1(0.25%), F3(0.75%)] and [F1(0.5%), F3(0.5%)] among the mixes which contained F1 and F3. And for the F2,F3 mixes, [F2(0.75%), F3(0.25%)] had the highest decrease which was about 5.91%.

Among three types of fibers combinations, [F1(0.25%), F2(0.5%), F3(0.25%)] had the lowest pulse velocity. This combination also had more longer fibers through these mixes.

It can be determined from the results that there is not a clear relation between the length and amount of the fibers with the ultrasonic pulse velocity, but it can be said that combination of different fibers decreased the pulse velocity more than mixes having only one type steel fibers. This might be due the entrapped air voids that increased by adding fibers to the plain concrete. In this study F3(1%) has the minimum pulse velocity among all other mixes. It was about 7% smaller than the plain concrete.

The ultrasonic pulse velocity can tell us how good  the quality of the concrete is. If the pulse velocity is more than 4.0 km/sec, 3.5-4.0 km/sec, 3.0-3.5 km/sec and less than 3.0 km/sec then the concrete quality is defined to be very good to excellent, good to very good and slight porosity may exist, satisfactory but loss of integrity is suspected and poor and los of integrity exist respectively(Whitehurst, 1951).

According to the results obtained from this study, it can be said that all the measurements gave pulse velocities larger than 4.0 km/sec which means that all of the mixes have a very good quality.

Table 13: Ultrasonic pulse velocity test results

| Concrete type | Time (μs) | Pulse velocity (km/sec) | Pulse velocity change (%) |
|---|---|---|---|
| plain | 30.22 | 4.96 | - |
| F1 (0.5%) | 30.31 | 4.95 | -0.32 |
| F1 (1%) | 30.57 | 4.91 | -0.98 |
| F1 (1.5%) | 30.76 | 4.88 | -1.62 |
| F2 (0.5%) | 31.16 | 4.82 | -2.89 |
| F2 (1%) | 31.34 | 4.79 | -3.51 |
| F2 (1.5%) | 31.23 | 4.80 | -3.20 |
| F3 (0.5%) | 31.31 | 4.79 | -3.51 |
| F3 (1%) | 32.54 | 4.61 | -7.07 |
| F3 (1.5%) | 32.15 | 4.67 | -5.91 |
| F1(0.25%), F2(0.75%) | 31.77 | 4.73 | -4.73 |
| F1(0.5%), F2(0.5%) | 31.63 | 4.74 | -4.42 |
| F1(0.75%), F2(0.25%) | 31.97 | 4.70 | -5.32 |
| F1(0.25%), F3(0.75%) | 31.79 | 4.73 | -4.73 |
| F1(0.5%), F3(0.5%) | 31.76 | 4.73 | -4.73 |
| F1(0.75%), F3(0.25%) | 31.68 | 4.74 | -4.42 |
| F2(0.25%), F3(0.75%) | 31.27 | 4.80 | -3.20 |
| F2(0.5%), F3(0.5%) | 31.83 | 4.71 | -5.02 |
| F2(0.75%), F3(0.25%) | 32.10 | 4.67 | -5.91 |
| F1(0.25%), F2(0.25%), F3(0.5%) | 30.88 | 4.87 | -1.94 |
| F1(0.5%), F2(0.25%), F3(0.25%) | 31.74 | 4.73 | -4.73 |
| F1(0.25%), F2(0.5%), F3(0.25%) | 32.36 | 4.64 | -6.49 |
| F1(0.33%), F2(0.33%), F3(0.33%) | 31.94 | 4.70 | -5.32 |

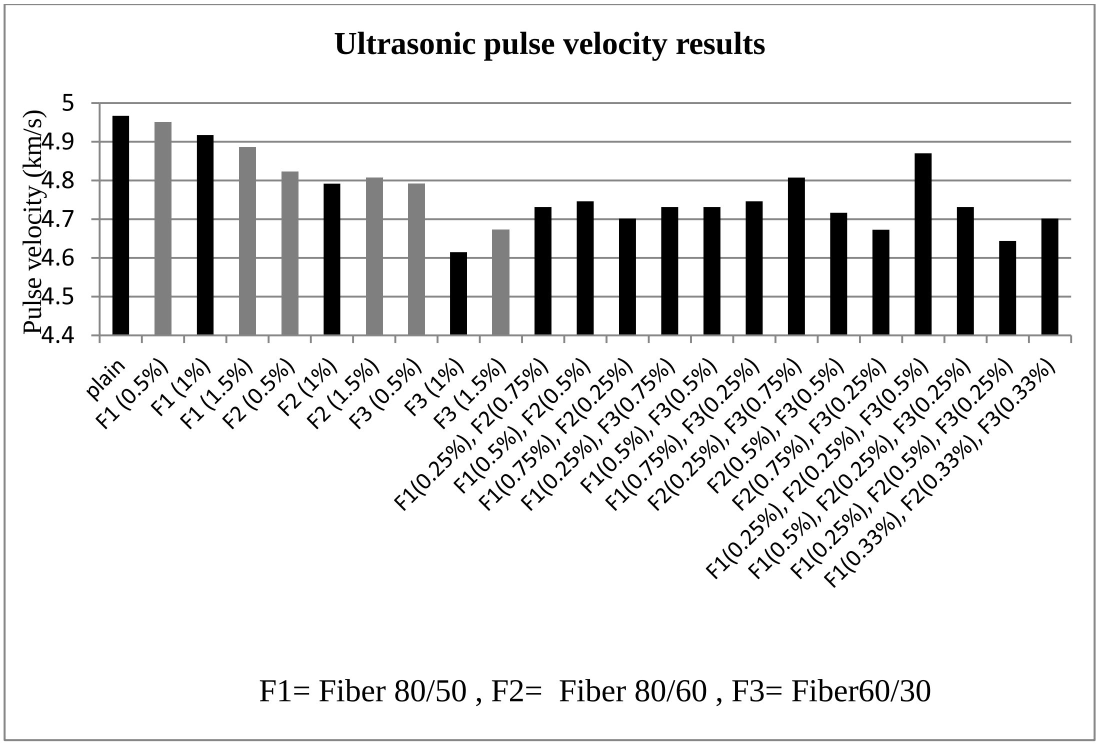


Figure 18: Ultrasonic pulse velocity graph

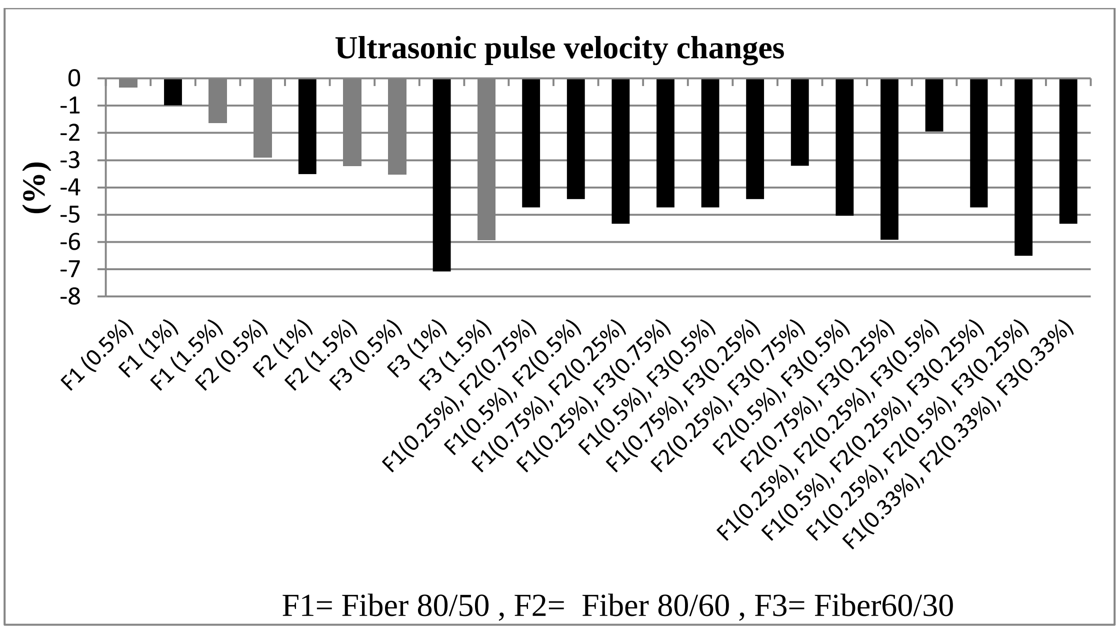


Figure 19: Percentage changes for pulse velocity

## 4.6 Drying shrinkage

After hardening, concrete begins to shrink as water that is not consumed by cement hydration leaves the system. In general, the higher the additional water content, the higher the shrinkage potential is. In this study as the water content and aggregate contents were the same for all the mixes, the only parameter that can affect the shrinkage was the presence of steel fibers.

For this test, twenty three samples were tested and the results are shown in Table 14. Figure 19 and Figure 20 shows the shrinkage and the percentage change in shrinkage results, respectively.

The results shows that for the mixes that were contained only F1, F1(0.5%) and F1(1%) had the lowest drying shrinkage which was about 4.55%. This value is 17.99% less than the drying shrinkage of plain concrete. For F2 mixes, F2(1.5%) had the least drying shrinkage, which was about 3.4%. For F3 mixes, which contained the shorter fibers, F3(1%) and F3(1.5%) had the lowest drying shrinkage.

In the mixes with the combination of two types of fibers, the mixes that had more effects on drying shrinkage are as follows:

For F1and F2 mixes, [F1(0.75%), F2(0.25%)] decreased the drying shrinkage about 27.99% compared to the plain concrete. For F1 and F3 mixes, [F1(0.25%), F3(0.75%)] decreased the drying shrinkage about 15.99% in comparison with plain concrete. Among F2 and F3 mixes, [F2(0.25%), F3(0.75%)] increased the drying shrinkage about 7.99% compared to plain concrete.

For the concretes having three types of fibers, [F1(0.5%), F2(0.25%), F3(0.25%)] decreases were observed in drying shrinkage more than the other mixes which was about 17.99% in comparison to the plain concrete.

It can be observed from the results that F2(1.5%) has significant effects on drying shrinkage which was obtained to be 37.99% in comparison to plain concrete.

Table 14 : Drying shrinkage test results

| **Concrete type** | **Shrinkage (%)** | **Shrinkage change (%)** |
|---|---|---|
| **plain** | 5.555 | - |
| **F1 (0.5%)** | 4.555 | -17.999 |
| **F1 (1%)** | 4.555 | -17.999 |
| **F1 (1.5%)** | 5.111 | -7.999 |
| **F2 (0.5%)** | 4.444 | -19.999 |
| **F2 (1%)** | 6.000 | 8.001 |
| **F2 (1.5%)** | 3.444 | -37.999 |
| **F3 (0.5%)** | 5.555 | 0.001 |
| **F3 (1%)** | 4.777 | -13.999 |
| **F3 (1.5%)** | 4.777 | -13.999 |
| **F1(0.25%), F2(0.75%)** | 4.111 | -25.999 |
| **F1(0.5%), F2(0.5%)** | 5.444 | -1.999 |
| **F1(0.75%), F2(0.25%)** | 4.000 | -27.999 |
| **F1(0.25%), F3(0.75%)** | 4.666 | -15.999 |
| **F1(0.5%), F3(0.5%)** | 6.111 | 10.001 |
| **F1(0.75%), F3(0.25%)** | 4.888 | -11.999 |
| **F2(0.25%), F3(0.75%)** | 5.111 | -7.999 |
| **F2(0.5%), F3(0.5%)** | 5.666 | 2.001 |
| **F2(0.75%), F3(0.25%)** | 6.333 | 14.001 |
| **F1(0.25%), F2(0.25%), F3(0.5%)** | 6.333 | 14.001 |
| **F1(0.5%), F2(0.25%), F3(0.25%)** | 4.555 | -17.999 |
| **F1(0.25%), F2(0.5%), F3(0.25%)** | 5.000 | -9.999 |
| **F1(0.33%), F2(0.33%), F3(0.33%)** | 4.777 | -13.999 |

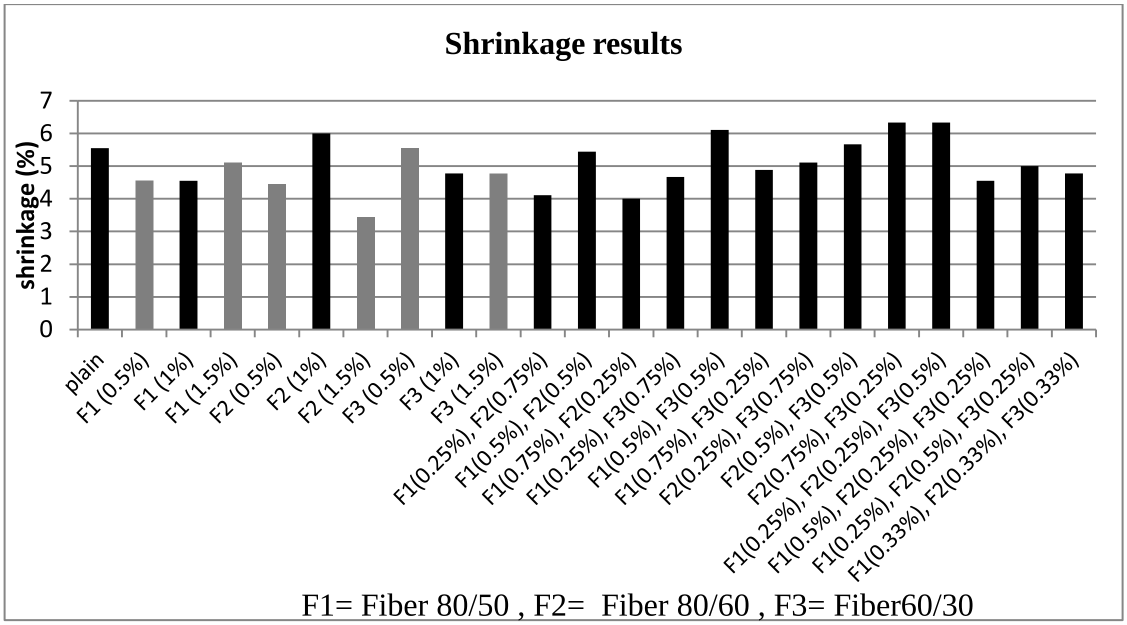


Figure 20: Drying shrinkage curve

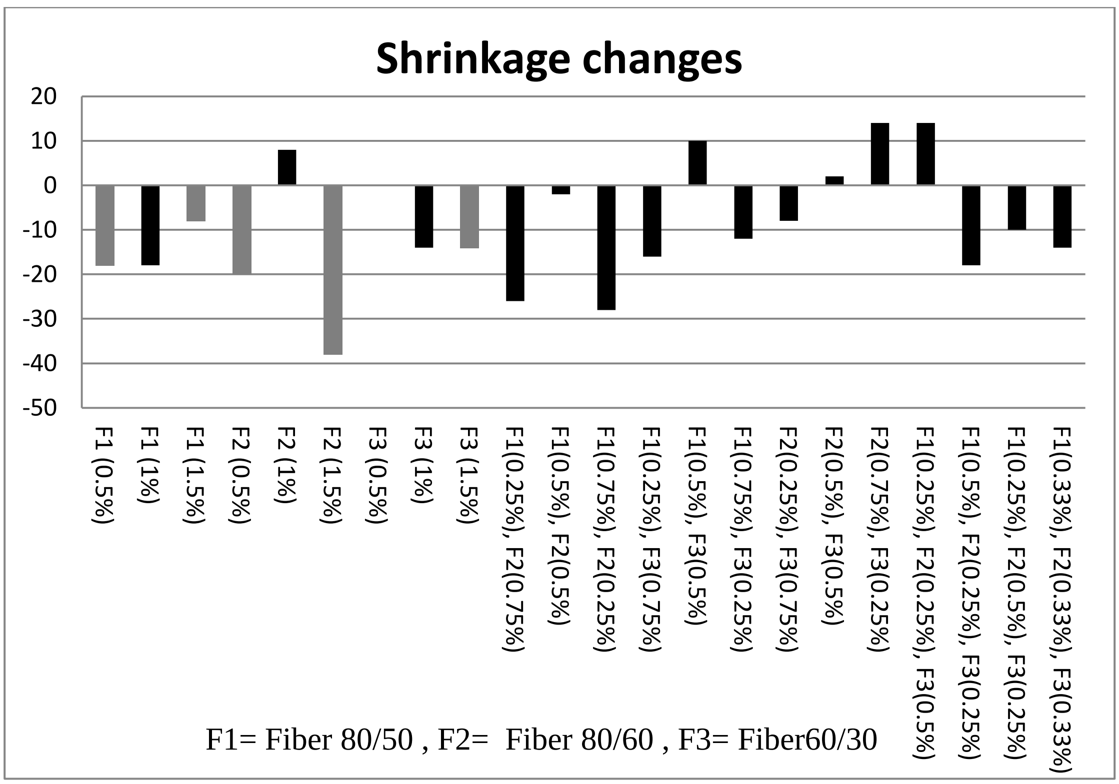


Figure 21: Drying shrinkage percentage change graph

# Chapter 5

# CONCLUSION

## 5.1 Conclusion

In this study different proportions and combinations of steel fibers with three different aspect ratio/length were used to produce steel fiber reinforced concrete. The properties of SFRC were examined in order to find out the effects of various proportions and combination of steel fibers on fresh and hardened state. The effect of steel fibers on fresh properties of SFRC such as Vebe time and on hardened properties such as compressive strength, flexural strength, rebound number, ultrasonic pulse velocity and drying shrinkage were examined.

The following conclusions have been achieved:

For fresh properties:

1. Using steel fibers with different amount and different combinations decreased the workability.

2. Long steel fibers in concrete decrease the workability more than short steel fibers.

3. Increasing the amount of steel fibers decreases the workability more.

4. Combination of two or three different sizes of steel fibers also decreases the workability in the same way as using one type of steel fiber.

For hardened properties:

1. Using steel fibers increases the compressive strength. Longer steel fibers in concrete improved the compressive strength more than short fibers. Increasing the amount of steel fibers improves the compressive strength. The combination of two or three different sizes of steel fibers increases the compressive strength, although for the combination of two sizes of steel fibers, improvement in compressive strength is less than concretes having one or three sizes of steel fibers.

2. Adding steel fibers increases the flexural strength. Longer steel fibers in concretes causes higher increase in flexural strength than short steel fibers. Increasing the amount of steel fibers increase the flexural strength. The combination of two different sizes of steel fibers have better effects on flexural strength than the combination of three different fiber sizes.

3. Using steel fibers in concrete increases the rebound number. Longer steel fibers enhances the rebound number more than short steel fibers. Increasing the amount of steel fibers increases the rebound number. Although adding two or three different sizes of steel fibers increase the rebound number, the combination of three different sizes of steel fibers enhances the rebound number more than the combination of two different sizes of steel fibers.

4.Adding steel fibers reduces the pulse velocity, the higher the amount of fiber the lesser the pulse velocity. Concretes having shorter steel fibers gave less pulse velocity than longer steel fibers. Combination of two or three different sizes of steel fibers have a significant effect on pulse velocity reduction.

5. Steel fibers decrease the drying shrinkage in most cases. Long steel fibers have a better effect on reduction of drying shrinkage. The combination of two or three different steel fibers does not have a clear effect on drying shrinkage.

## 5.2 Recommendation

1. This study was done on two different length of steel fibers. More different sizes of steel fibers could be used in concrete and tested.

2. In this investigation, the water/cement ratio was kept constant and the amount and combinations of fibers changed. In order to see the effect of water/cement ratio on the properties of SFRC in fresh and hardened state, different water/cement ratios with constant combinations of fibers could be tried.

3. Instead of using steel fibers, other type of fibers could be tested.

4. In this study the aggregates type was crushed limestone, other type of aggregates such as lightweight aggregates could be used for other studies.

5. Other tests such as water penetration and impact resistance could be done on different combination of steel fiber mixes.

6. Supplementary materials such as fly ash, silica fume and limestone can be added to the mixes in order to study the effects of them on the SFRCs with the combination of different sizes of fibers.

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