Influence of Amount and Aspect Ratio on Direct Shear Behavior of Fiber Reinforced Concrete

Hooman Roughani

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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.

Asst. Prof. Dr. Mürüde 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.

Prof. Dr. Özgür Eren
Supervisor

Examining Committee

1. Prof. Dr. Özgür Eren

2. Assoc. Prof. Dr. Khaled Marar

3. Assist. Prof. Dr. Serhan Şensoy

ABSTRACT

It is generally believed that one of the most important steps in the design of concrete members is the shear design.

The main objective of this study is to analyze the shear behavior of two different types of fiber reinforced concrete. This experiment of reinforcement has been carried out with different amounts of steel fibers and aspect ratios. The current study therefore will conduct an experiment on a comparison between steel fibers reinforced concrete and plain concrete.

The materials used in the concrete mix are blast furnace slag cement (BFSC), crushed limestone coarse and fine aggregates from Beparmak Mountains. Other materials include hooked-end steel fibers, super-plasticizing admixture, and drinkable water. Water to cement ratio for normal strength concrete is 0.50 and for high strength is 0.43.

In the shear test the strength of reinforced concrete went up by increasing the volume fraction of fiber. Increasing volume from 0 to 1.5% increased 122.7% shear strength for C30, l/d 65. Similar results were obtained for C30, with l/d 80. Volume fractions of steel fibers ranging from 0 to 0.5 %, shear strength increased 35 % and from 0 to 1%, 78.7% increase in shear strength were obtained.

In high strength concrete C50 the shear strength was affected by adding volume fraction of fibers. The results show that applied shear strength increased 151.4% for 1.5% amount of steel fiber and also 66% for 0.5% amount and 114% increased for 1% volume fraction of steel fibers. Results have shown that aspect ratio has no clear effect on shear strength. Because there is not much different between results of concrete with l/d 65 and concrete with l/d 80.

Keywords: Shear strength, Steel fiber, Concrete class, Fiber reinforced concrete.

ÖZ

Genellikle betonarme eşemanların tasarımında göz önünde bulundurulan en önemli parametrelerden birisi kesme kuvvetleridir.

Bu çalışmanın esas amacı ise iki farklı narinlik oranı ve miktarı olan çelik elyaf ile üretilen beton elamanların kesme kuvvetlerinin davranışlarının analiz edilmesidir. Kesme kuvvetlerinin ölçülmesi için kullanılan deney metodu ile elde edilen sonuçlar üretilen çelik elyaflı betonlar şahit beton ile kıyaslanmıştır.

Betonların üretilmesi amacı ile kullanılan malzemeler ise curuflu çimento, beşparmak dağlarından elde edilen kırma kireçtaşı agragaları, çengelli çelik elyaf, kimyasal katkı ve içme suyudur. Su çimento oranı ise normal mukavemetli betonlarda 0,50, yüksek mukavemetli betonlarda ise 0,43 olarak tasarlanmıştır.

Elde edilen sonuçlara bakıldığında ise betonda kullanılan çelik elyaf miktarının arttıkça kesme kuvvetine olumlu etki ederek artmasına neden olmuştur. Çelik lif miktarı sıfırdan %1,5'e yükseltildiği zaman kesme kuvveti C30 l/d 65 (beton sınıfı C30, çelik elyaf narinlik oranı 65) betonunda %122,7 artışa sebep olmuştur. Benzer sonuçlar C30 l/d 80 (beton sınıfı C30, çelik elyaf narinlik oranı 80) betonu için de elde edilmiştir. Çelik elyaf miktarı %0,5 olan betonlarda kesme kuvveti artış oranı %35, çelik elyaf miktarı %1 olan betonlarda ise kesme kuvveti artış oranı %78,7 olmuştur.

Beton sınıfı C50 olan çelik elyaflı betonlarda ise %1,5 elyaf miktarı kesme kuvvetini %151,4, %0,5 olan çelik elyaf miktarı ise kesme kuvvetini %66 artırmıştır.Yüzde 1

olan çelik elyaf miktarı ise kesme kuvvetini %114 oranında artırmıştır. Bunların yanında elde edilen sonuçlara bakıldığında çelik elyaf narinlik oranının kesme kuvveti üzerine herhangi belirgin bir etkisi olmadığı görülmüştür.

AnahtarKelimeler: Kesmedirenci, çelikelyaf, betonsınıfı, çelikelyaflıbeton.

To my dear parents

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I thank with love to my parents for their unconditional trust, timely encouragement, and endless patience. It was their love that raised me up.

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LIST OF SYMBOLS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS EN	British European Standard
FRC	fiber reinforced concrete
HSFRC	high strength fiber reinforced concrete
l/d	length/diameter ratio, fiber aspect ratio
SFRC	steel fiber reinforced concrete
UPV	Ultrasonic Pulse Velocity

Chapter 1

INTRODUCTION

1.1 General

In the design of concrete members, one of the most important steps is shear design. A different experiment in the process of concrete production calls for reconsideration in sheer design since shear failure is one of the most recurring flaws that impends the safety of structures (ASCE-ACI 455, 1998).

To be able to understand the behavior of concrete elements against shear force, it is of utmost important to consider the mechanism of shear transfer. Another significant aspect is to find a way to reduce the shear cracks. Shear reinforcement is necessary to prevent these kinds of cracks during structural design. In beams, stirrups are used as shear reinforcement. To achieve the same sort of reinforcement in slabs, the designers make use of dowels.

In addition to the points mentioned above, it is difficult to put steel bars in critical sections. The previous studies done on concrete design and shear reinforcement have manifested that using steel fibers in concrete production as a method of reinforcement can enhance the performance of concrete structural members. In addition to concrete performance, it has positive effects on shear performance (Batson&Jenkins, 1972).

Batson and Jenkins (1972) examined the use of steel fibers with different types, shapes and sizes instead of vertical stirrups in conventional beams loaded. The results of their study showed that steel fiber had some advantages over vertical stirrups or bend up flexural steels. Fibers were randomly distributed through the volume of concrete and therefore the strength of first tensile crack was increased by steel fibers (Swamy, 1987).

Fiber reinforced concrete is usually used to overcome the tension and weakness of all types of concrete. The experiments in the literature have demonstrated that compressive strength and tensile strength are directly related to the strength of concrete. In other words, by increasing the strength of concrete, compressive strength and also tensile strength will be affected and increased (Batson & Jenkins, 1972).

To sum up, the addition of steel fibers in the production of concrete can provides effective reinforcement against shear failure. This fact has been pointed out all through the literature in a wide range of studies (Cucchiara, Lameudola, Papia, 2004).

1.2. Statement of the Problem

Despite the fact that some studies have previously been done on shear reinforcement and the effect of fiber reinforced concrete, the principle of shear behavior of fiber reinforced concrete is still under review and revision to establish a standardized test method to measure the materials properties like shear strength and shear toughness. The current study will study this problem to get definite results with regards to shear reinforcement.

1.3 Objectives of the Study

The main objective of this study is to analyze the shear behavior of two different types of fiber reinforced concrete. This experiment of reinforcement has been carried out with different amounts and aspect ratios of steel fibers. The current study therefore will conduct an experiment on a comparison between steel FRC and plane concrete.

In addition to the main objective mentioned above, another aim of this research is to measure the compressive strength of all the mentioned samples. A destructive test has been performed by utilizing a compression test machine. Moreover, a non-destructive test has been carried out making use of the Schmidt hammer and pundit test. In summary, the following are the main objectives of the current study:

1. To design all the concrete mixes with available materials at the laboratory of materials construction of the Civil Engineering Department of Eastern Mediterranean University in north Cyprus.

2. To perform shear test on concrete samples and find out the effect of using steel fibers and its relation with shear strength.

3. To investigate the effect of volume fraction of fibers and the aspect ratio on mechanical properties of concrete.

1.4 Achievements

As mentioned above, the purpose of the current study is to analyze the shear behavior of two different types of fiber reinforced concrete. With this aim, two mixes of concrete had to be prepared. Mix design proportioning for normal strength concrete and high strength concrete with the locally available materials are demonstrated in Table 1.1.

Table 1: Concrete Types and Specifications

Concrete Type ↓	Specs →	Cement Content (kg/m³)	Water/cement Ratio	Fine/coarse Aggregate	Passing Percentage	Superplastisizer Percentage (by weight of cement)
Normal Strength		455	0.5	1.0	50	0.4
High Strength		581	0.43	1.0	50	0.5

Some tests were done to evaluate aggregate and cement properties. The effect of different amounts and different aspect ratios of steel fibers were also obtained. It was evaluated based on fresh and hardened properties.

1.5 Hypotheses

The hypothesis which has been examined in the current is study is that the addition of steel fibers has an effect on material properties of concrete. The reinforcement of concrete by adding steel fibers is the suggested method for the improvement of shear strength.

1.6 Research Question

Having mentioned the objectives of this study and the hypothesis to be tested, it is worth making mention of the research question to better clarify the purpose of this experiment. The following is the research question to be answered by the study:

What are the influences of volume friction and aspect ratio of hooked end steel fibers on shear strength of fiber reinforced concrete?

1.7 Conceptual Definitions

1.7.1 Definition of Variable Parameters

1. Normal strength concrete: this type of concrete has a compressive strength between 20-50 MPa.

2. High strength concrete: this type of concrete has a compressive strength between 60-130 MPa.

3. Volume fraction: The amount of steel fiber used in concrete is calculated according to volume of concrete.

4. Aspect ratio: defined as fiber length over fiber diameter (L/D).

1.8 Works Done

1. This study includes a review of the related articles and lecture notes to assess and overview the major achievements from previous works on this subject.

2. As the research framework, the current study has followed British European Standards (BS EN).

3. Compressive test machine and flexural test machine have been used to evaluate compressive strength and shear strength. For flexural test machine some new setup has done.

1.9 Guide to the Thesis

The first chapter of this study includes a general introduction about FRC, SFRC and shear behavior, hypotheses and aims of this study.

The second chapter is comprised of the background, definition and some general results from previous studies and literature overview of the topic.

The third chapter includes the procedures of the current experiment. This chapter focuses on the experimental work, materials properties and an explanation of the methodology.

Chapter four focuses on the results and outcomes of the current experiments and comparison, and discussion of these results.

The fifth chapter covers conclusions, recommendations, implications and applications of the results.

Chapter2

LITERATURE REVIEW AND BACKGROUND

2.1 Introduction

Capacity design is considered as critical factor in structural design. For seismic resistant of concrete frame, consideration of this factor is important, when hard movements happen an extreme scatter falling mechanism is necessary. As a result, it is needed to eliminate the occurring shear failure that happens with large amount of shear stress and inadequate shear reinforcement to achieve of a complete flexural bearing capacity in the acute region. Experimental investigations have demonstrated that using adequate quantities of steel fibers in the concrete structure amends resistance against shear. This is because of a number of factors such as an increment in tensile strength, retarding the formation and pickup of cracks, reducing the space between stirrups, mention greater impressiveness in the crack-controlling mechanism, and better repartition of tensile cracks (Cucchiare, Mendola, Papia, 2003).

As Narayanan and Darwish (1987) have mentioned, the crack template that expands in fiber reinforced concrete beams which are exposed to shear is same to the pattern were seen in the equivalent reinforced concrete beams which are conventionally subjected to stirrups.

The shear strength of steel fiber reinforced concrete has always been the topic of research since the mid-1980s. All through the years, researchers have surveyed different classification of SFRC, for instance, high and low strength concrete, self-consolidating and mechanical properties of SFRC by means of lateral and longitudinal reinforcement. From previous studies, it is concluded that shear strength of structural components which are reinforced by steel fibers, can be increased consequential by the using of steel fibers (Slater, Moniruzzaman, Shahira, 2011).

With the addition of steel fibers to the structure of concrete, in some cases shear strength of plain concrete is more less than concrete with normal strength (Shin & Oh &Ghosh, 1994).

It could not find out the uniform behavior and relation with shear strength and compressive strength. Moreover, the compressive strength of SFRC does not always increase with a boost in the volume of steel fibers. It is mainly due to the fact that the compressive strength of SFRC is more reliant on the characteristics of fibers and matrix of concrete than it is dependent on the fiber volume (ACI 544, 1999).

2.2 FRC

2.2.1 Definition of FRC

In the previous section, the effect of steel fiber addition was briefly touched upon. In this section, Fiber Reinforced Concrete (FRC) will be defined. Composition of Portland cement, aggregates, and incorporating discrete discontinuous fibers is traditionally what defines Fiber Reinforced Concrete. Plain concrete or unreinforced concrete is a frail substance. This brittleness of materials can be better described by naming certain properties. Those properties are such as low tensile strength and also low strain capacity. In addition, random distribution of fibers can cause an increase in ductility. In order to have pliable concrete the fibers used must be strong enough and have a strong bond to the rest of the materials. This will bring about more tolerability of significant stresses over a relatively large strain capacity. Moreover, the real role of fibers is increasing the toughness of concrete (Colin, 2001) (Perumalsamy, Balaguru, Shah, 1992).

In addition to the advantages of fiber addition pointed out above, it is worth mentioning that the addition of fibers in concrete brings a better control of its cracking and it also improves the mechanical properties of the concrete. Particularly, it adds to the post-cracking load-carrying capacity of the material which will eventually induce a sort of pseudo ductility. This, in turn, decreases its level of fragility. Several types of fibers can be exerted in the structure of cement which will yield satisfactory results. The metal and, more specially, steel fibers are more commonly used. Although the performance of steel fibers reinforced concrete has started to be well known in the case of a first short-term loading, the lastingness of their vital character in the structural application leaves room for experimentation and exploration. The long-term manner of the steel fiber reinforced concrete in the cracked mode appertains on their volume of endeavor which is obtained by the steel fiber that is placed between the two lips of cracks (Granju & Balouch, 2004).

Under any type of loading the inclination and purpose of fiber is increasing the strain. According to Naaman (1985), by adding fiber to the concrete structure, it can be expected to achieve more resistance of reinforced concrete members against flaws and shortcomings such as cracking, deflection and other conditions.

The experiments of using fibers for reinforcement of brittle materials which exist in the literature can be traced to ancient times. In the history, certain materials such as straw and horsehair have been used as fiber. Reinforcement of sun baked bricks was done by the addition of straw. Moreover, horsehair was used as fiber in masonry mortar and plaster. As an example of this ancient technique, one of the old buildings that still remains from 1540 is Pueblo House. It was built by sun baked bricks reinforced with straw. In later times, asbestos was used as fiber in cement paste with a large scale commercial success by a new manufacturing process that was invented by an Austrian engineer, Ludwig Hatschek in 1898 (Ramuadli & Batson, 1983).

The utilization of asbestos fiber in construction products has continued to be applied widely throughout the world today. In Figure1 asbestos was shown. But due to the health hazards linked with asbestos in 1960s and 1970s, some countries are preventing the inclusion of asbestos (ACI 544, 2009).


Figure 1: Asbestos fiber (standardenergy.eu, 2013)

In the modern day, the composition of engineering material by fibers will magnify the concrete's composite properties. Engineering materials refer to products such as ceramic, plastics, cement, and gypsum productions. Figure 2 shows steel fiber in concrete. The strengthened properties include tensile and compressive strength, crack resistance, crack control and elastic modulus, longer durability, more resistance to impact, scratch resistance, shrinkage, fatigue life, expansion, fire resistance, and thermal characteristics (ACI 544, 2009).

Figure 2: Fiber reinforced concrete (ASTM C1609, 2013)

2.2.2 Types of FRC

Since 100 years ago to the present time, fiber reinforcement has been growing in popularity and application (ACI 544, 2002). Caused by this wide range of fiber utilization, numerous fiber types are available for commercial and experimental purposes. Among the basic fiber categories, one can name steel, glass, synthetic and natural fiber materials (ACI 544, 2002).

Augmenting the flexural, shear and tensile strength of concrete are the features of using natural fibers in concrete structure. Types of natural fibers are shown in Figure 3.The only downside is that natural fibers are less durable than the other types (ACI 544, 2009).

Figure 3: Natural fibers (natrualfiber.org, 2013)

An alternative to natural fiber is synthetic fibers which are manmade and were produced in 1965.The performance of this type of fiber is not as efficient as the performance of glass and steel types of fiber. Nonetheless, synthetic fiber is able to successfully reinforce concrete (ACI 544, 2009). (Figure4).This is mainly because the use of a small amount of this type of fiber in concrete composites can increase failure resistance and strength (Greenough & Nehdi, 2008) (Majdzadeh & Soleimani, 2006).

Figure 4: Synthetic fibers (profoundit.com, 2013)

In 1960 glass fiber was produced. Glass fiber is shown in Figure 5 and Figure 6.This type of fiber could also lead to the reinforcement of concrete since is a light-weight material and has tended to be placed upright. Concrete which is reinforced with glass fibers are utilized in architectural applications. How the largest use of glass fiber reinforced in U.S is currently for production of exterior architectural cladding panels (ACI 544, 2002).


Figure 5: Glass fibers (Azom.com, 2013)

2.2.3 Applications of FRC

In the previous section, FRC was defined and the features and types of it were illustrated. This section is dedicated to the different applications of FRC.

FRC is used in different elements of structure and productions. As an example, one can name the implementation of Glass fiber for many plant manufactured products. It has also been used in mines for dry stocked concrete masonry walls (ACI 544, 2002).

In the history of construction, synthetic fiber has been used in slabs in grade, floor slabs and stay-in-place forms in multi-story buildings.

Natural fibers have been used in manufacturing the sheet products such as roof shingles siding, planks and pipes and utility boards (ACI 544, 2002).

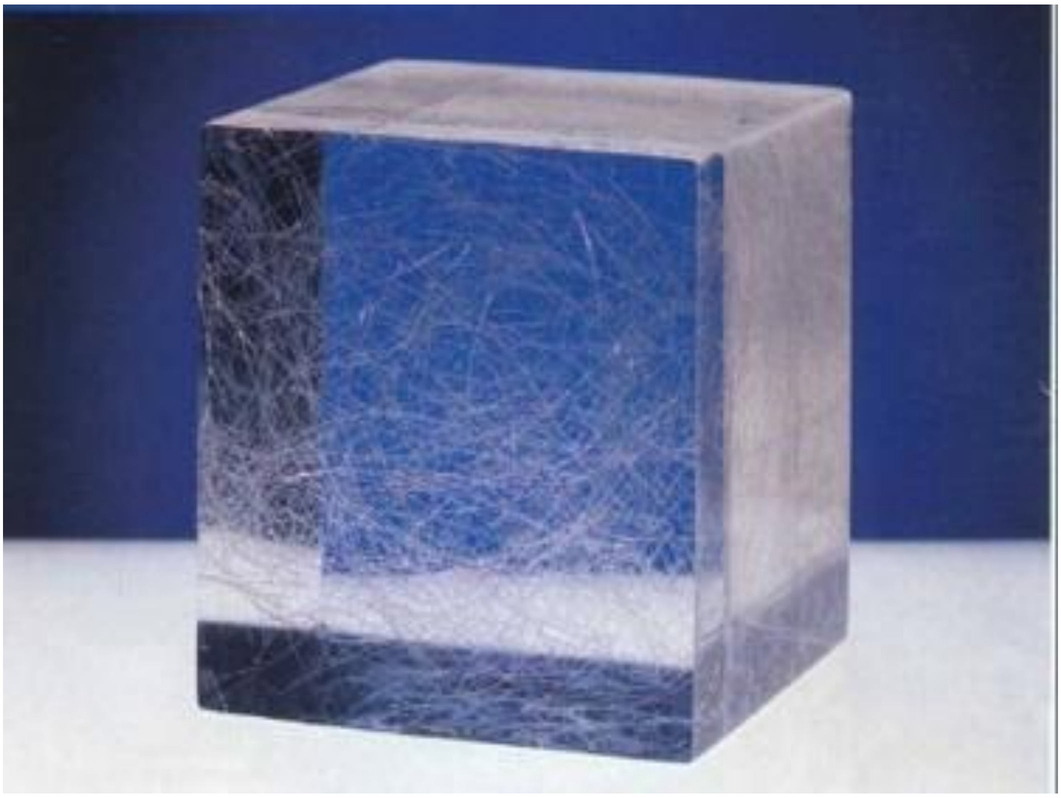

Figure 6: Orientation of glass fibers (construction.sunroc.com, 2013)

2.3 Definition of SFRC

In the previous sections, different types of fiber were discussed. Steel is another type of fiber which is used in the structure of concrete. Concrete which reinforced with steel fibers (SFRC) is made by hydraulic (reacting by water) cement and fine aggregates or fine and coarse (rough) aggregate and steel fiber. Failure of SFRC is in tension just after steel fiber crushed or when it is dragged out of matrix of cement. This phenomenon is shown in the typical fractured surface of SFRC (ACI 544, 2002).

SFRC can be utilized to strengthen the beam-column hinges of frames which are made up by reinforced concrete in region with earthquake tendencies. Wang and Lee (2007) mentioned the significant improvement on ductility, flexural and shear strength of interior beam-column joints by using SFRC jacketing. Steel fiber can also improve crack resistance to crack growth (Lim & Oh, 1999).

Durability and other properties of steel fiber reinforced concrete are directly dependent on its composite nature. Those properties such as strength, fiber volume percentages and elastic modulus are related to the crossing point between the fiber and matrix (ACI 544, 2002).Steel fibers are defined as little, separate lengths of steel which have an aspect ratio between 20 and 100 with different cross sections (ACI 544, 2002).

Classification of steel fiber: according to manufacturing process steel fibers are classified as: cut wire (cold drawn), cut steel, melt-extracted and other fibers. This classification has been done by ASTM A 820 (Figure 9).

Figure 7 and Figure 8 are showing crimped-end- wire by details.

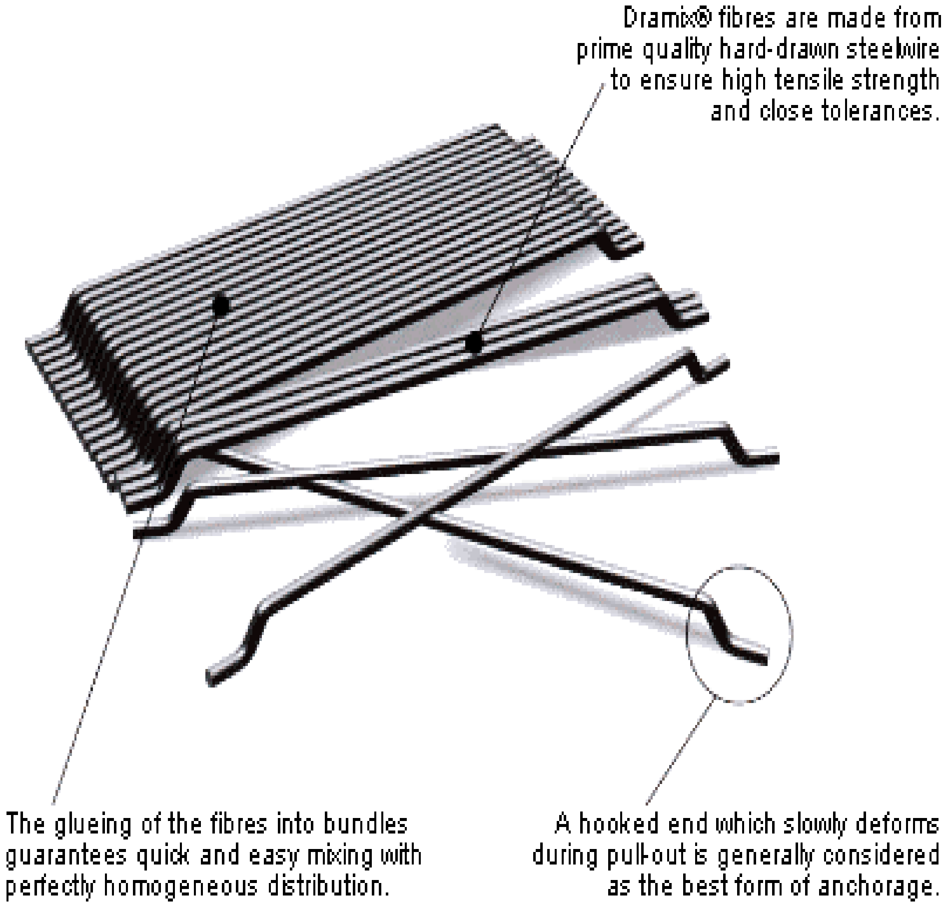

Figure 7: Crimped-end-wire (bekaert.com, 2013)


Figure 8: Crimped-end-wire (apecind.en.ec21.com, 2013)

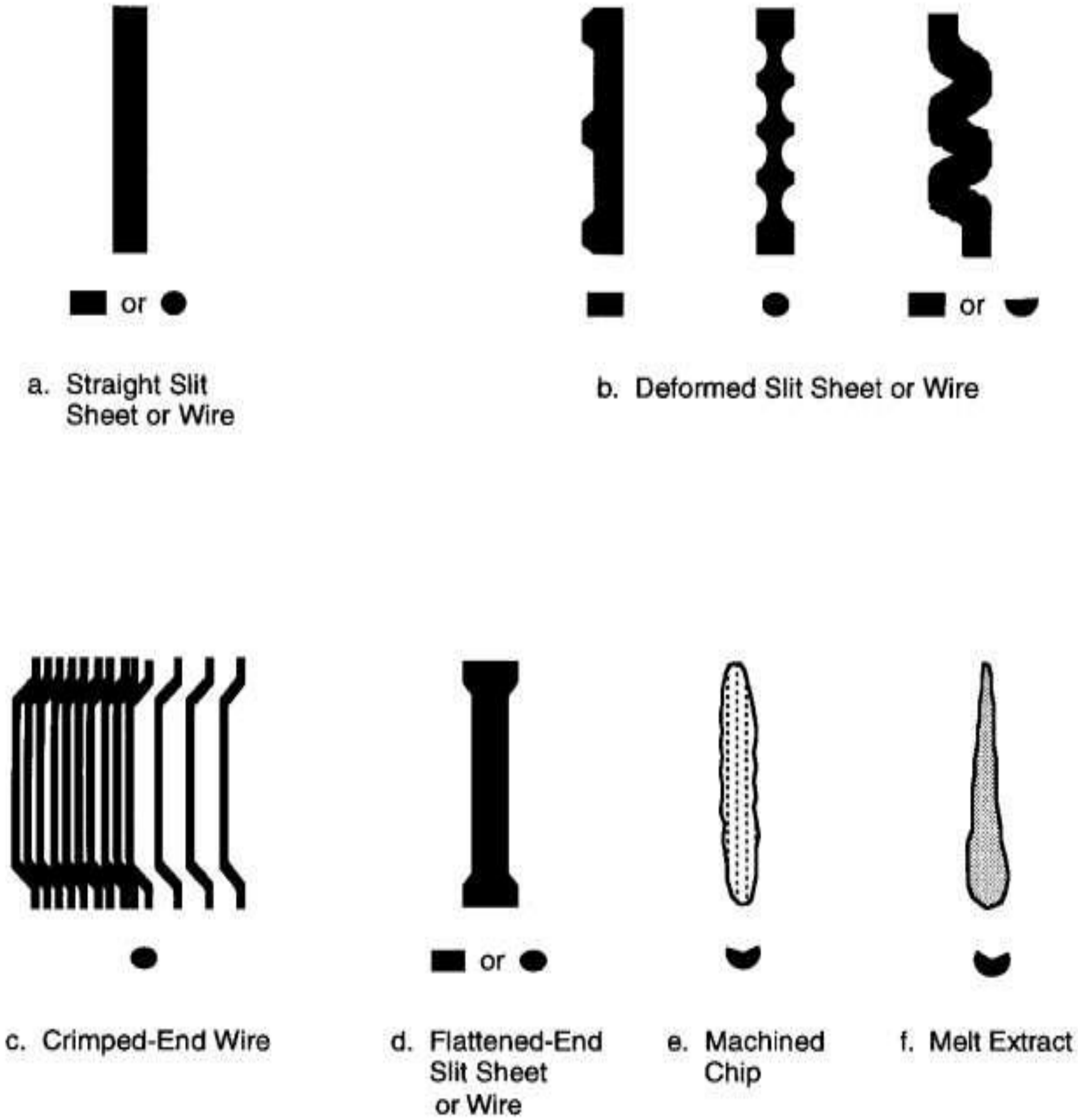

Figure 9: Types of steel fibers (ACI 544.1, 1996)

2.3.1 Applications of SFRC

The previous part of the literature covered the definition of SFRCs. In this part, the different applications of SFRCs are illustrated according to the literature. Applications of SFRC are based on some significant properties of this type of fiber reinforced concrete. These properties are improved flexural toughness, impact resistance, and flexural fatigue. For these reasons, SFRC has been used in many structural elements (ACI 544, 2002).

The difficulty of placing bars for reinforcement of some concrete structures is caused to utilize SFRC in some applications those are needed to be reinforcement, such as hydraulic structures, large industrial slabs, tunnel lining, and also bridge decks (Dinh& Parra-Montensions& Wight, 2010).

In addition to the applications mentioned above, SFRC has also been used in flat slabs on grade when it is subjected to high loads and impact. Also, SFRC is utilized in Shot-Crete applications, ground support, rock slope stabilization, and repairs (Monfore, 1968).

Figure 10 is showing mixed concrete by steel fibers before placed in molds.

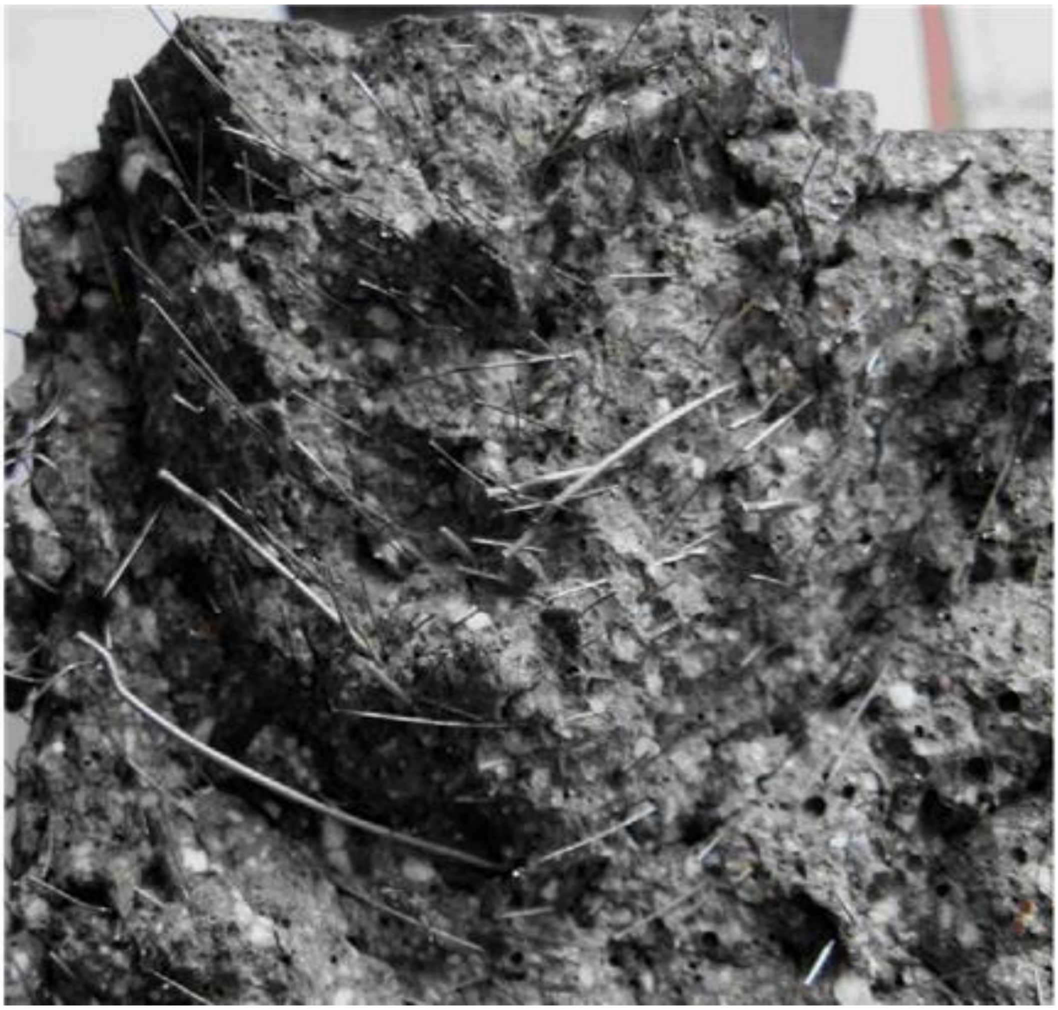

Figure 10: mortar mixed by fibers (Jsce.or.jp, 2013)

2.3.2 Mechanical Properties of SFRC

2.3.2.1 Toughness:

According to ACI committee 544(2002), toughness is defined as the total energy which is absorbed before the complete separation of specimens (Shah & Winter, 1966). The area under load-deflection curve plot for beam specimen flexure test shows toughness and this toughness can be calculated. Steel fiber has improved the toughness of concrete (Shah& Winter, 1966) (Figure 11).

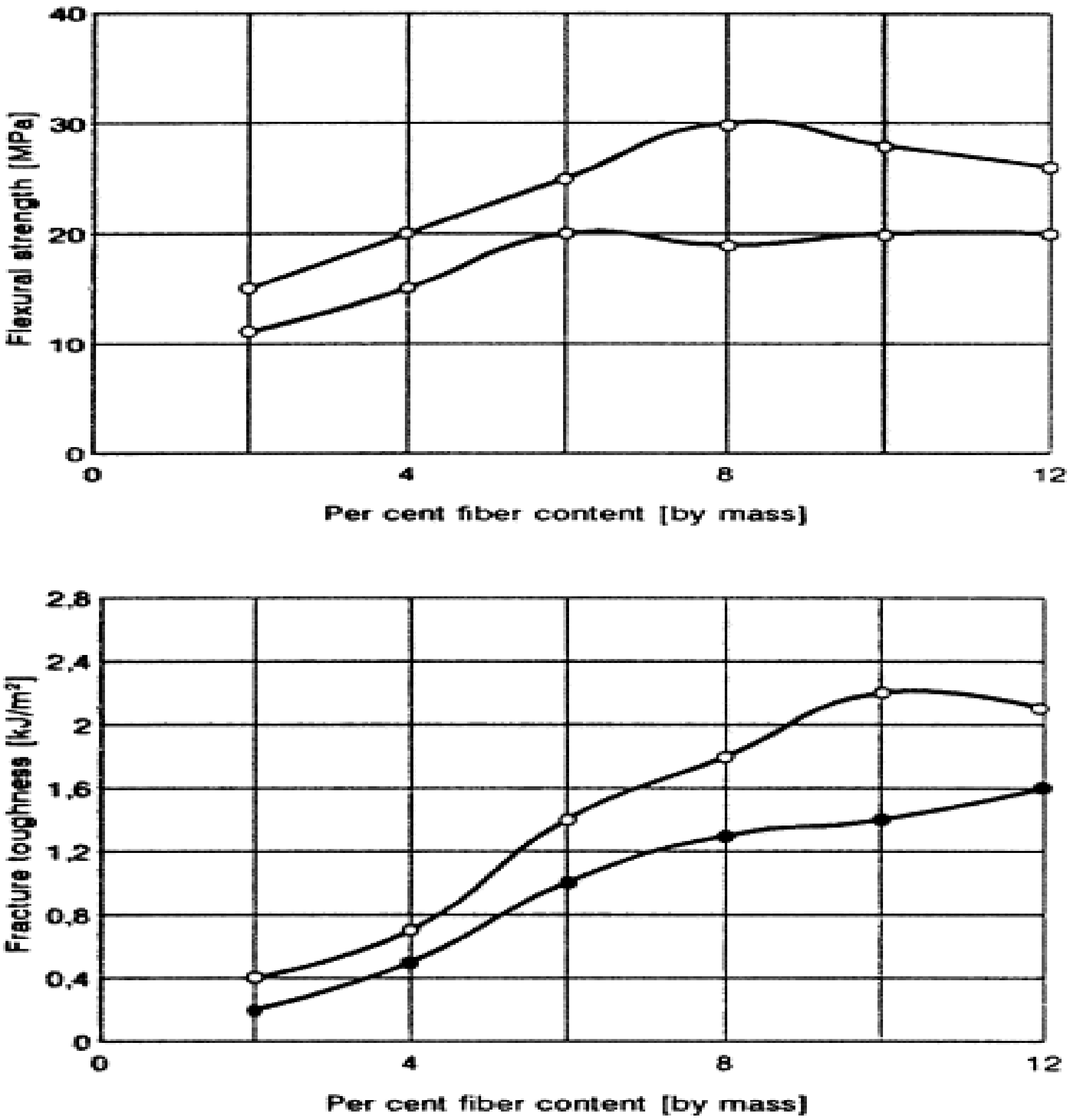

Figure 11: Relation between toughness and volume fraction of fibers (circuitsonline.net, 2013)

2.3.2.2 Flexural Strength:

Flexural strength for plain concrete is its stress capacity which can be determined by a third-point loading test, to find the stress at maximum load. Flexural strength of plain concrete is low. To improve this strength, the addition of fiber is helpful (Hannant, 1978) (Naaman& Shah, 1975).It is also very well established that the flexural strength grows up by amount and aspect ratio of the fibers (Eren, 1999) (Figure 12).

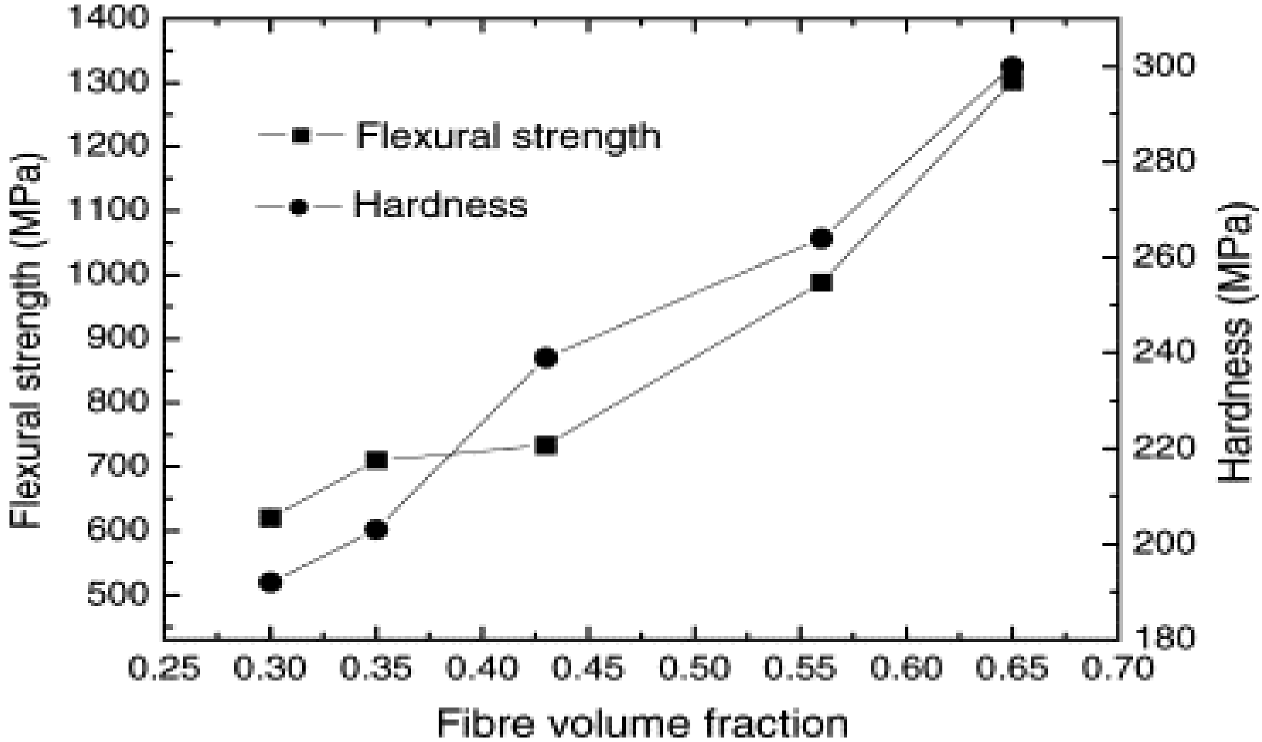

Figure 12: Relation between volume fraction and flexure strength (sciencedirect.com, 2013)

2.3.2.3Fatigue Endurance

Fatigue endurance is expressed by an S-N curve. S is the ratio of the maximum stress to the statistic strength and N shows the number of cycles at failure. As mentioned by Zollo& Ronald (1975), by adding steel fiber to the composite of concrete, improvement of fatigue endurance is achievable.

2.3.2.**4 Impact Strength**

In describing impact strength, strength and fracture energy are important parameters. According to an ACI committee report, the improvement of impact resistance of concrete has been achieved by the addition of steel fibers (Namur &Naaman, 1986).

2.3.2.5 Compressive Strength

Compressive strength of concrete is another factor which can be affected by adding steel fiber. Studies such as Johnston (1974), Eren and Celik (2001) have illustrated that this strength can be increased by the inclusion of steel fiber (Figure 13).

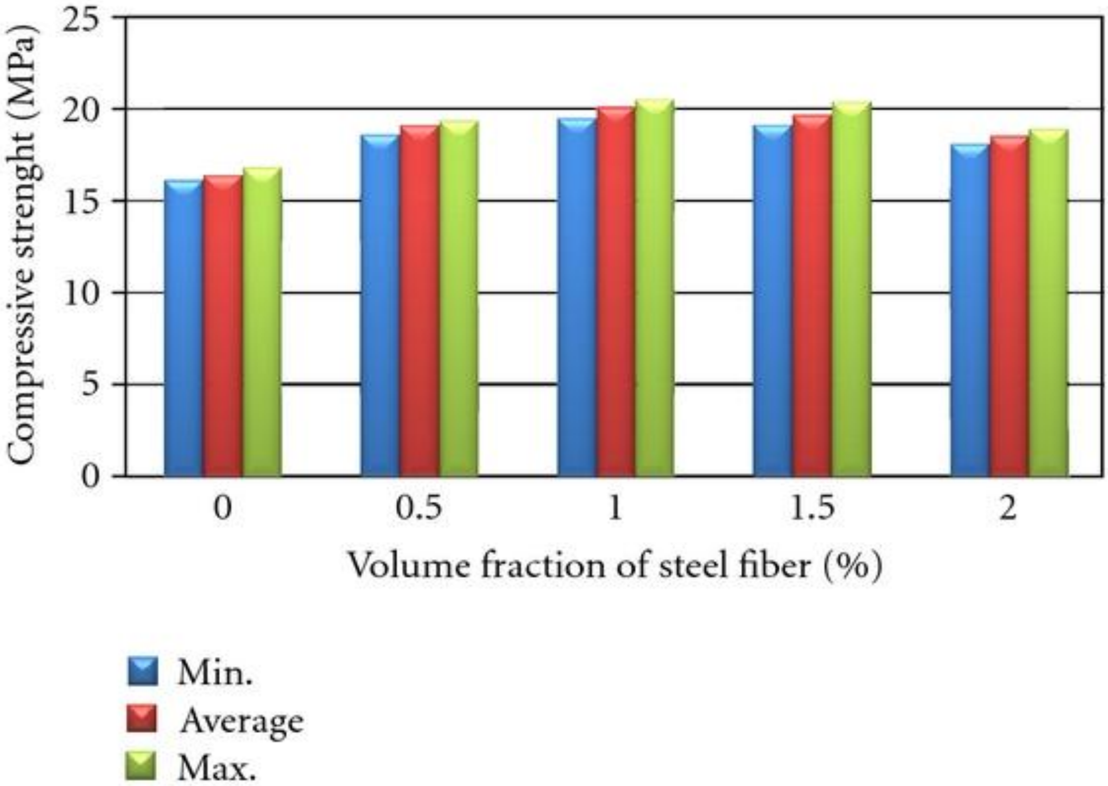

Figure 13: Relation between volume fraction and compressive strength (hindawi.com, 2013)

2.3.2.6 Shear Strength:

Shear capacity can also be increased by augmenting the amount of steel fibers in concrete structure (Baar, 1987) (Figure 14).

Figure 15 shows what will happen after cracking loads.

Figure 14: behavior of FRC after shear loading

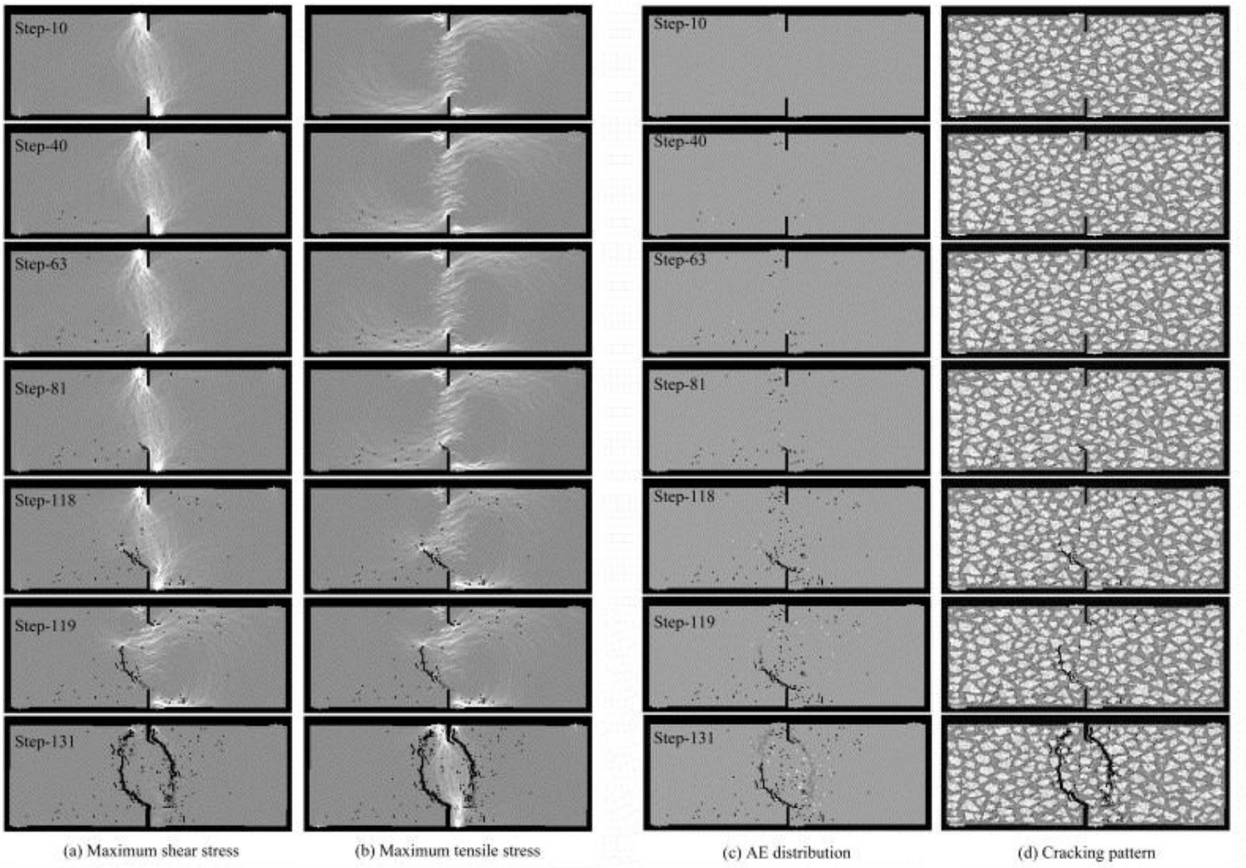

Figure 15: Cracking pattern of shear stress and tensile stress (antiquityofman.com, 2013)

2.3.2.7 Modulus of Elasticity and Poisson Ratio:

Despite what has been discussed so far with regards to a direct relationship between steel fiber and strength, studies have shown that the addition of steel fiber to concrete has no significant effect on the modulus of elasticity and Poisson ratio value (ACI 544, 2002).

2.3.3 Physical Properties:

2.3.3.1 Shrinkage:

Shrinkage can be defined as a change in the volume of concrete body by losing water. A study conducted by Balaguru and Ramakrishnan (1988) has shown that steel fiber reduces the plastic shrinkage crack width but it has no effect on drying shrinkage.

2.3.3.2 Creep:

Creep is described as the long-term deformation of material under sustained load. There is no such effect observed which can be traced to the addition of a small amount of steel fiber. However, by adding a large amount, significant improvement is gained (Grzybowski& Shah, 1990).

2.3.3.3Durability:

Corrosion of steel fiber is one of the main problems which have a negative impact on durability of steel fibers in concrete (Balaguru& Ramakrishnan, 1986).

2.3.3.4Abrasion Resistance and Skid Resistance:

Steel fiber has been proven to have a positive impact and better performance regarding its erosion, abrasion and skid resistance but those effects are not significant according to the results of a study carried out by Cook &Uher (1974).

2.3.3.5 Thermal Properties:

2.3.3.5.1 Thermal Conductivity:

A number of relevant studies have reported that the addition of steel fiber to concrete will lead to a small increase in thermal conductivity.

2.3.3.5.2Thermal Expansion:

Some test results have shown that no significant effect has been observed by adding steel fiber to concrete (Cook &Uher, 1974).

2.4 Volume Fraction of SFRC

The range of an efficient amount of fiber is from 0.5% to 1.5 % by volume of concrete in percent. These amounts can be mixed and placed by conventional equipment. Some studies and experimental results have shown that by increasing the volume fraction of steel fiber, significant improvement on flexural strength, toughness, shear and compressive strength can be attained (Song &Hwang &Sheu,

2005). By addition of steel fiber to mortar, slump will decrease significantly (Figure 16).

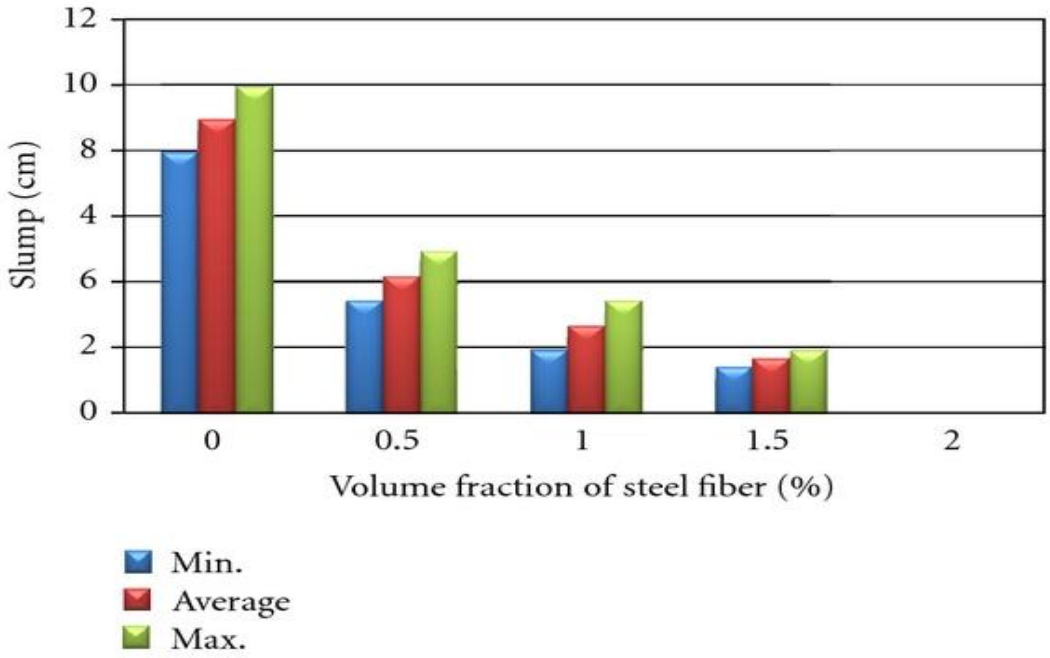

Figure 16: Relation between volume fraction and slump (hindawi.com, 2013)

2.5 Aspect Ratio

According to the literature, the high efficiency of fiber is related to high aspect ratios. Aspect ratio is defined as ratio of length to diameter of fiber. Fibers with enough aspect ratios have been proven to increase tensile strength, but aspect ratios greater than 100 usually cause inadequate workability of the concrete mixture. (Figure 17).Figure 18 shows how steel fibers are oriented in mortar.

High aspect ratio can lead to an improvement in the post-peak performance, because it brings about high resistance when being pulled out from the matrix.

The potential of balling of fibers during mixing is a detriment of using fibers with high aspect ratios (ACI 544, 1999).

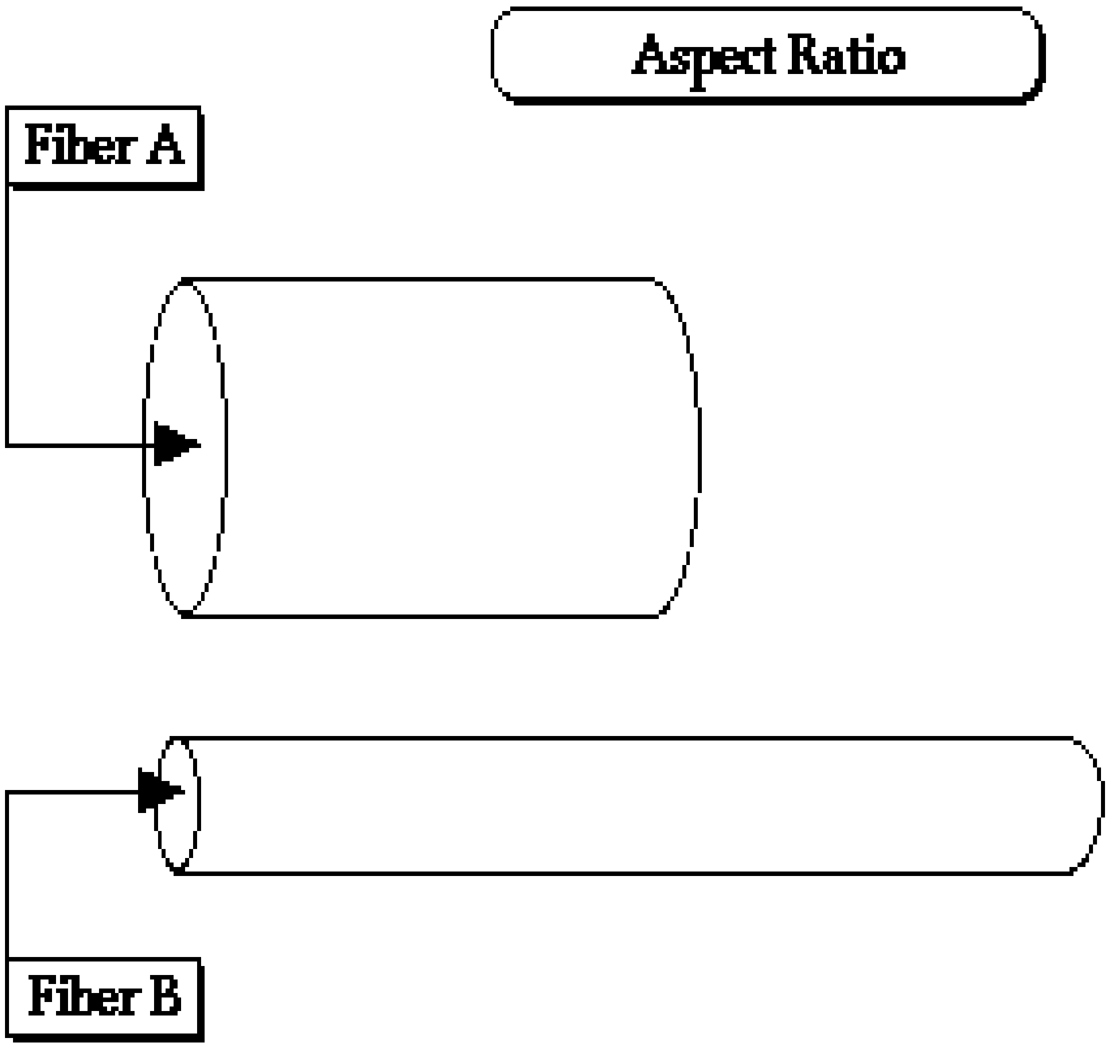

Figure 17: Definition of the aspect ratio of fiber (mae.syn,edu, 2013)

Figure 18: Orientation of fiber in concrete and mortar (Jsce.or.pi, 2013)

2.6 Effect of Amount and Aspect Ratio of Fiber on SFRC Properties

The combination of aspect ratio and volume fraction of fiber has a great influence on some mechanical properties of concrete such as increasing shear strength and flexural strength (Khaloo& Kim, 1997).

2.7 Advantages and Disadvantages of SFRC

Among the advantages of SFRC, one can mention an increase in ductility, toughness strength, and a reduction of fatigue. These positive impacts lead to saving time and cost in construction project.

The main disadvantage of SFRC is that its utilization in structural elements has some fails. As an example, one can name labor and personnel being scraped or cut by expose fiber while working on concrete surface.

In addition to that, some residential complaint has been reported about children who suffered skin abrasion from falls on the pavement. Moreover, at the airport loose fibers at the hardened surface might be blown onto aircraft engines or tire which leads to unsafe operation (Vandewalle, 1990).

2.8 Definition of Shear Force

Cracks in concrete or mortar have been generally assumed to propagate in the direction normal to the maximum principle stress, which represents the tensile, opening fracture mode, designed as mode I. this type of cracking has been observed even for failure of many structures loaded in shear. Mode I crack propagating sideway from the notch tip would, in double-notched test with a narrow shear force zone, quickly run into a low stress zone of the material and would therefore, release little energy. Mode I fracture energy is according to the crack band model, represent by the area under the tensile stress strain diagram, multiplied by the width of the fracture process zone. Mode II shear fracture, tensile cracking is not all that is needed for shear failure. Shear strength is kind of strength that is tending to prevent yield failure in materials or any structural components. This kind of strength is formed when materials are faced to shear force. Shear force is describing as a kind of load that is trying to create the sliding failure. This kind of failure is occurred parallel to direction of the applied force. The simple example that can describe shear failure is cutting paper by scissors. This failure is happening exactly in shear. In some engineering fields such as mechanical and civil engineering, considering shear force, shear strength and shear failure are important factors for designing level (e.g. beams, plates, or bolts).for example the most important purpose of using stirrups in concrete beams is making higher shear strength against structural failure.

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Chapter 3

EXPERIMENTAL WORK

3.1 Introduction

The objective of this research is to examine shear strength and shear behavior of normal strength and high strength fiber reinforced concrete. Both types of concrete were reinforced by hooked-end steel fiber. The effects of some important parameters of steel fibers on shear strength are going to be investigated. The chosen parameters are compressive strength of two different types of concrete, different volume fraction of hooked-end steel fiber, and two different fiber aspect ratios (l/d). The results of the current experiment have been compared with plain concrete. Steel fiber on concrete improves crack behavior under dynamic loads. Consequently, the results are due to parameters such as the amount of fiber and l/d ratio.

3.2 Materials

The materials used in the concrete mix are blast furnace slag cement (BFSC), crushed limestone coarse and fine aggregates from Beparmak Mountains. Other materials include hooked-end steel fibers, super plasticizing admixture, and drinkable water. Water to cement ratio for normal strength concrete is 0.50 and for high strength is 0.43.

3.2.1 Cement

The type of cement used throughout this study is blast furnace slag cement (BFSC). Composition properties of cement are 67% Portland cement bricks, 16% granulated blast furnace slag, low TOC limestone as little as 11%, and natural anhydrite for less than 6%.

Cement type and characteristics is CEM II/B-M(S-L) 32.5 R. Specifications of this cement allow it for using in lean concrete and normal concrete in sites. Initial and finial setting time of this cement are 225 (min) and 345(min) and the Specific Weight is 3.23 (gram/cm^3).

3.2.2 Aggregates

The aggregates which are utilized in this study include crushed limestone and lime dust. The maximum size of the coarse in this experiment is 10mm. The detailed properties of aggregates are given in Table 2.

Table 2: Aggregate properties

properties	Relative standards	Fine Aggregate	Coarse Aggregate
Relative Density (SSD)	(ASTM C 127) (ASTM C 128)	2.67	2.69
Water absorption (%)		2.73	0.70
Limestone crusher dust content (%)	(ASTM C 117)	16.5	4.6

3.2.3 Mixing Water

Drinkable water was used all through this study. The main reason for having chosen drinkable water was that is clear and has no pronounced taste or odor. Therefore it has been used as mixing water for making the concrete. The water used in this experiment was available at the EMU Department of Civil Engineering laboratory.

3.2.4 Superplastisizer

High range water reducers were used in the concrete mix to avoid segregation and improve the flow ability. Adding Superplastisizer to the mix allows reducing water-cement ratio. It is used where slump retention, high strength and durability are required. Gelenium 27 was used in this study as the Superplastisizer (Figure 19).

Table 3: Properties of superplatisizer

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 gallons 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. It should be added carefully for a complete dispersion during the mix. Should not be added to the dry aggregates.

Features and Benefits	Having concrete with good workability and no segregation with the lowest w/c ratio. Excellent slump retention without retardation. Reduce the curing cycle. Reducing the vibration time even in case of congested steel reinforcement. Developing the surface and quality of finished concrete. Gelenium 27 has more benefits than old Superplastisizer, adding it to the mix will improve concrete durability and physical properties. Decreases the risk of shrinkage

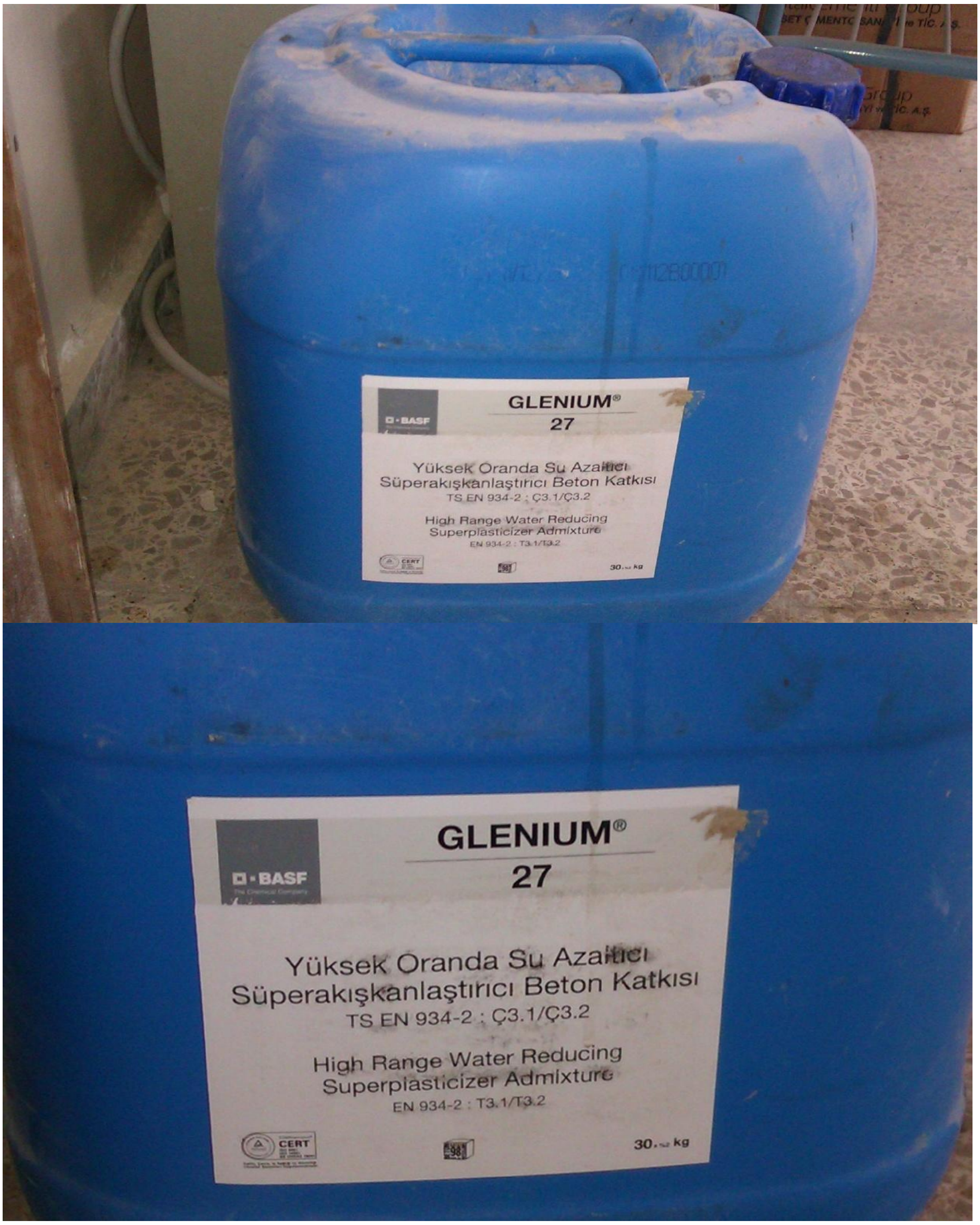

Figure 19: water reducing admixture

3.2.5 Steel Fiber

The type of used fiber in this study is hooked-end steel fiber. Two different aspect ratios (l/d) were considered, namely, 65and 80. Three different volume fractions of steel fiber were added to each batch of concrete. Those fiber amounts were 0.5%, 1.0% and 1.5% by volume of concrete. Figure 20 and 21 are showing steel fibers used in this study. 65/60 is described as 65 is aspect ratio of steel fibers and 60mm is length and diameter of steel fiber is 0.92 mm. For the other type of aspect ratio (80/60), diameter is 0.75 and the length is 60mm.

Figure 20: hooked-end steel fibers

Figure 21: hook-end steel fiber with l/d (65/60)

3.3 Mix Details

In this study concrete mix proportion has been designed according to Building Research Establishment (BRE, 2007). All mix properties are by weight and two different types of concrete have been used. One is normal strength and the other one is high strength concrete. For each type, different W/C ratios have been considered. A superplastisizer has also been added based of the weight of the used cement in each batch. The amount of the superplastisizer was 0.4% of the weight of the cement for the normal strength concrete and 0.50 % of the weight of cement for the high strength concrete.

3.4 Procedure

For any batch, the ingredients were put inside the mixer in the subsequent order: coarse aggregates (10mm), fine aggregates (5mm), cement, water, steel fibers and finally the superplastisizer. This mixing method has been followed for all mixes to make homogenous fresh concrete. After 1minute from starting the mixing process, water was added gradually, and 30 seconds after the addition of water, discrete steel fibers were added into the mix. Then 30 seconds after adding fibers, the superplastisizer was added to the mix. The mix was under the process for 2 minutes to provide a uniform fresh concrete. Total mixing process took 4 minutes all through. VEBE test were done to check the workability of mix (Figure 22).

Figure 22: VEBE test machine

3.5 Casting Plain Concrete and SFRC

3.5.1 Compressive Strength:

Cubic molds were utilized for evaluating compressive strength for SFRC and plain concretes. The dimension of the cubes was 150 mm. For any batch, 9 samples were casted, 3cubes for 7 days of curing, 3cubes for 14 days of curing and 3 cubes for 28 days of curing. It should be noted that all casting was according to BS EN 12390-

3(2002) and whole specimens were cured in a curing tank with 20°C temperature. Figure 23 and 24 shows placed fresh concrete in molds.

Figure 23: vibrating cubic concrete samples

3.5.2 Casting Shear Strength Test Specimens

In the current experiment, rectangular molds were used for shear tests. The size of the molds is 100*100*300 mm. For any mix 3 test beams were needed. All of the proof specimens were cured in a curing reservoir for 28 days.

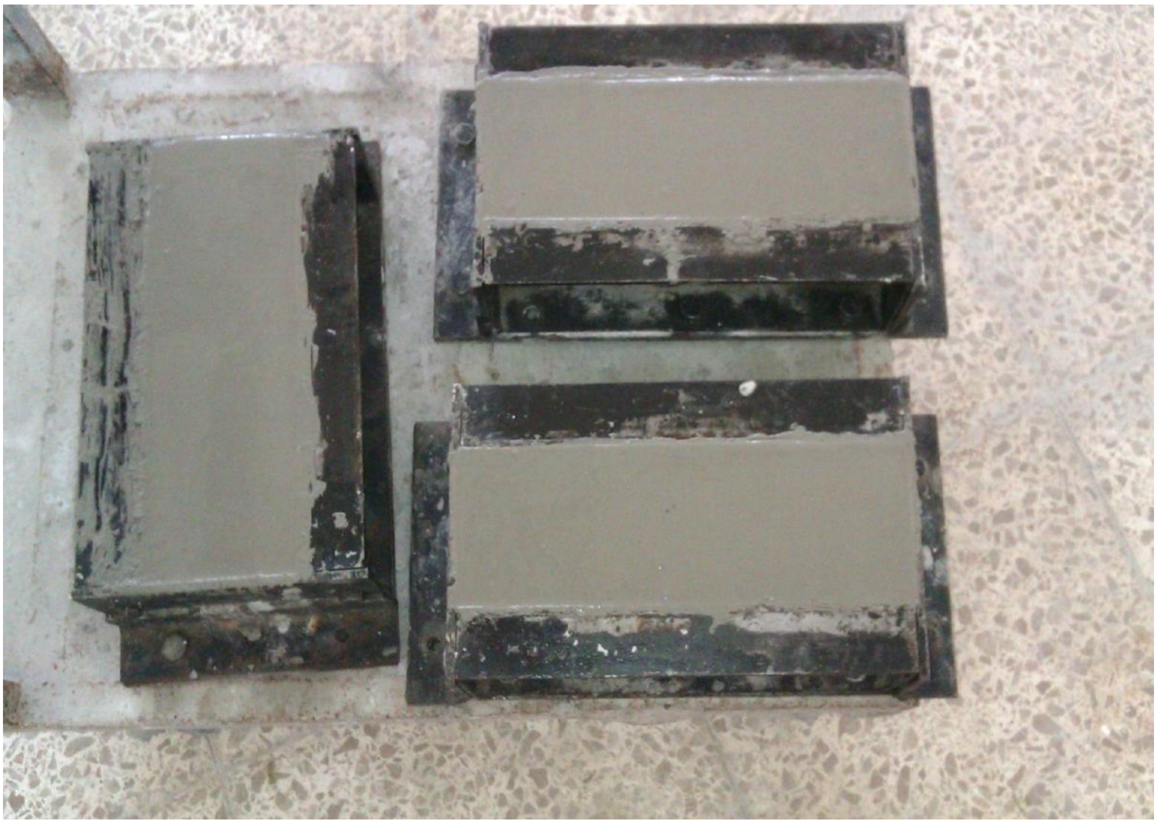

Figure 24: casted samples for shear test

After casting concrete, samples got ready for vibration (Figure 25).

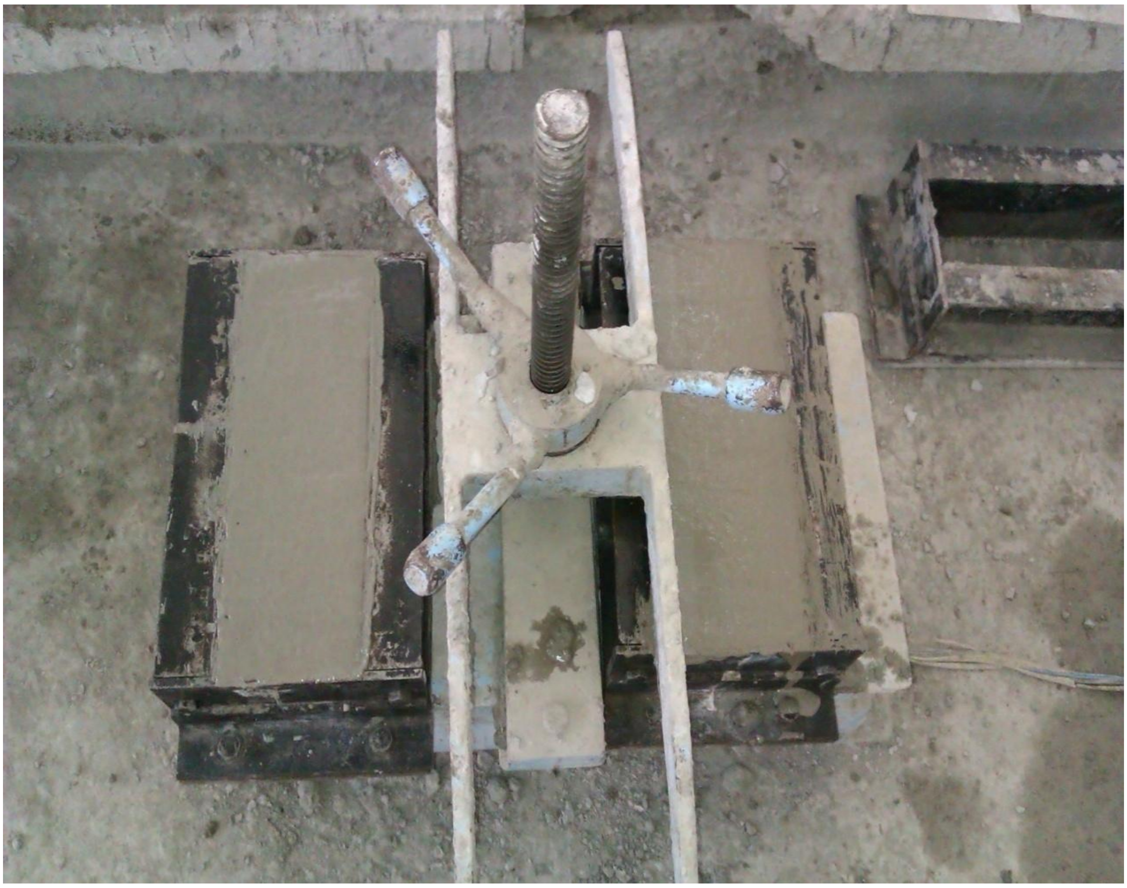

Figure 25: vibration machine was used for shear test samples

3.6 Curing

Curing can be defined as a procedure for insuring the hydration of Portland cement in newly-placed concrete. It controls the moisture loss and temperature. In this study, after casting, all specimens were kept in their mold in a moisture room for a day, and after 24 hours of air curing specimens were taken out of the molds and were put in curing tanks for water curing. The water temperature was constant and about 22±2°C, For 7, 14, 28 days, the standards followed were BS EN 1239(2002).Figure 26 and 27 show air curing room and Figure 28 show water curing tank.


Figure 26: Air curing room

Figure 27: Air curing room where samples placed for 24 hours

Figure 28: Water curing tank

3.7 Determination of Mechanical Properties

3.7.1 Testing for Compressive Strength

Following the standards (BS EN 12390-3, 2002) a compressive strength test was carried out on 150mm cubes. The test was performed on 7-, 14-, 28-days-old samples. All the tests were performed by using a compressive strength test machine. Test machine is shown in Figure 29 and 30.

Figure 29: Compressive strength test machine

Figure 30: Testing samples is compressive strength test machine

3.7.2 Ultrasonic Pulse Velocity (UPV)

Ultrasonic pulse velocity as a non-destructive test was performed on 150mm cubes (Figure 31). In the same line as the standards of ASTM C 597(2009), to determine the pulse velocity the following was done:

V=L/t

V=Velocity (km/sec)

L=length of path (km)

t=time (second)

Figure 31: UPV test machine

3.7.3 Schmitt Hammer

The other non-destructive test performed in the current study was the Schmitt hammer test (Figure 32). Schmitt hammer was used to measure the strength of concrete, mainly the surface hardness. Schmitt hammer test was performed on 150 mm cubes. For each sample, 10 rebounds were done. Compressive strength was determined by the rebound values (Figure33).

Figure 32: Schmidt hammer

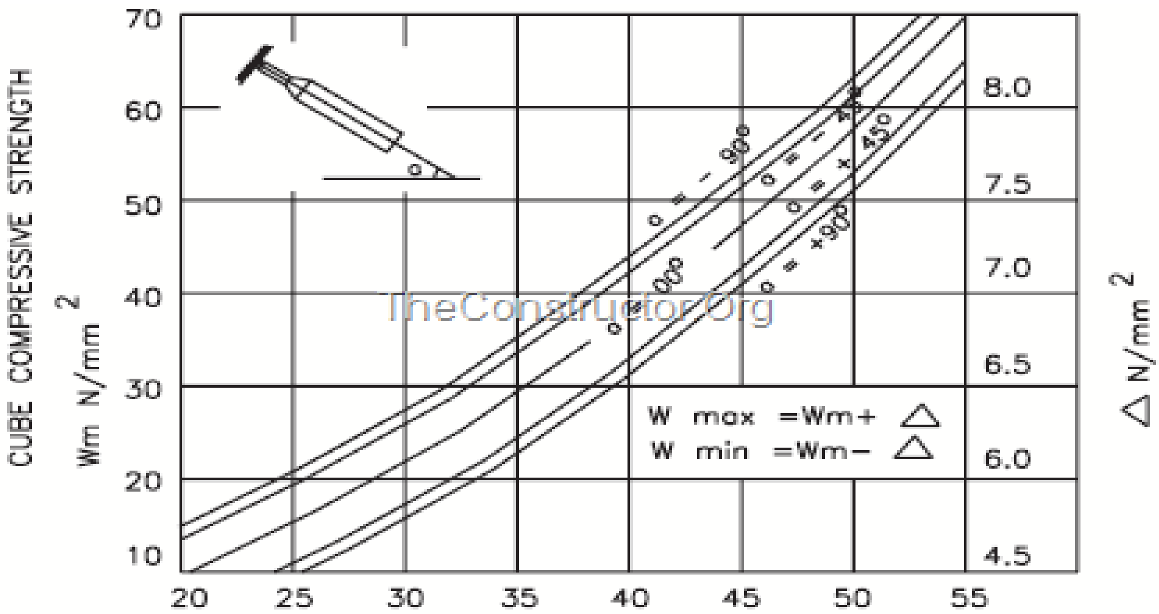

Figure 33: guidance figure for Schmidt hammer

3.7.4 Testing for Shear Strength

Beams of 100*100*300mm were used in this step of the experiment. Symmetrically double-notch test was performed. The notches were cut by a diamond saw machine for all specimens. The depth of the notches was 2cm and the width of the notches was 3 mm. Testing machine used in this section was flexural strength test machine, but some changes were applied in the setup of the machine to prepare it for testing the shear strength. MTS (mechanical test system) testing machines are the original machines that are utilized for double-notch tests. However, by making some changes in the flexural strength apparatus, the machine will perform as MTS testing machines. Preparing samples by cutting with diamond saw and getting ready to perform the shear test are shown is Figures 35, 36, 37, 38. Test machine is shown in Figure 39 and 40.

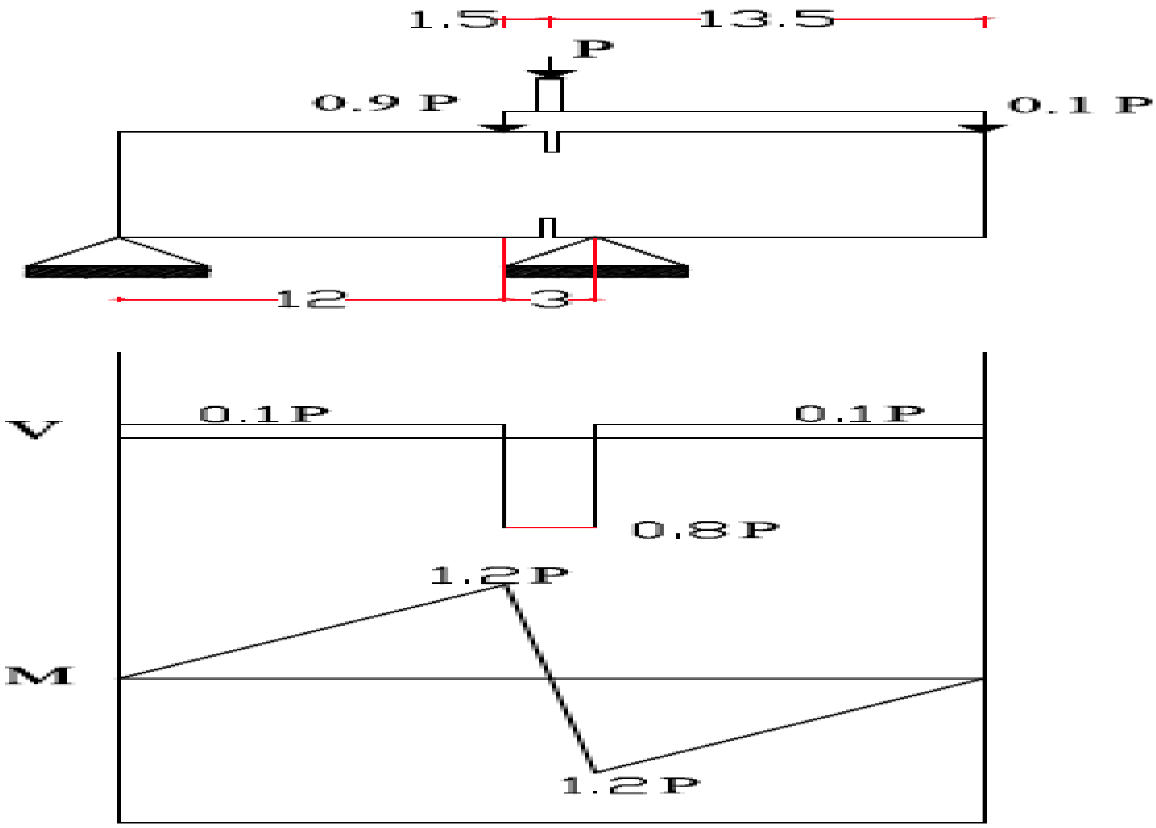

Figure 34: new setup of test machine according to structural analysis

The following formulas were used to make sure that the occurred cracks were based on shear force. $\sigma = Mc/I \Rightarrow \frac{Mc}{(bh^3/12)}$, R=PL/bd².And $\tau_{max} = 1.5 \times (\frac{V}{A})$. According to calculations, maximum shear stress and modulus of raptures should be greater than max bending moment. Where b, d and h are dimensions of samples and c is centroid of cross section V is shear force and M is bending moment.

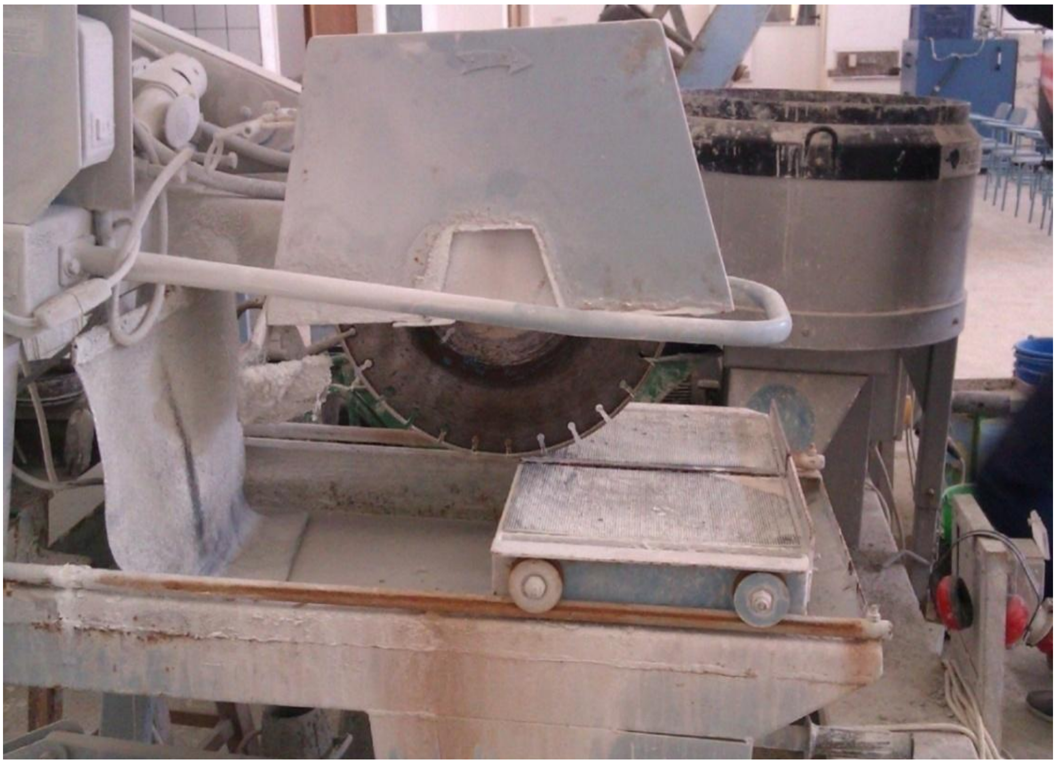

Figure 35: Diamond saw machine

Figure 36: cutting sample for shear test

Figure 37: prepared samples for shear test

Figure 38: third point load flexure test machine


Figure 39: Shear test sample on testing machine

Chapter 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The main objective of this study was to analyze the shears behavior of two different types of fiber reinforced concrete. To this aim, the tests performed through the experiment were: compressive strength, ultrasonic pulse velocity, Schmidt hammer, and shear strength.

The results of these tests and a discussion of the results will follow in the subsequent sections.

4.2 Compressive Strength

After 28 days of compressive strength, fibers slightly improved the compressive strength of the samples in comparison with 7 and 14 days of compressive strength samples. Nevertheless, it was not possible to obtain a significant effect of fibers on compressive strength of samples. It is clear that the chemical structure of the cement types is directly related to the compressive strength of concrete. In addition, the types and the amount of fine and coarse aggregates were effective factors which were directly related to the strength and durability of concrete. According to ACI, addition of fibers to the concrete structure has an effect on strength of concrete by increasing the strength from 0 to 15% (ACI 544.1, 2002).Table 4 and 5 present the results. Relation between compressive strength and curing ages are shown in Figures 40, 41, 42, 43.

Table 4: results of compressive strength for concrete class C30

C30											
Aspect Ratio 65							**Aspect Ratio 80**				
	Volume Fraction of fibers (%)						**Volume Fraction of fibers (%)**				
AGE(day)		**0**	**0.5**	**1.0**	**1.5**			**0**	**0.5**	**1.0**	**1.5**
7	**Strength (N/mm^2)**	**23.8**	**30.5**	**28.6**	**29.9**		**Strength (N/mm^2)**	**24.3**	**29.3**	**28.8**	**30.3**
14	**Strength (N/mm^2)**	**29.6**	**33.5**	**33.3**	**36**		**Strength (N/mm^2)**	**29.7**	**34.7**	**33.7**	**36.1**
28	**Strength (N/mm^2)**	**39.8**	**38.2**	**47.4**	**38.5**		**Strength (N/mm^2)**	**39.9**	**40.5**	**41.1**	**43.6**

Table 5: results of compressive strength for concrete class C50

C50												
Aspect Ratio 65							Aspect Ratio 80					
	Volume Fraction of fibers (%)						Volume Fraction of fibers (%)					
AGE (day)		0	0.5	1.0	1.5			0	0.5	1.0	1.5
7	Strength (N/mm²)	37.5	34.5	36.9	36.6		Strength (N/mm²)	36.9	37.2	35.5	36.0
14	Strength (N/mm²)	45.6	44.2	44.8	43.8		Strength (N/mm²)	44.5	44.7	44.1	43.8
28	Strength (N/mm²)	55.5	52.9	55.3	58.2		Strength (N/mm²)	54.5	52.5	52.0	50.4

Compressive strength of both concrete classes is changed by increasing curing ages. In this study, compressive strength of samples with less curing ages like 7days is less than compressive strength of samples which had higher curing ages like 14 days and 28 days.

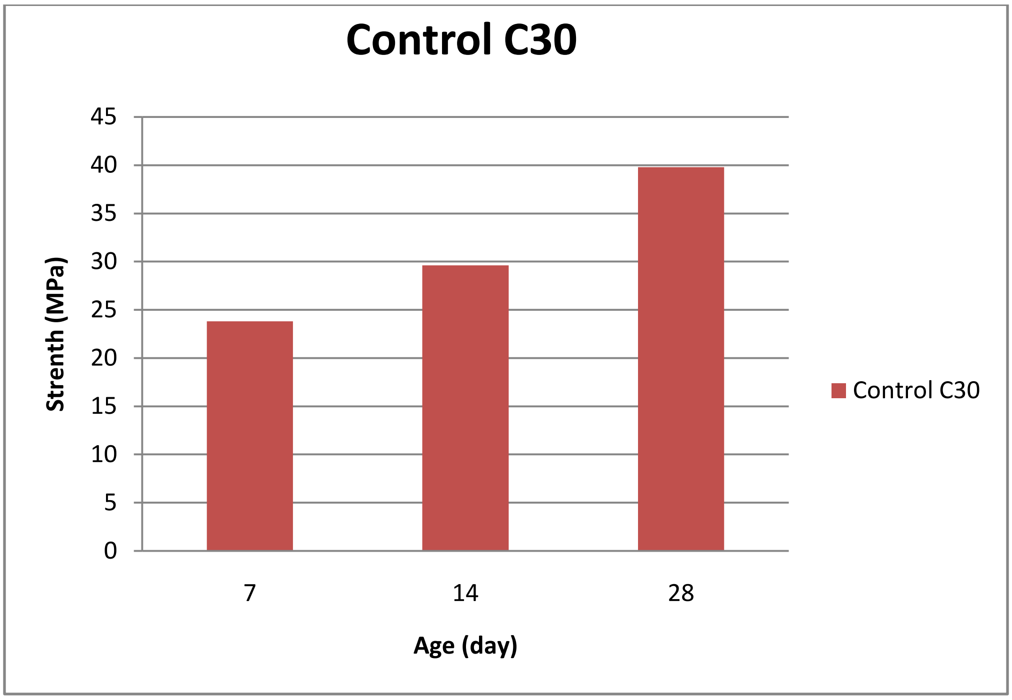

Figure 40: Compressive strength of plain concrete

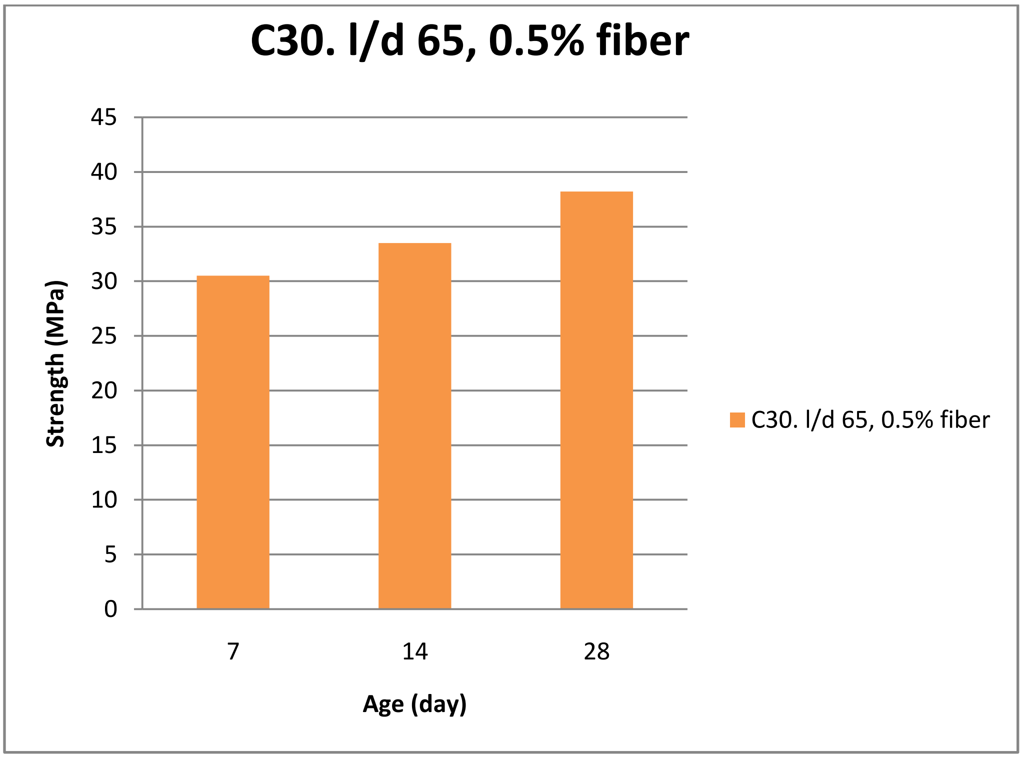

Figure 41: Compressive strength of SFRC with volume fraction 0.5%

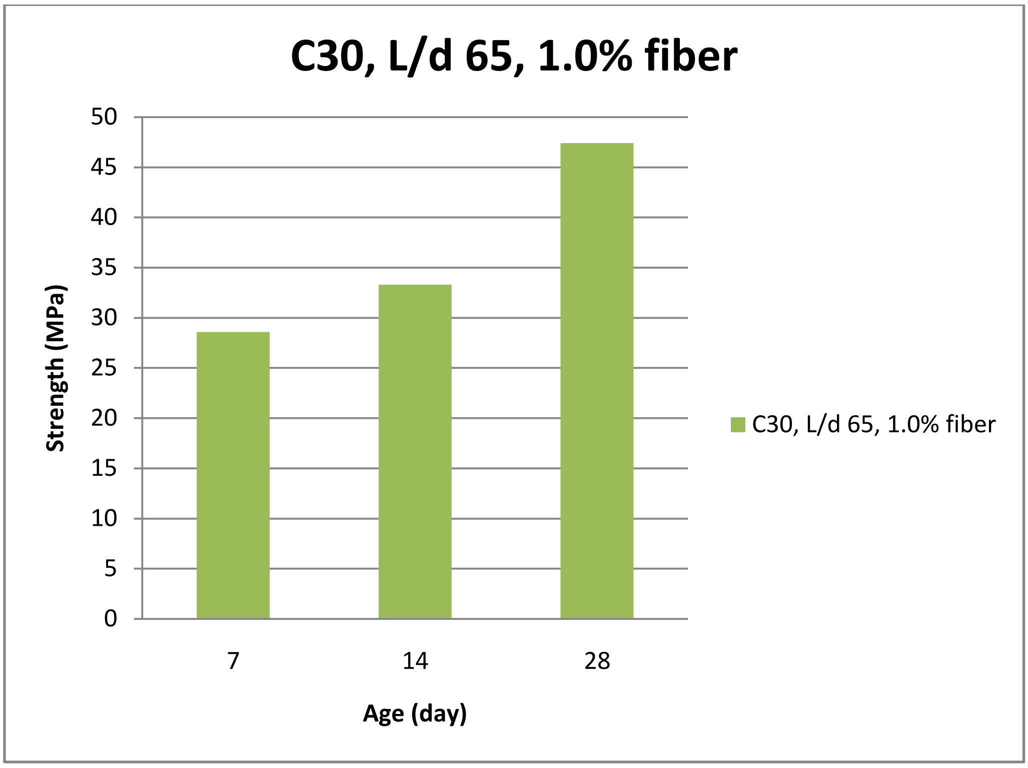

Figure 42: Compressive strength of SFRC with volume fraction 1.0%

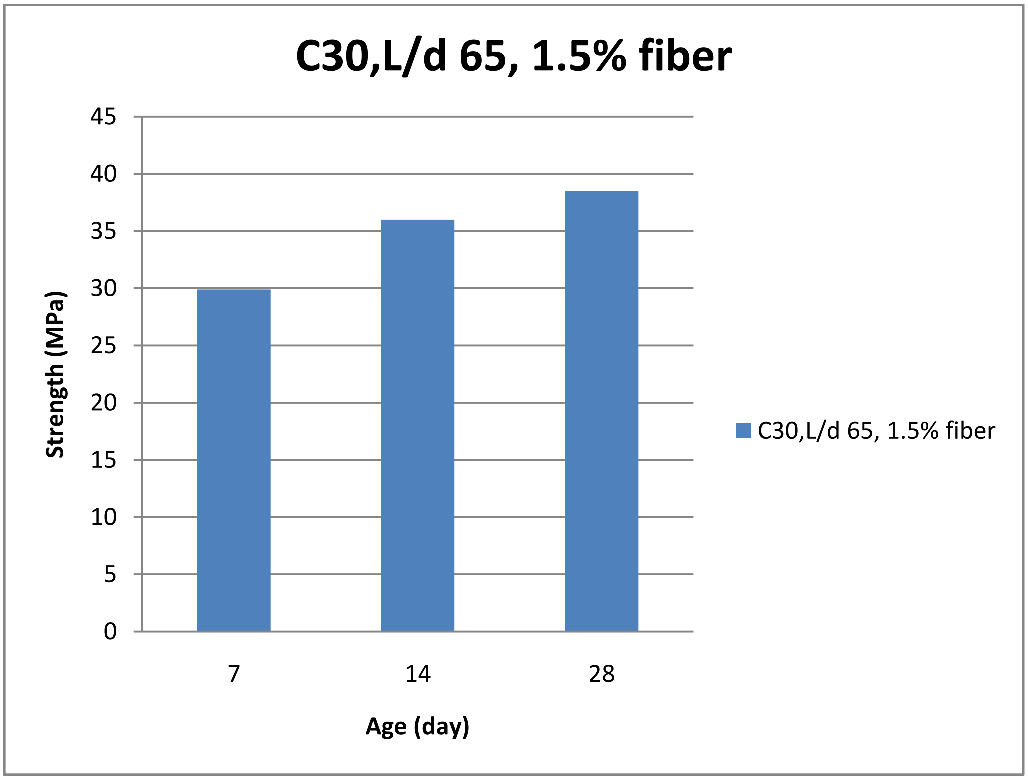

Figure 43: Compressive strength of SFRC with volume fraction 1.5%

Different Regression analyses for test result are given in Figures 44,45,46,47.

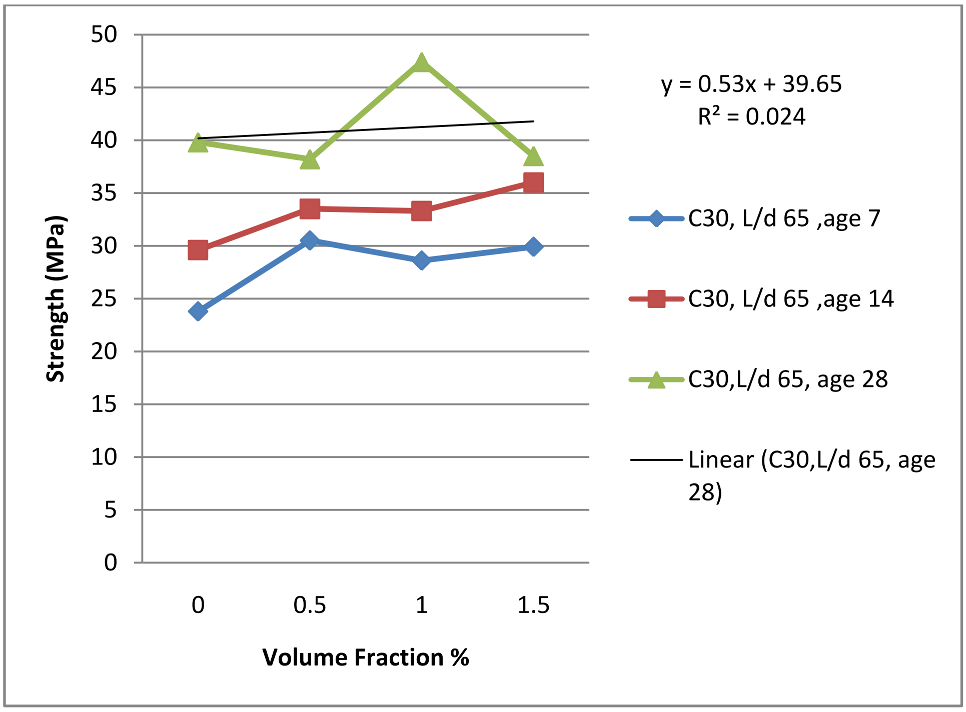

Figure 44: Regression analysis for test result of 28 days samples (l/d 65), C30

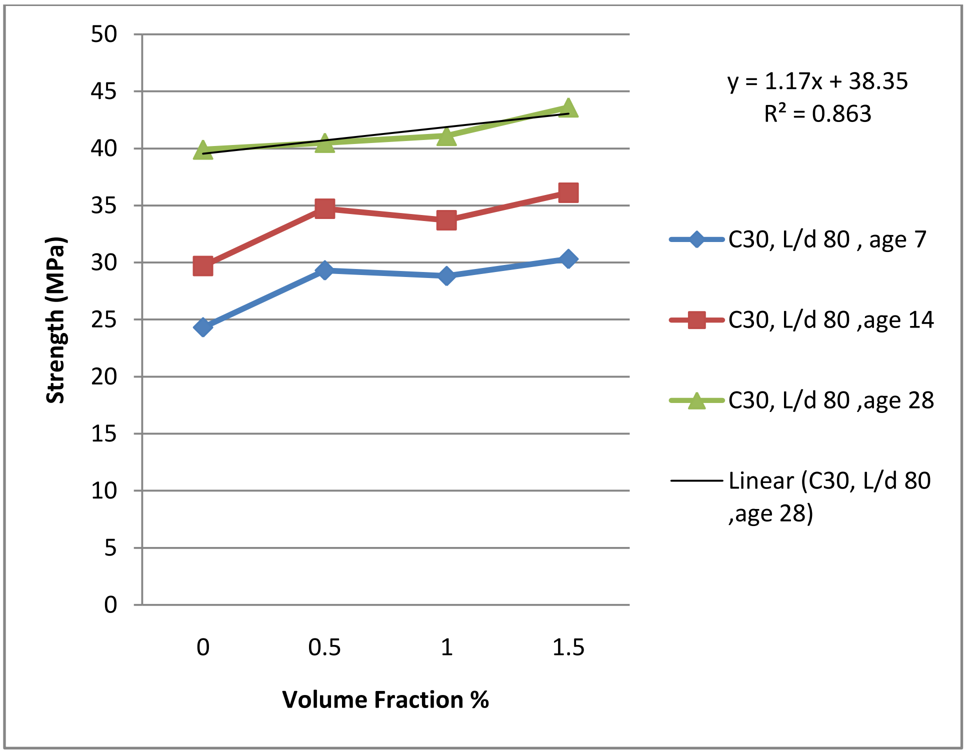

Figure 45: Regression analysis of test result of 28 days samples (l/d 80), C30

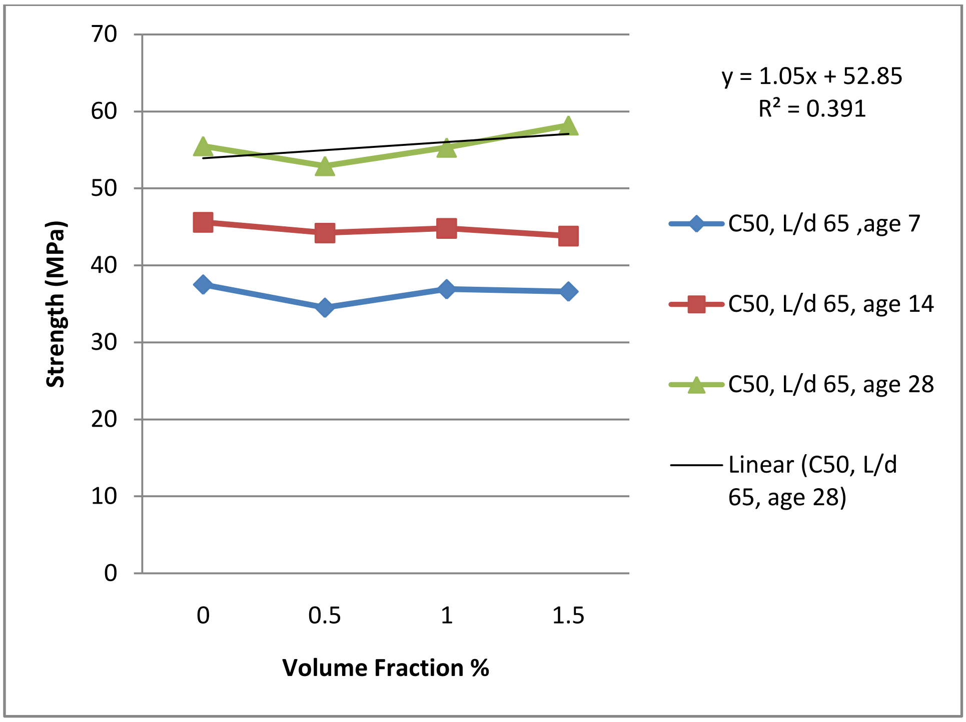

Figure 46: Regression analysis of test result of 28 days samples (l/d 65), C50

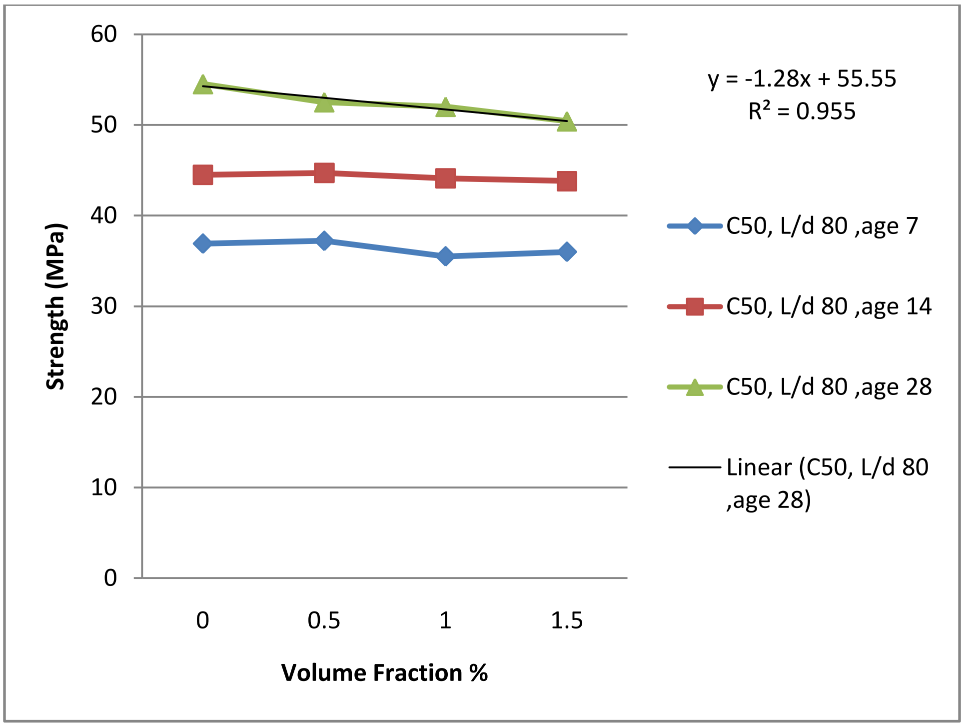

Figure 47: Regression analysis of test result of 28 days samples (l/d 80), C50

Table 6: Regression analysis of compressive strength of C30 and C50 concrete classes

Concrete classes, aspect ratios	Type of regression	Equation of line	R^2 (regression coefficient)
C30, l/d 65	**linear**	**y = 0.53x + 39.65**	**0.024**
C30, l/d 80	**linear**	**y = 1.17x + 38.35**	**0.863**
C50, l/d 65	**linear**	**y = 1.05x + 52.85**	**0.391**
C50, l/d 80	**linear**	**y = -1.28x + 55.55**	**0.955**

According to linear equations and regression lines in table 6, the addition of fibers to concrete has not constant effect on compressive strength. Compressive strength of Concrete C30 with l/d 80 and 65 and C50 class with l/d 65 have slightly increased by increasing volume fraction of fiber but C50 with l/d 80 had reduction of compressive strength by increasing volume fractions. R^2 values are increased by increasing 3 factors volume fraction of fibers, aspect ratios of fibers and also changing the class of concrete C30 to C50.

4.3 Schmidt Hammer

A comparison of the estimated compressive strength with “Schmidt Hammer” was carried out and the outcomes show an overall underestimation in the expected compressive strength. Having said this, the results agree with each other in the sense that the mean value of acceptable rebound numbers increases with an increase in the compressive strength. This phenomenon implies that the device can be used for comparison purposes, given that a precise calibration is made. Moreover, the presence of fibers does not change the trend. Results of test are given in Table 7 and Table 8.

Table 7: results of Schmidt hammer test for C30

	C30							
	l/d 65				l/d 80			
	Volume fraction of fibers (%)				Volume fraction of fibers (%)			
	0	**0.5**	**1.0**	**1.5**	**0**	**0.5**	**1.0**	**1.5**
Rebound number(average)	**31.2**	**31.3**	**31.5**	**31.7**	**30.5**	**31.1**	**31.5**	**31.6**
Compressive strength(N/mm²)	**26.36**	**26.44**	**26.60**	**26.76**	**25.60**	**26.28**	**26.60**	**26.68**

Table 8: results of Schmidt hammer test for C50

	C50							
	l/d 65				l/d 80			
	Volume fraction of fibers (%)				Volume fraction of fibers (%)			
	0	**0.5**	**1.0**	**1.5**	**0**	**0.5**	**1.0**	**1.5**
Rebound number(average)	**36.2**	**36.4**	**37.1**	**37.2**	**34.9**	**36.6**	**36.9**	**37.8**
Compressive strength(N/mm²)	**34.6**	**34.7**	**35.2**	**35.4**	**32.2**	**34.8**	**34.9**	**36.6**

Relation between average rebound and volume fraction of all types of samples are shown in Figures 48, 49, 50, 51.

By increasing volume fraction of fibers, small increasing of compressive strenght are observed. And also increasing the amount of fibers has positive effect on average rebound numbers. Resultsof Table 7 and Table 8 are shown that avererage rebound numbers are increased.

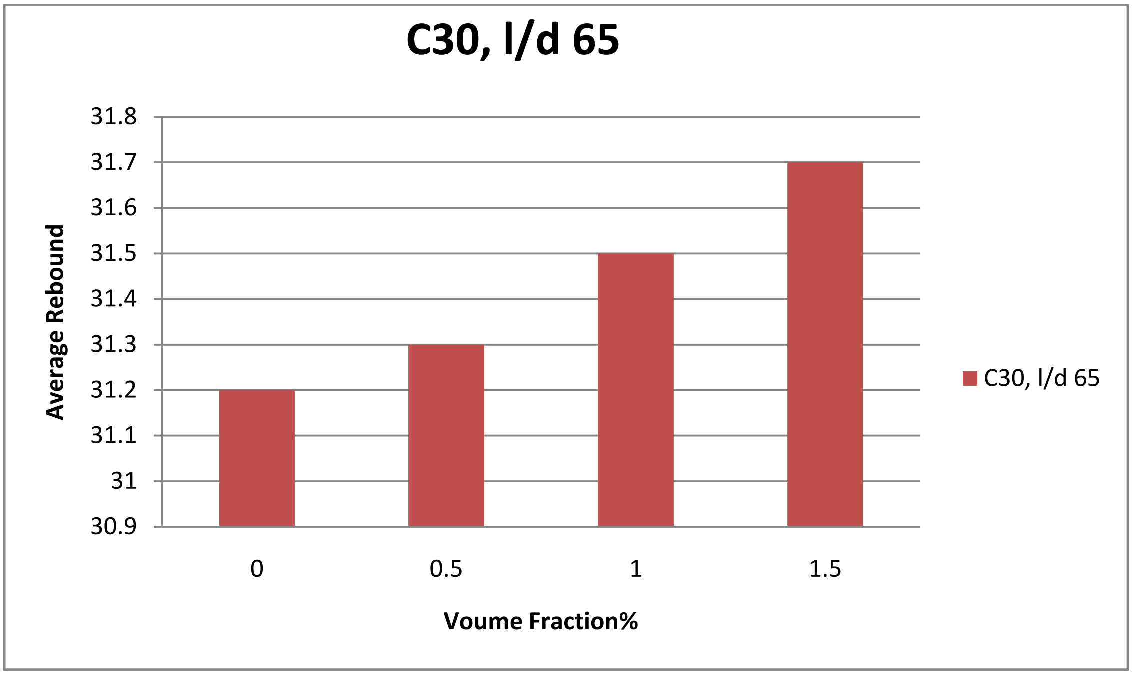

Figure 48: Relation between volume fraction and rebound number for C30, l/d 65

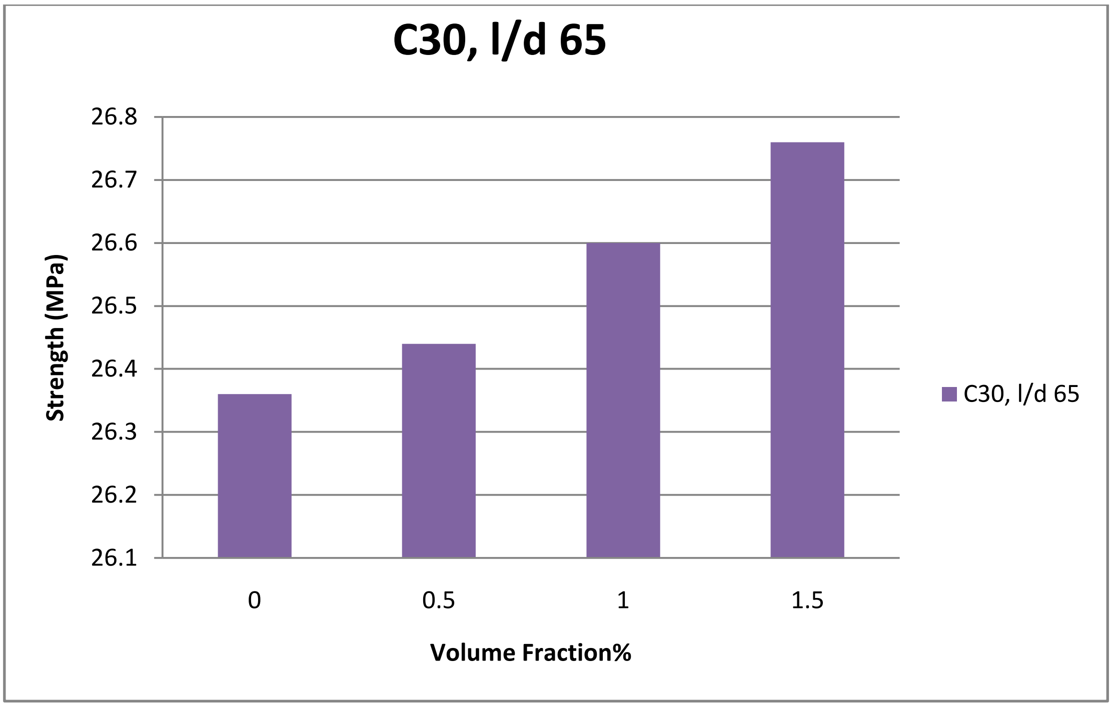

Figure 49: Relation between volume fraction and strength obtained from rebound number for C30, l/d65

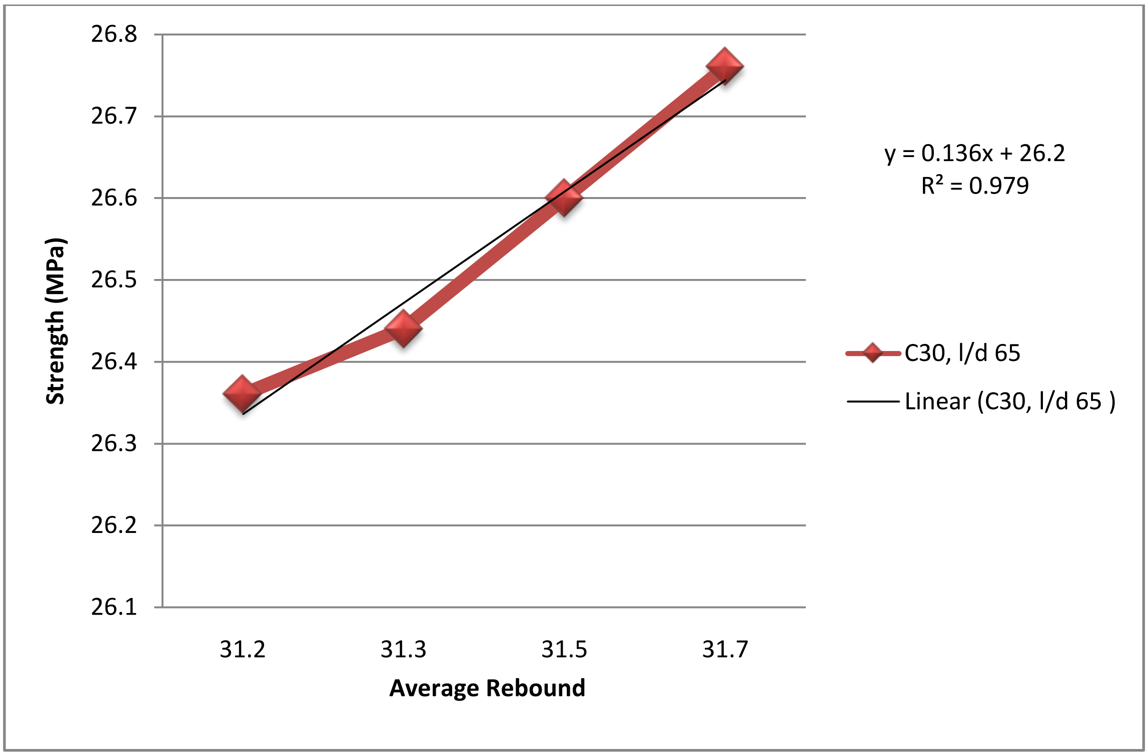

Figure 50: Relation between strength & Average rebound number

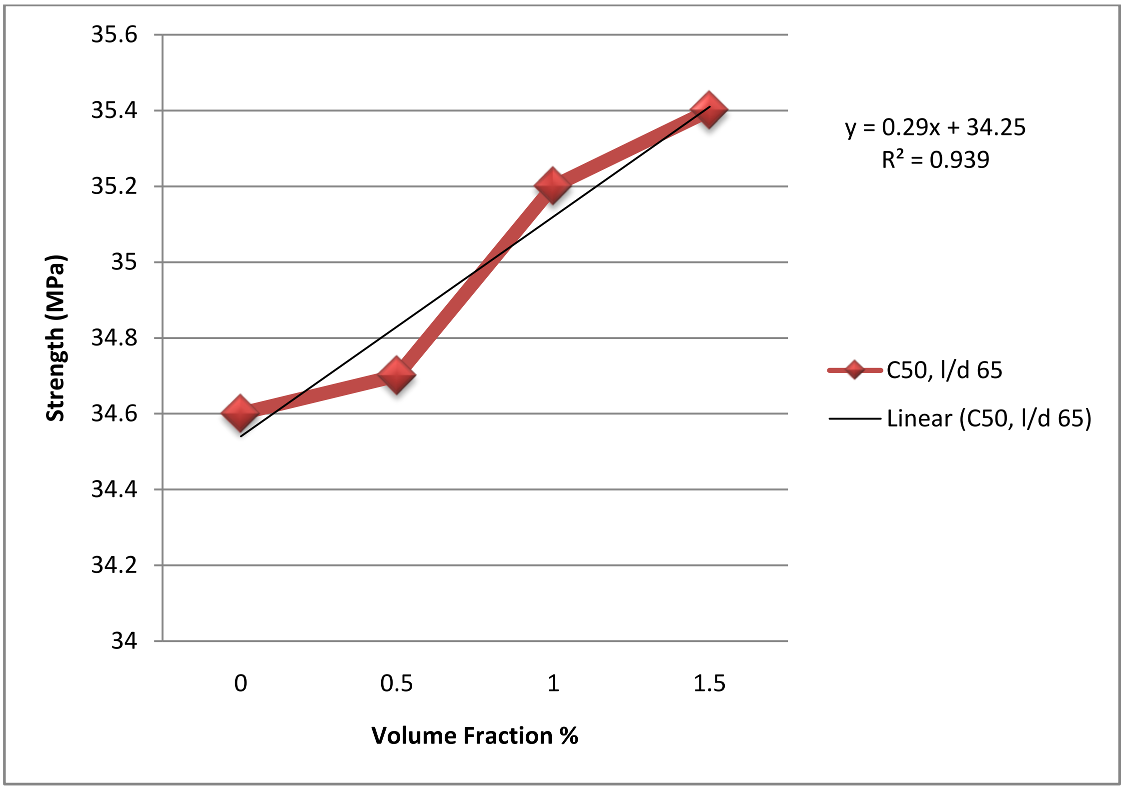

Figure 51: Relation between strength and amount of fibers for C50 l/d 65

Table 9: Regression analysis of Schmidt hammer test

Concrete classes, aspect ratio	**Type of regression**	**Equation of line**	**R^2 (regression coefficient)**
C30, l/d 65	**linear**	**y = 0.136x + 26.2**	**0.979**
C30, l/d 80	**linear**	**y = 0.356x + 25.4**	**0.874**
C50, l/d 65	**linear**	**y = 0.29x + 34.25**	**0.939**
C50, l/d 80	**linear**	**y = 1.32x + 31.35**	**0.900**

There are not much difference amount results of Schmidt hammer test. All regressions a line are almost same and slopes of all linear equations are positive, it is shown that increasing volume fraction has effect of strength and rebound numbers. It is caused to have small increasing on them. Table 9 is showing regression analysis.

4.4 Ultrasonic Pulse Velocity

Teat results have represented that the addition of fibers will slightly increase the ultrasonic pulse velocity. This may be due to an increase in the amount of the voids contents in the samples by increasing the amount of fibers. This means that steel fibers will decrease the density of the sample and create more voids content than plain concrete. These voids will decrease the needed time for passing ultrasonic waves through the samples. The classification of concrete according to ultrasonic pulse velocity is as follows:

Excellent (4.5 km/s and above),

Good (3.50-4.50 km/s),

Doubtful (3.0-3.5km/s),

Poor (2.0-3.0 km/s),

Very poor (2.0 km/s and below)

Following Tables (Table10, Table11) are given the results of UPV test of two different concrete classes with different amount of fibers. Regression analysis and relation between pulse velocity and volume fraction are shown in Figures 52, 53, 54, 55.

Increasing volume fraction of fibers has an effect on pulse velocity. As results shown pulse velocity is increasing by increase the amount of fibers in concrete.

Table 10: Result of UPV test for C30

	C30							
	l/d 65				**l/d 80**			
	Volume fraction of fibers (%)				**Volume fraction of fibers (%)**			
	0	**0.5**	**1.0**	**1.5**	**0**	**0.5**	**1.0**	**1.5**
T(second)	**3.22E-5**	**3.17E-5**	**3.05 E-5**	**2.92 E-5**	**3.28 E-5**	**3.14 E-5**	**3.01 E-5**	**2.93 E-5**
V (km/s)	**4.658**	**4.731**	**4.918**	**5.136**	**4.537**	**4.777**	**4.983**	**5.119**

Table 11: Result of UPV test for C50

	C50							
	l/d 65				**l/d 80**			
	Volume fraction of fibers (%)				**Volume fraction of fibers (%)**			
	0	**0.5**	**1.0**	**1.5**	**0**	**0.5**	**1.0**	**1.5**
T(second)	**3.27 E-5**	**3.23 E-5**	**3.15 E-5**	**3.07 E-5**	**3.31 E-5**	**3.24 E-5**	**3.16 E-5**	**3.06 E-5**
V=l/d(km/s	**4.584**	**4.641**	**4.761**	**4.885**	**4.531**	**4.622**	**4.746**	**4.900**

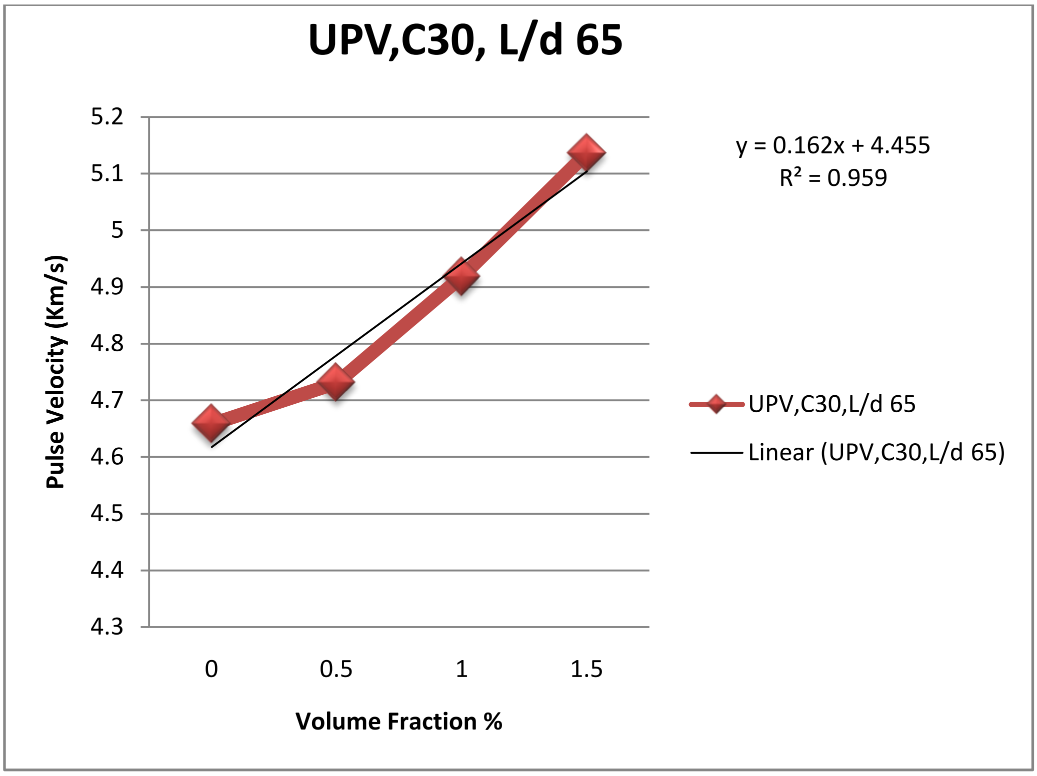

Figure 52: Relation between pulse velocity and volume fraction of C30 , l/d 65

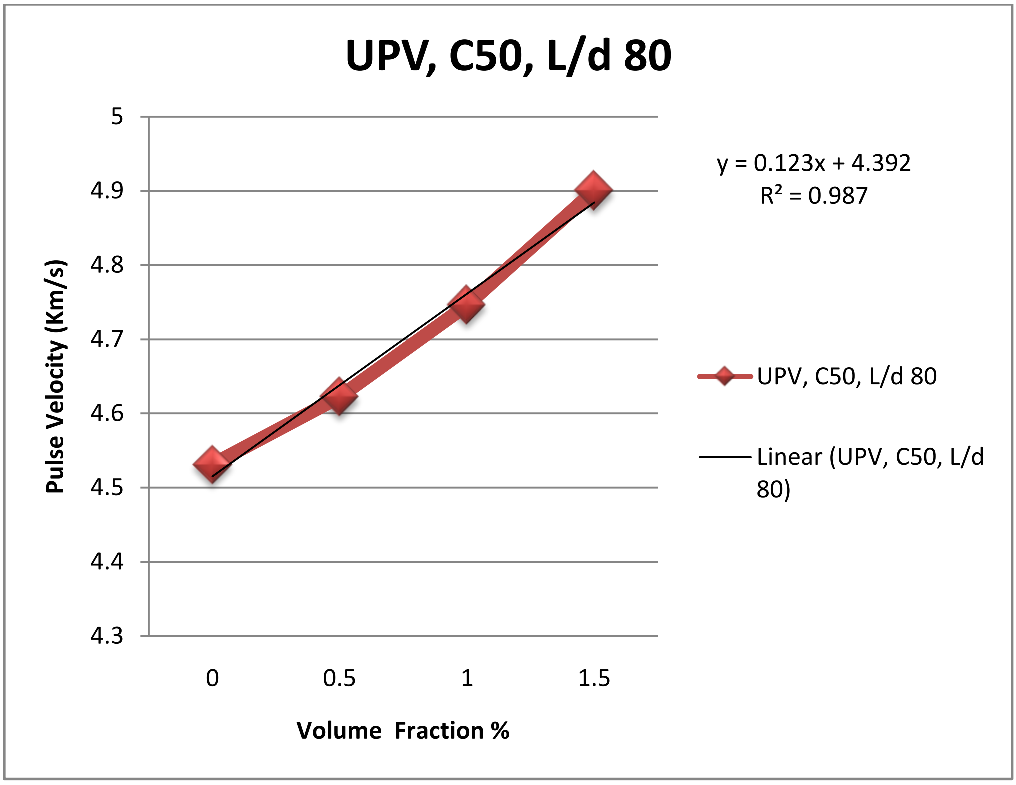

Figure 53: Relation between pulse velocity and volume fraction of C50, l/d 80

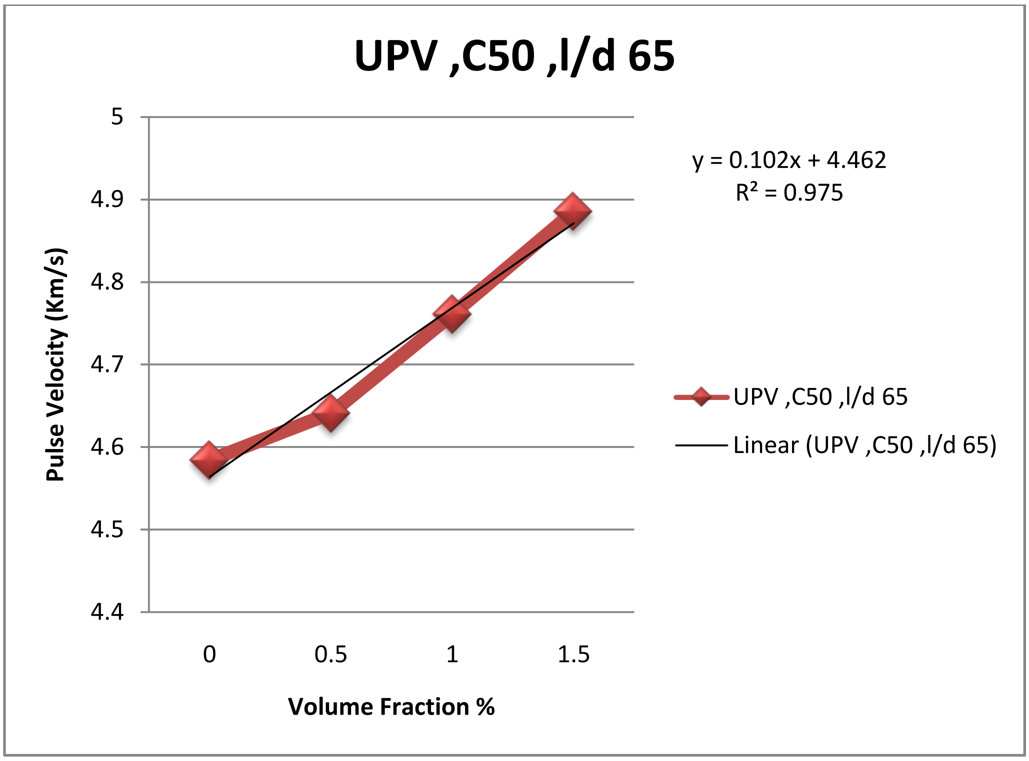

Figure 54: Relation between pulse velocity and volume fraction of C50, l/d 65

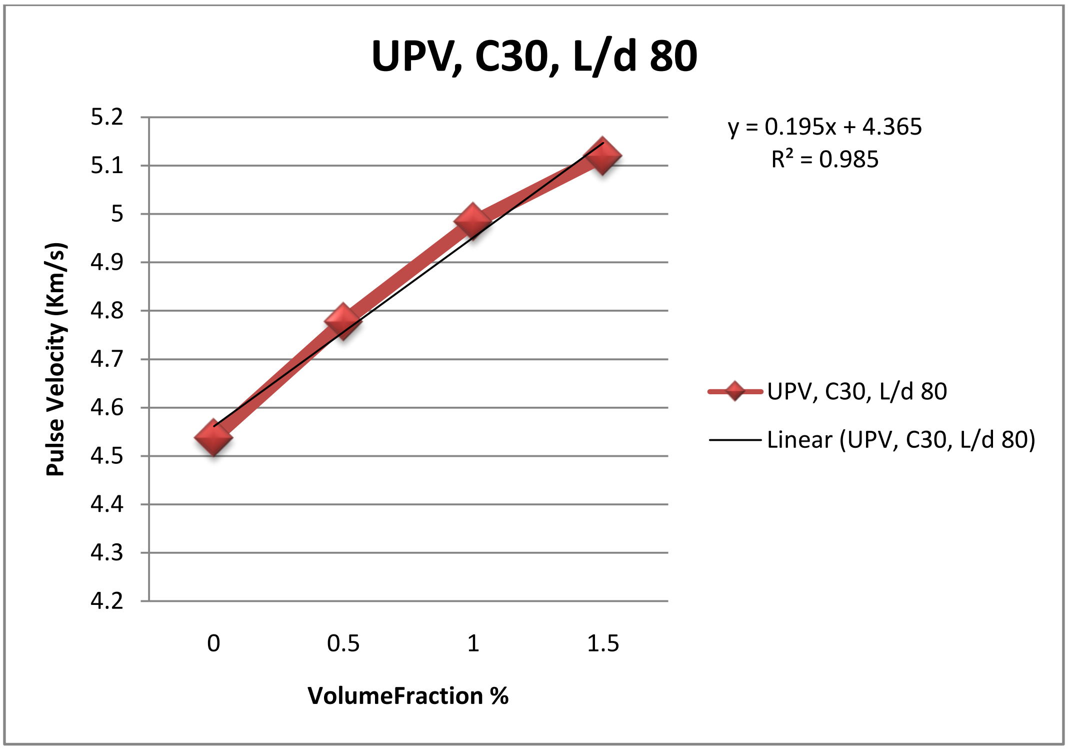

Figure 55: Relation between pulse velocity and volume fraction of C30, l/d 80

Table 12: Regression analysis of UPV test

Concrete classes, aspect ratio	Type of regression	Equation of line	R^2(regression coefficient)
C30, l/d 65	**linear**	**y = 0.162x + 4.455**	**0.959**
C30, l/d 80	**linear**	**y = 0.195x + 4.365**	**0.985**
C50, l/d 65	**linear**	**y = 0.102x + 4.462**	**0.975**
C50, l/d 80	**linear**	**y = 0.123x + 4.392**	**0.987**

Regression analysis of ultrasonic pulse velocity is shown that all results are almost same. It means that these are not much difference among all types of concrete samples. Regression lines of all type of concrete are almost same and slopes of linear equations are positive. It is shown that change in amount of fibers has effects on velocity of waves.

4.5 Shear Strength

The results of shear strength test of samples are given in Table 13 and Table 14.

Table 13: Results of shear strength test of C30 concrete

C30		
Volume fraction %	**Aspect ratio 65**	**Aspect ratio 80**
	Shear force (KN)	**Shear force(KN)**
0	**36.2**	**33.7**
0.5	**47.4**	**42.4**
1.0	**64.7**	**58.5**
1.5	**72.5**	**71.2**

Table 14: Results of shear strength test ofC50 concrete

C50		
Volume fraction %	**Aspect ratio 65**	**Aspect ratio 80**
	Shear force (KN)	**Shear force(KN)**
0	**32.1**	**37.2**
0.5	**53.4**	**44.3**
1.0	**68.8**	**67.9**
1.5	**80.7**	**91.6**

The following assumptions can be made: An increase is expected in shear strength of fiber reinforced concrete by increasing the amount of steel fibers. As the volume fraction increases, shear strength at the complete failure also increases for all samples. This is exactly related to betterment in other characteristics related to cracking. Relation between shear strength and volume fraction are given in Figures 56, 57, 58, 59. And the regression analyses of test result are given in Figures 60, 61, 62, 63.

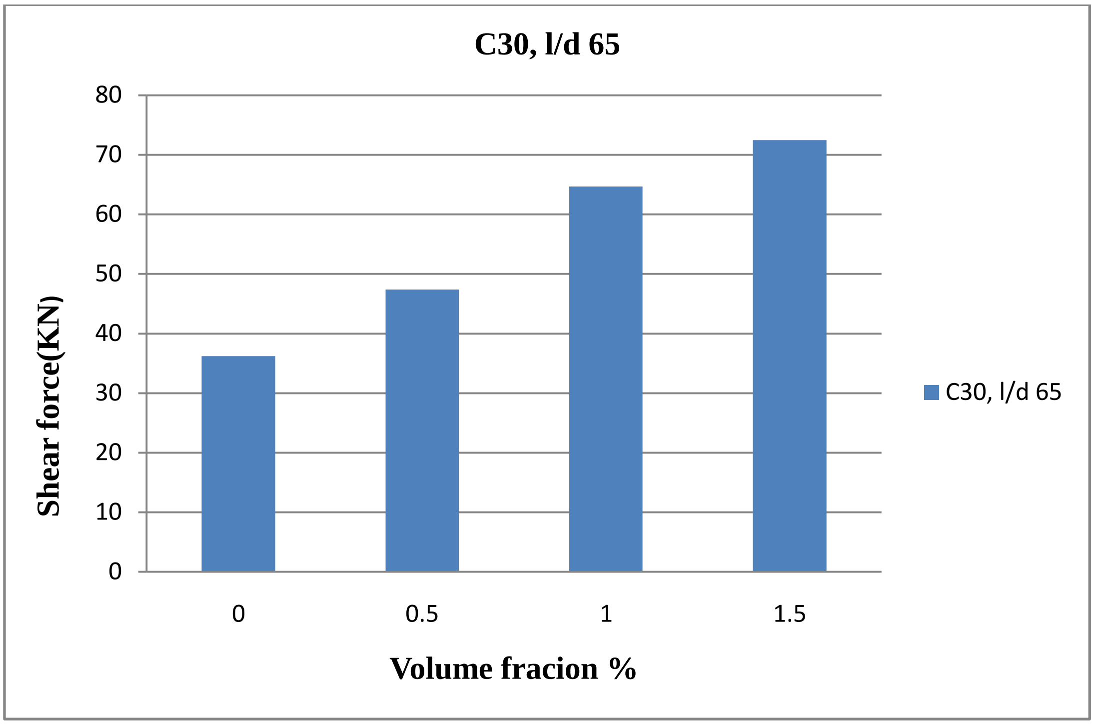

Figure 56: Relation between shear strength and volume fraction of C30, l/d 65

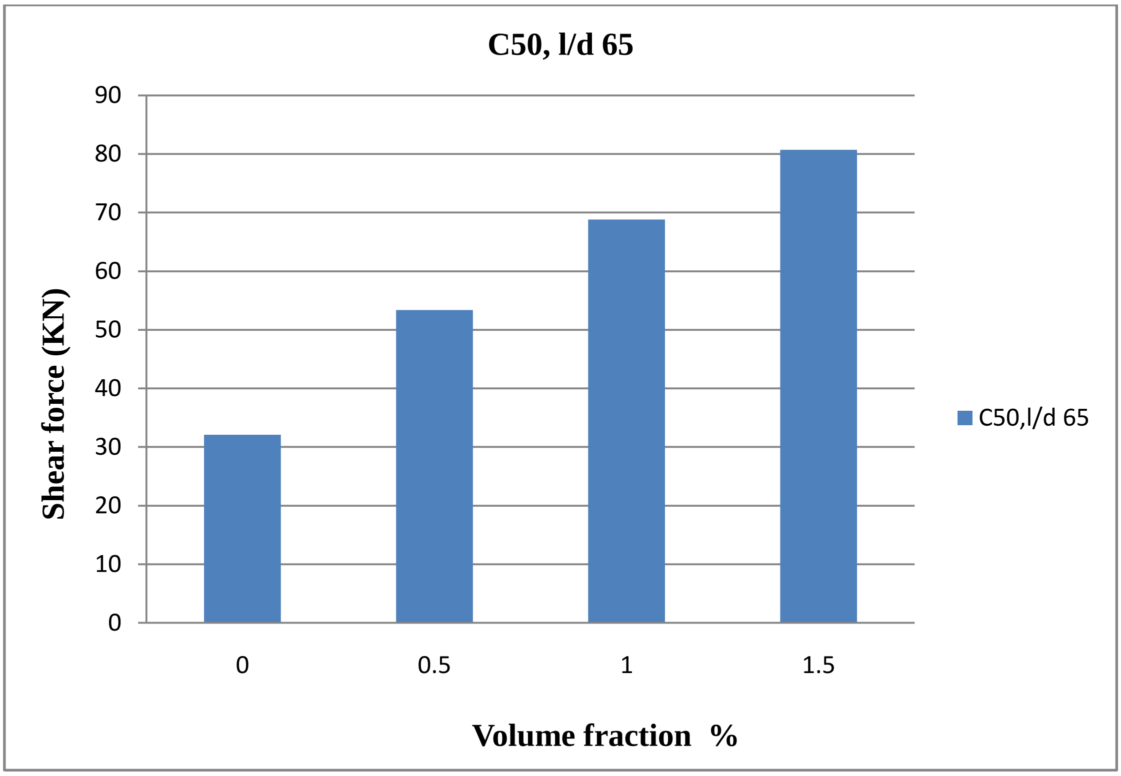

Figure 57: Relation between shear strength and volume fraction of C50, l/d 65

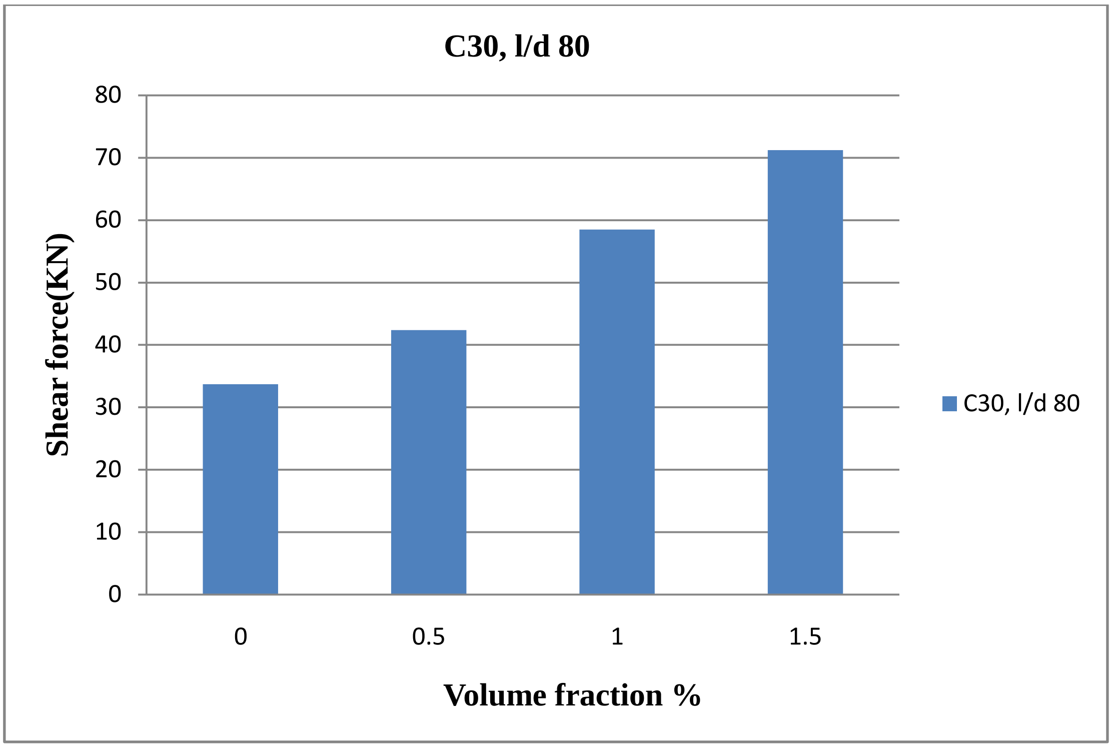

Figure 58: Relation between shear strength and volume fraction of C30, l/d 80

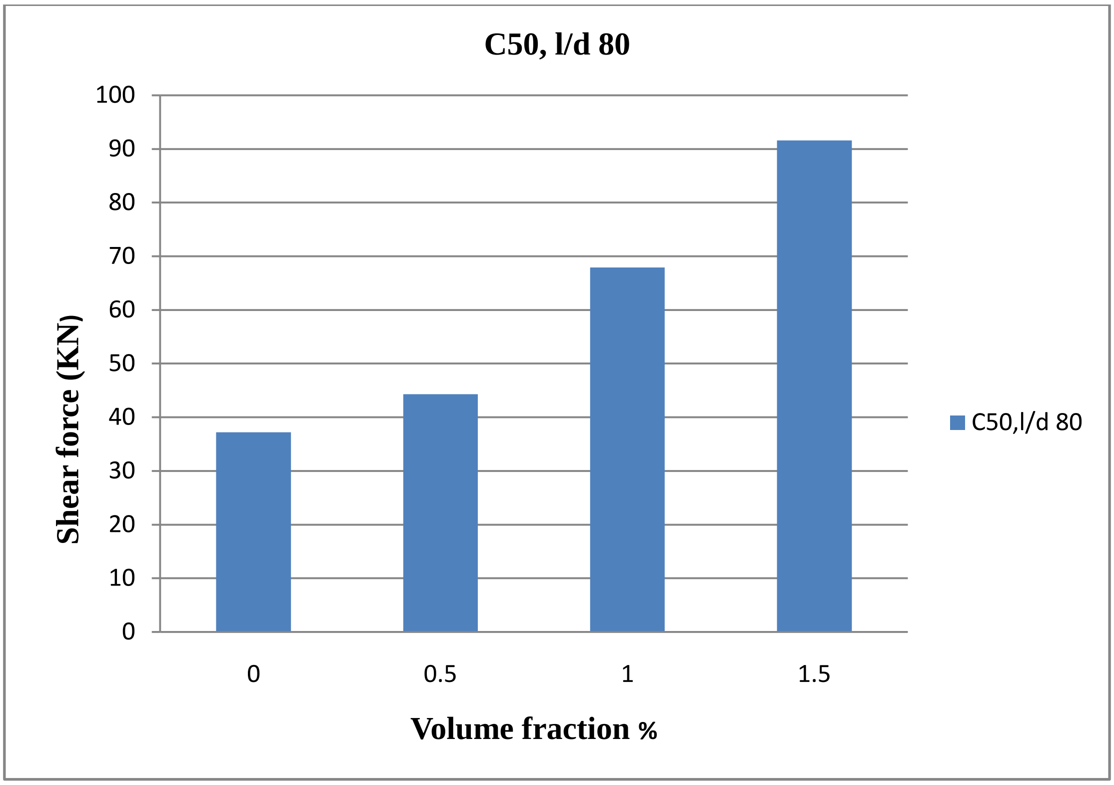

Figure 59: Relation between shear strength and volume fraction of C50, l/d 80

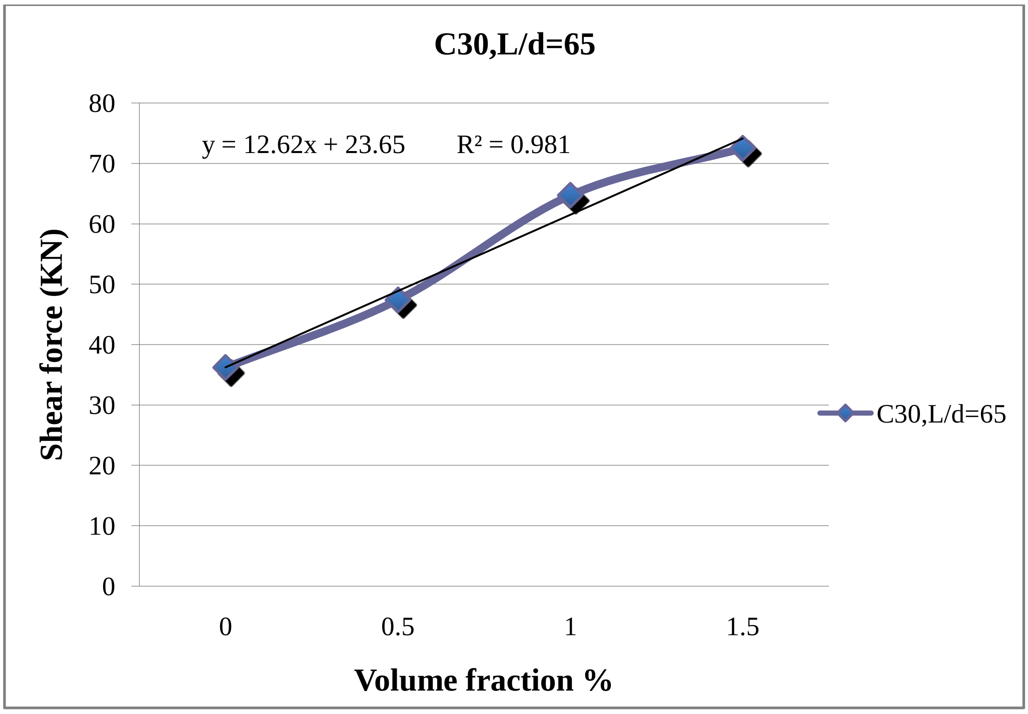

Figure 60: Relation between volume fraction and shear force of C30, l/d 65

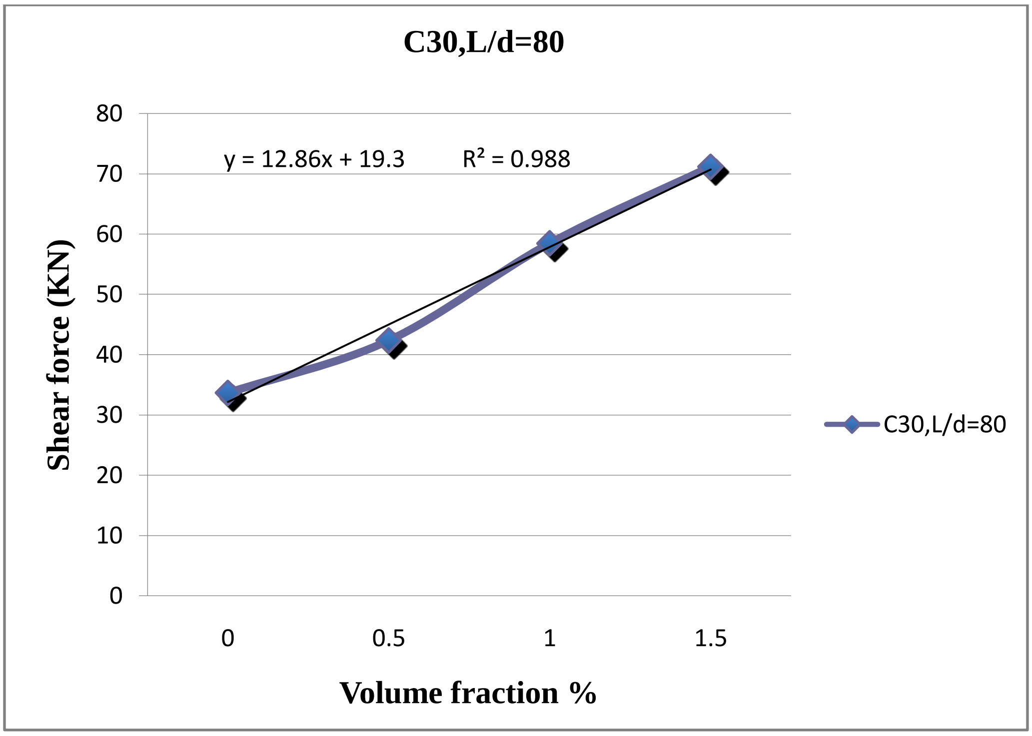

Figure 61: Relation between volume fraction and shear force of C30, l/d 80

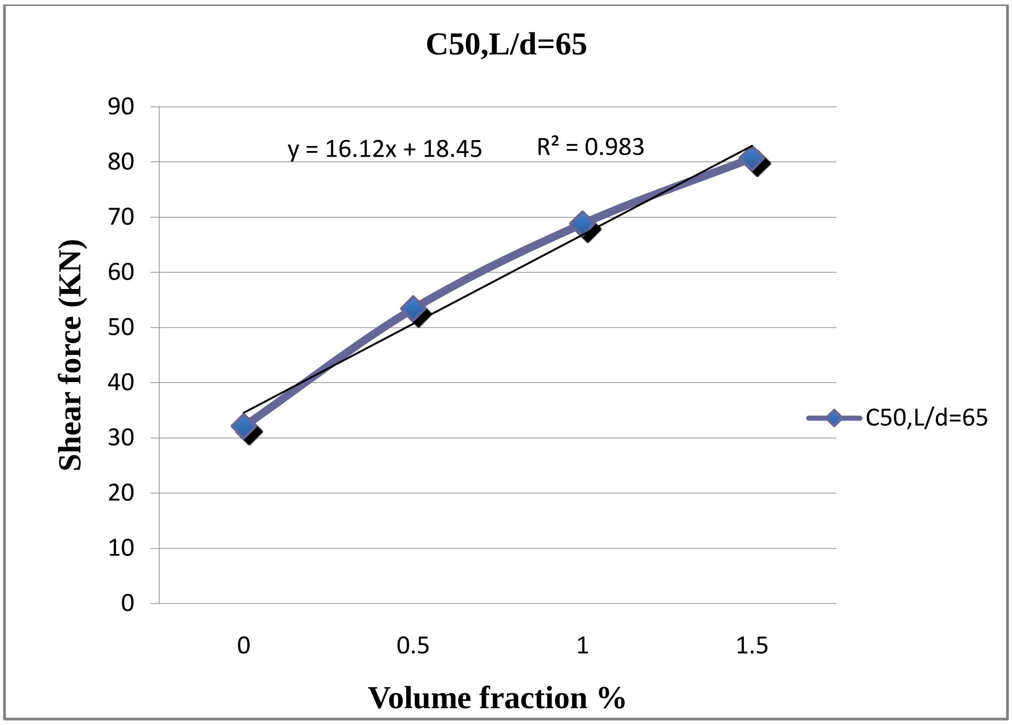

Figure 62: Relation between volume fraction and shear force of C50, l/d 65

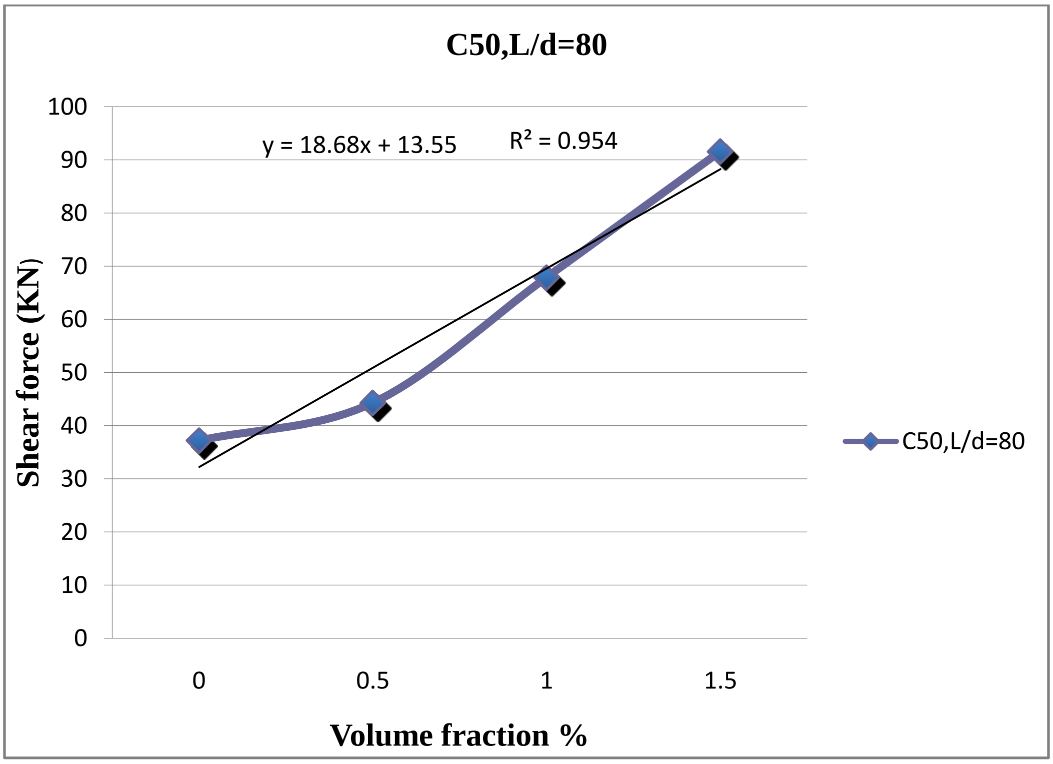

Figure 63: Relation between volume fraction and shear force of C30, l/d 80

Table 15: Regression analysis of shear test

Concrete classes, aspect ratio	Type of regression	Equation of line	R^2(regression coefficient)
C30, l/d 65	**linear**	**y = 12.62x + 23.65**	**0.981**
C30, l/d 80	**linear**	**y = 12.86x + 19.3**	**0.988**
C50, l/d 65	**linear**	**y = 16.12x + 18.45**	**0.983**
C50, l/d 80	**linear**	**y = 18.68x + 13.55**	**0.954**

Shear strength is increasing by adding fibers to concrete. Regression analysis is shown that increasing volume fraction of fibers has very good effect on shear behavior. All regression lines are closed to 1. Inclination of all line are positive it shows that addition of fibers, make concrete more strong against shear force.

Figure 64: Sample after shear failure

Figure 65: moment of shear cracking

Figure 64 and Figure 65 are showing failure after applied shear force.

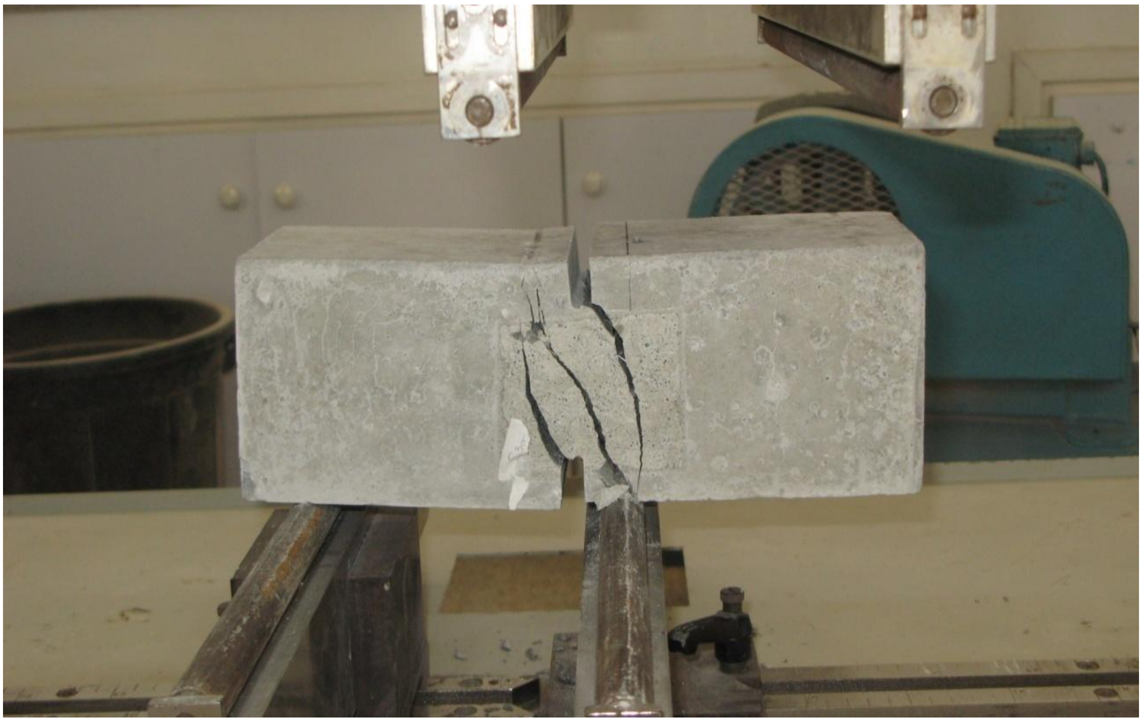

Figure 66: Cracked sample

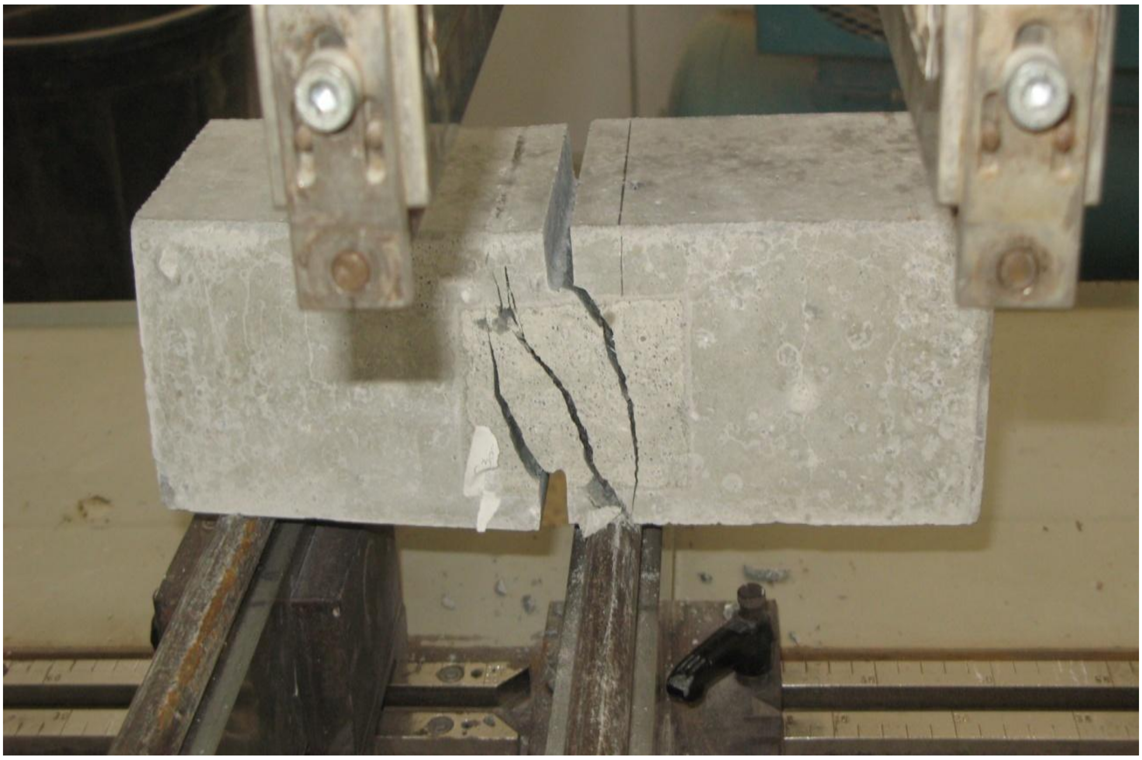

Figure 67: Fibers prevent separation

Widths of cracks are shown that steel fiber tries to crack control (Figure 66), (Figure 67).

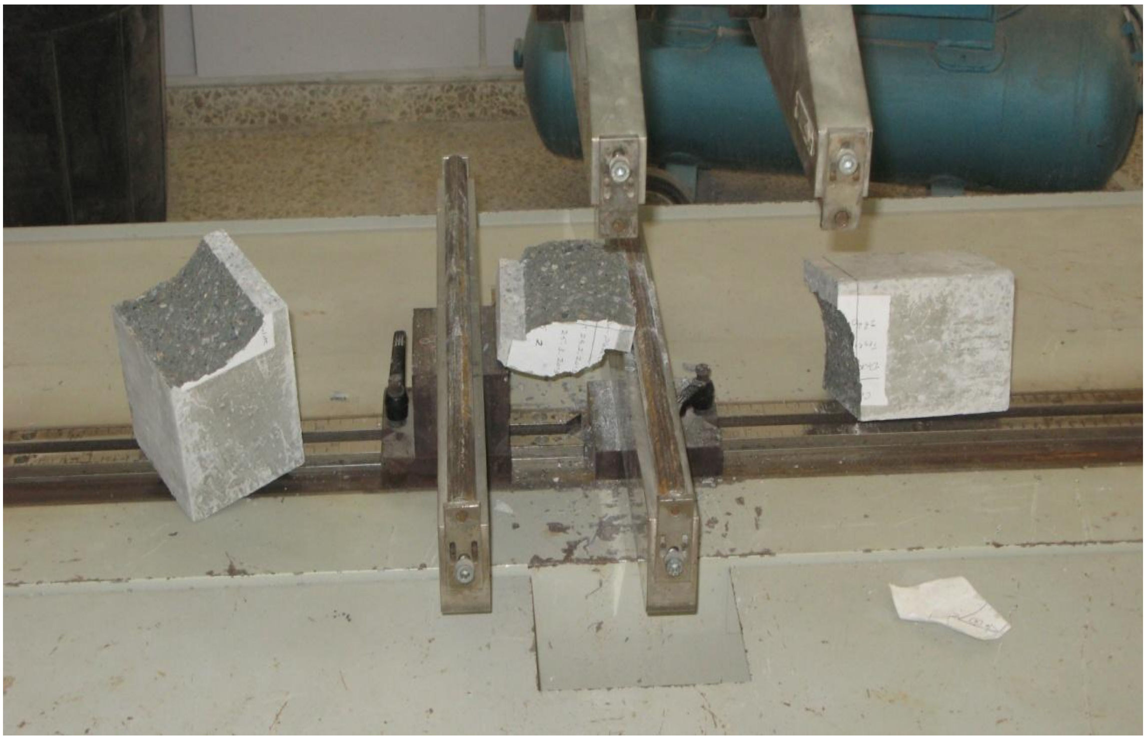

Figure 68: plain concrete after loading for shear

Figure 69: Shear cracking in plain concrete

Plain concrete were separated to 3 parts after loading, because of using no steel fibers (Figure 68), (Figure 69).

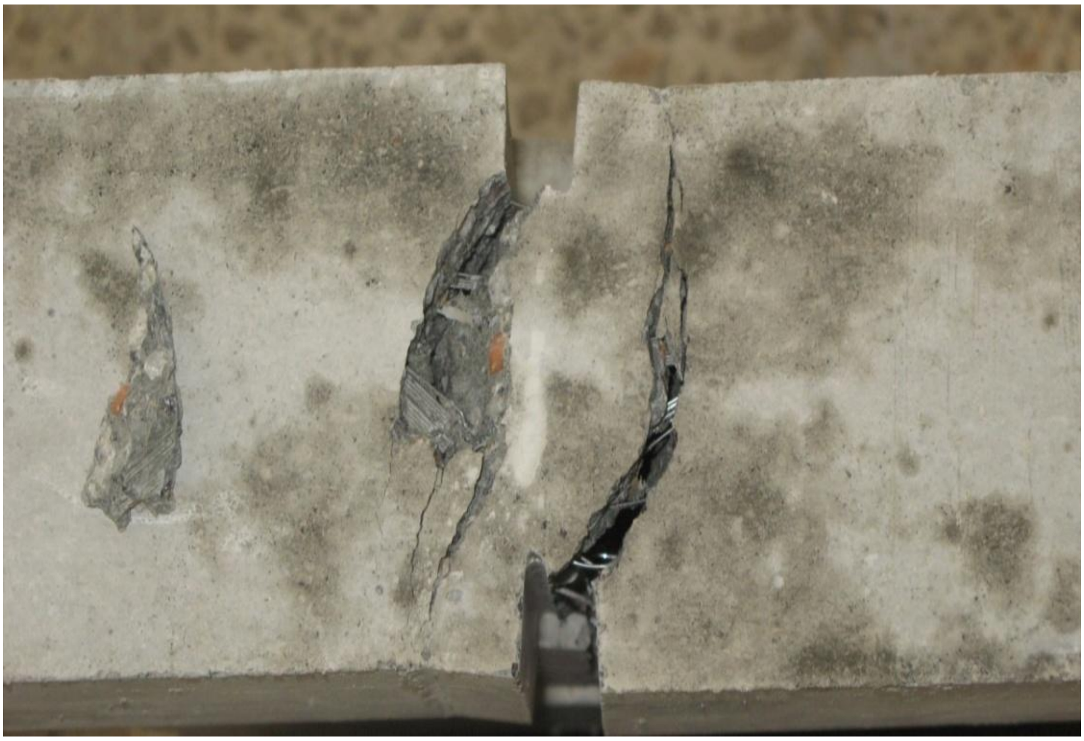

Figure 70: Affected sample by steel fiber

Figure 71: SFRC after cracking

Crack controlled by steel fibers is obvious in Figure 70 and Figure 71.

Following picture shows shear cracks were controlled by increasing the amount of steel fibers. Uppers one has highest amount and the sample were placed at ground is plain concrete (Figure 72).

Figure 72: Effectiveness of using different amounts of steel fiber

Figure 73: C30 with two different volume fraction of fibers

Comparison between concrete class C30 samples with different volume fraction and same aspect ratios. There is not much difference between shear cracks (Figure 73).

Figure 74: C30 and C50 with same aspect ratios (80)

Comparison between concrete class C50 and class C30 samples with different volume fraction and same aspect ratios. The width of shear cracks will decrease by increasing volume fraction and by increasing the strength of concrete (Figure 74).

Figure 75: C50 reinforced by steel fiber with two different aspect ratios (65) and (80)

Comparison between concrete class C50 samples with different volume fraction and different aspect ratios. Shear test was done on the samples. There is not much difference between widths of cracks (Figure 75).

Chapter 5

CONCLUSIONS

In this study, three different amounts of hooked-end steel fibers with two different aspect ratios were used. All the experiments were done on two different concrete classes. One of them was C30 concrete and the other one was C50 concrete. To find the effects of steel fibers on some mechanical properties of concrete, some tests were done. These are direct shear test, compressive strength test, Schmidt hammer test, and ultrasonic pulse velocity test.

The following results were obtained:

In the shear test the strength of reinforced concrete went up by increasing the volume fraction of fiber. Increasing volume from 0 to 1.5 is increased shear forces 3 times for C30, l/d 65. Similar results were obtained for C30, with l/d 80. Volume fractions of steel fibers ranging from 0 to 0.5, increased shear force by 35 % and from 0 to 1.0, 78.7% increase in shear force were obtained. Increasing shear force, shear strength will increase.

In high strength concrete C50 the shear strength was affected by adding volume fraction of fibers. The results show that applied shear force increased too much for 1.5 % amount of steel fiber and also 70% increased for 0.5 % amounts and 2 times increased for 1.0 % volume fraction of steel fibers. Results have shown that aspect ratio has no clear effect on shear strength. Because these is not much different between results of concrete with l/d 65 and concrete with l/d 80 were observed. Because the lengths of used steel fibers in this study are same, just diameters of fibers are different. This difference is not too much to make big different in obtained results.

Compressive strength: The addition of steel fibers slightly increased the compressive strength.

Ultrasonic pulse velocity: The result shows that steel fibers have an effect on pulse velocity. By increasing the volume fraction of fibers, pulse velocity will increase.

Schmidt hammer test: Addition of steel fibers has no clear effect in the Schmidt hammer test. The results showed there is not much difference been observed, by increasing volume fraction of steel fibers. Little change has been observed as result of increasing the volume fraction of steel fibers.

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