DECEMBER 2017

M.Sc. in Civil Engineering

RAAD A.NASIR AL-AMERI

UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

INVESTIGATION OF FLEXURAL BEHAVIOR OF THE STEEL FIBER REINFORCED CONCRETE HOLLOW SECTION BEAMS

M. Sc. THESIS

in

CIVIL ENGINEERING

BY

RAAD A. NASIR AL-AMERI

DECEMBER 2017

Investigation of Flexural Behavior of the Steel Fiber Reinforced Concrete Hollow Section Beams

M. Sc. Thesis

In

Civil Engineering

University of Gaziantep

Supervisor
Prof. Dr. Mustafa ÖZAKÇA

By
Raad A. Nasir AL-AMERI
December 2017

REPUBLIC OF TURKEY
UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES
CIVIL ENGINEERING DEPARTMENT

Name of the thesis: The Flexural Behavior of the Steel fiber Reinforced Concrete Hollow Beams.

Name of the student: Raad A. Nasir AL-AMERI

Exam date: December 25, 2017

Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. Ahmet Necmeddin YAZICI
Director

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

Prof. Dr. Abdulkadir ÇEVİK
Head of Department

This is to certify that we have read this thesis and that in our concerns opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Prof. Dr. Mustafa ÖZAKÇA
Supervisor

Examining Committee Members	Signature
Prof. Dr. Mustafa ÖZAKÇA	………………………
Assoc. Prof. Dr. Hamza TANRIKULU	………………………
Assoc. Prof. Dr. Nildem TAYŞİ	………………………

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Raad A.Nasir AL-AMERI

ABSTRACT

INVESTIGATION OF FLEXURAL BEHAVIOR OF THE STEEL FIBER REINFORCED CONCRETE HOLLOW SECTION BEAMS

AL-AMERI, Raad A. Nasir

M.Sc. Thesis in Civil Engineering

Supervisor: Prof. Dr. Mustafa ÖZAKÇA

December 2017

80 pages

The flexural behavior of the steel fiber reinforced concrete hollow beams under two-point load is discussed in this study. The ultimate load capacity and deformation of hollow beams were investigated experimentally and compared with the solid beams) which have the same properties of the concrete mixture. All the beams that were tested in this study were square beams with a section width of 150 mm, section depth of 150 mm and the beam length of 850 mm (the span of 750 mm). All beams were simply supported tested under two points load. Twelve concrete beams including four solid sections, while the rest eight beams are hollow with a square cavity. The effect of opening size, steel fiber content and longitudinal steel reinforcement are investigated to evaluate the response of beams to carry the applied load. The current experimental results approve that the usage of steel fiber in concrete mixture did not noticeably affect the compressive strength while significant increase in splitting tensile strength and led to better flexural behavior and increased the ultimate load capacity, on the other hand, the hollow beams resulted in lower ultimate load, which was decreased as the opening size increase.

Keywords: Steel fiber reinforced concrete, flexural failure, hollow beam and ultimate load

ÖZET

ÇELİK LİFLİ DELİK KESITLI BETONARME KIRISLERIN EGILME DAVRANISLARININ INCELENMESI.

AL-AMERI, Raad A. Nasir

Yüksek Lisans Tezi, İnşaat Mühendisliğinde

Tez Danışmanı: Prof. Dr. Mustafa ÖZAKÇA

Aralık 2017

80 sayfa

Bu çalışmada, iki noktalı yük altında çelik telle güçlendirilmiş delik kesitli beton kirişlerin eğilme davranışı incelenmiştir. Nihai yük kapasitesi ve delik kesitli kirişlerin deformasyonu deneysel olarak araştırılmış ve beton karışımının aynı özelliklerine sahip olan normal kirişlerle karşılaştırılmıştır. Bu çalışmada test edilen tüm kirişler, kesit genişliği 150 mm, kesit derinliği 150 mm ve kiriş uzunluğu 850 mm (750 mm açıklık) olan kare kirişlerdir. Tüm kirişler basitçe iki nokta yük altında test edildi. Test edilen 12 kirişin dördü normal kesitli diğer sekizi ise delik kesitli kiriştir. Kesit delik boyutu, çelik lif içeriği ve uzunlamasına çelik donatı etkisinin yük taşıma kapasitesine etkisi araştırılmıştır. Mevcut deneysel sonuçlar, beton karışımındaki çelik lif kullanımının basınç dayanımını belirgin bir şekilde etkilemediği halde, çekme gerilimi mukavemetinde önemli bir artış sağladığını ve daha iyi bükülme davranışına yol açtığını ve nihai yük kapasitesini arttırdığını gösterirken, delik kesitli kirişlerde, delik boyutu arttıkça nihai yükün azaldığını göstermiştir.

.

Anahtar Kelimeler: Çelik lif takviyeli beton, eğilme yetersizliği, delikli kiriş ve nihai yük.

To My Mother and father

A strong and gentle soul they taught me to trust in Allah and believe in hard work and for supporting and encouraging me to believe in my self.

ACKNOWLEDGEMENTS

Praise and glory be to Allah who guided me in every step to finish my thesis project. My deep gratitude goes to my supervisor Prof. Dr. Mustafa ÖZAKÇA who gave me the golden opportunity to do this wonderful project which also helped me in doing a lot of research and I came to know about so many new things.

Additionally, I would like to thank both Asst.Prof.Dr. Talha EKMEKYAPAR and Asst.Prof.Dr. Mehmet Tolga GÖĞÜŞ for their help and support for me to test my specimens.

My final thanks go to my family, my wife and friends who helped me a lot and support me in finalizing this project within the limited time frame My thanks for the Ph.D. student Farid ARNA'OT, Dr. Sallal R. ABID and Ph.D. student Hayder ALI.

TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

LIST OF SYMBOLS / ABBREVIATIONS

RC	Reinforced Concrete
SFRC	Steel Fiber Reinforced Concrete
FRC	Fiber Reinforced Concrete
SF	Steel Fiber
V_f	Fiber volume fraction
SP	Super Plasticizer
HRWRA	High Range Water Reducing Admixture
f'_c	cylinders compressive strength
h	Beam depth
l/d	Aspect ratio of steel fiber
A	Area
d	Effective depth
EAC	Energy Absorption Capacity
E_C	Modulus of elasticity or concrete
a/d	Shear span over effective depth
L	Beam length
B	Beam width
T	Thickness of wall of beam
f_y	Yield stress of steel

l_f	Length of fiber
f_{sp}	Tensile strength for concrete
f_{st}	Splitting tensile strength for concrete
ACI	Amrecan Concrete Institute
P	Applied Load
X	Shorter dimension for beam
Dc	Diameter of cylinder
c/c	Center to center of rebar
L	Length of cylinder
Δ	Displacement
δu	Deflection at ultimate
δy	Deflection at yielding
δcr	Deflection at fi st crack
P_u	Ultimate load
p_{cr}	Load cracks
P_{flex}	Flexural capacity
ρ	Reinforcement ratio
LVDT	Linear variable displacement transducers
FR	Fiber Reinforcement
SF	Steel fiber
Sf	Silica fume
LVDT	Linear variable displacement transducer
UHPC	Ultra-High Performance Concrete

CHAPTER ONE

INTRODUCTION

1.1 Introduction of Hollow Reinforced Concrete Beam

In recent years, the use of hollow members (beam, column, slab, and pier) has been widely increased in the new construction of engineering structures. The advantage of constructing the open in the structural member to allow the electrical and mechanical utilities to pass through the structure and also, to reduce the cost and weight of the construction.

Figure 1.1 Examples for the hollow section concrete members for constructing the buildings

Several studies and experimental works have been carried out on solid concrete members and can be applied also on (i.e. beams) to concrete building structures, however, for hollow concrete member like beam and few research or experimental work are found in the literature

Specifically, the requirements of high structural engineering performance are minimum weight, the hollow section structures can be designed that to exhibit a great load. One of the important properties of hollow sections members they have very light weight compared with alternative structures members and also, they are used in most cases in long span bridges and other structures where weight and cost of manufacture and transported are essential considerations.

1.2 Introduction of Steel Fiber Reinforced Concrete

FRC consists of cement-based composite material made up of cement, fine and coarse aggregates and water, as well as fibers. The stated fibers can be obtained from natural resources (coir, wood cellulose and bamboo) or synthetic products (polymeric, asbestos, steel, glass and carbon). In fact, the RC mixture with steel fiber is called SFRC.

Needless to mention, a concrete one from important construction materials stay has a brittle and has low tensile strength, weak during rising cracks, and a limited ductility. Recently for improving these deficiencies, the different volume fractions of steel fibers are used. Using steel fibers with concrete consists of (cement, sand, gravel) will enhance the following properties of concrete which became more active, the following properties: tensile strength, shear strength, strain capacity, limiting crack width, impact resistance, energy absorption, strength against impact load, increase in the brittle and stiffness characteristics of normal concrete and to convert it for a ductile one (Orange, 1999). The fibers may take many shapes, their cross sections include: circular, half-round, rectangular, and irregular or varying cross sections. They which is may have a straight or bent end and come in various lengths. A numerical parameter named the aspect ratio is used to describe the geometry. This ratio and is the fiber length divided by the diameter.

However, most of the experimental studies on SFRC were confined and limited to the determination of its flexural fatigue endurance limit for the parameters of the used steel fiber type, aspect ratio (l/d) volume fraction (V_f), and of steel fibers which are added (Batson, 1972; Ramakrishnan, 1987; Ramakrishnan, 1989; Johnston, 1991).

In addition, many studies mention that the usage of steel fibers with an aspect ratio by about 100 and more than or non-uniform fiber distribution observed causes unacceptable workability of the concrete mixture if the conventional mixing techniques are used. Steel fiber can be mixed and placed for the lower steel fiber percentage ranged by about from 0.5 to 1.5 volume percent fibers with conventional equipment and procedures. Specifically, the usage of higher percentages of fibers (by about 2 to 10 volume percent) supposed to be used with other special fiber and placement with techniques procedures. Indeed, most properties given in this thesis are for the lower steel fiber percentage range.

In most cases, the proportions of concrete mixture of steel fiber should be varied to obtain a good workability and take full advantage of the fibers, The uniform distribution an important point of consideration of concrete mixture containing steel fibers and also, avoid balling at the time of mixing and casting relatively may require limiting the aggregate size and perhaps adding other admixtures, are to improve workability like (Super Plasticizer (SP) or High Range Water Reducing Admixture (HRWRA)) which used in this research.

1.3 Advantage of Hollow Cross Section

The hollow cross section beam means closed thin or thick walled section beam. A thin walled beam is characterized by the relative of its dimensions.

The advantages of hollow member cross section were noted by Nimnim (1993).

- Substantial reduction of the weight, which affects especially the cost of transport, handling and fabrication for precast cross sections.
- Reducing the material quantities which required, the material which are used for hollow concrete member and usually much less than those needed for solid

1.4 Effect and Advantage of Use the Steel Fiber with Concrete Mixture.

FRC is a composite material adding for cement, coarse and fine aggregates, and water. The stated fibers can be either obtained from natural resources (wood cellulose, bamboo, coir) or synthetic products (steel, glass, asbestos, carbon, polymeric). In fact, the concrete mix that reinforced with steel fiber is known as SFRC.

Generally, concrete is a widely used as a construction material in all the world's construction industries; but unfortunately, it has major disadvantages properties like the low tensile strength, low strength to weight ratio, and also likely to result in cracking (Rossi et al, 1987).

Indeed, the brittle behavior of plain concrete cannot be neglected where immediate approaches should be taken to make the plain concrete a more ductile material. Needless to mention, steel is no doubt to be considered as a useful reinforcement material for enhancing the plain concrete whether it is in the form of a steel bar or steel fibers. The addition of steel fibers to plain concrete can enhance the mechanical properties such as tensile strength, ductility, flexural strength, cracks, and impact resistance (Orange et al, 1999).

On the other hand, the function of the steel fibers is to bond the coarse aggregate together and then works to reduce and prevent the propagation as well as the opening of micro cracks to form a macro crack. The tensile force is transferred across the crack by the fibers resulting in lower stress concentration at the crack ends, thus inhibiting crack growth and maintain some measures of load carrying capacity even after a visible crack pattern is established. Other than, previous researches also had shown the effectiveness of steel fibers in improving shear failure and performance of concrete.

According to the experiment work which was done by (Kwak et al, 2002) approved that can be replaced the shear reinforcement (stirrups) by steel fibers, which were poured and tested 12 specimens of SFRC beams without stirrups that failed in shear zone were studied. The result shows that when adding the steel fibers, will consistently reduce the crack spacing and sizes, change a brittle mode to ductile and increase the deformation capacity.

Although the steel fibers demonstrate a good improvement in concrete mechanical properties when they were distributed randomly, fibers when were distributed uniformly throughout the concrete matrix that provide post cracking ductility; however, there are limitation for the usage of steel fibers in order to avoid reversed effect (Chanh, 2005).

According to Chanh (2005), steel fibers cannot be used as a direct replacement instead of longitudinal reinforcement in concrete structural member, because the usage of steel fibers are usually not more than 2% in concrete mixture; therefore, conventional steel reinforcements are still needed at specific location to withstand designed tensile, shear or flexural loads.

Although more, steel fibers also tend to enhance the bond between concrete and conventional steel reinforcement in SFRC. In practice, SFRC may play an important role in many applications around the world due to the toughness imparted on concrete such as shotcrete, flooring and slab and precast element. In spite of, they are some numbers of studies and experimental works which have been carried out on the structural element such as beam, column, footing and slab using SFRC, the result proved to be able to enhance the mechanical properties of concrete.

In this project, it is aimed to investigate the flexural behavior of SFRC hollow beams. The results of this project are very important not only to provide safe, efficient, and economical designs for the present construction; but, also to serve as a rational basis for extended future applications in construction industries.

1.5 Factors Affecting Steel Fiber Reinforced Concrete Performance

According to Romualdi (1963) reported that the usage of the fibers in concrete delays the initial cracks by reducing the stress intensity, so that the energy which tends to cause extension of a crack is dissipated in deboning the fibers.

According to Yazici et al (2007), the aspect ratio (l/d ratios) and also the volume fraction V_f (%) of the fibers are the most important factors that affect the SFRC mechanical properties. The l/d ratio is important at mixing and replacement the stages of production. Generally, l/d ratios of steel fibers that specifically used in concrete mix are between 50 and 100.

According to Katzer (2006), the l/d ratio supposed to be not exceeded 150 to avoid the decreeing in workability of the SFRC will cause a lot of problems during the pouring concrete process. Furthermore, l/d ratio of steel fiber available on the world market ranges from 20.4 to 152, where 50% of the production is with aspect ratio range between 45 and 63.5 as shown by a statistical analysis.

On the other hand, V_f also tends to significant affect the workability of concrete where increasing of V_f will reduce the workability. Hence, the most suitable V_f values for concrete mixes are between 0.5% and 2.5% by volume of concrete (Yazici et al, 2007).

1.6 Purpose of the Thesis

Based on the above problem statement, the author purpose to use variable dosages of steel fiber with the concrete mixture which used to construct the hollow beams, therefore the main goal of the present research is to study experimentally the material properties and the flexural behavior of the beams under monotonic loading.

1.7 Problem Statements

In comparison with steel members, brittleness and heavy weight of the concrete members remain the main challenges that face the designers, especially in multi-story structures. Many methods and materials have been used to improve the ductility behavior of members, such as increasing the stirrups in beams in order to decrease the brittleness behavior of shear strength, which add an extra self-weight to the member. Moreover, compressive and tensile strength are the main two mechanical properties that control the strength of concrete under multi-state of stresses, therefore, the balance of these requirements (ductility, lightness, and high strength) stated as the design problem.

For the above reasons, researchers tend to improve the concrete properties with keeping the reinforcement as low as possible, in order to control the RC members related to ductility. One of the improvement methods which use fibrous materials. Among these materials, SFRC remains a good option.

Besides that, the parameters studied which are and limited to test the flexural strength, compressive strength, tensile strength, shear strength, and crack pattern

The steel fiber application may enhance the flexural strength and expect also to improve the crack pattern. With these problems and assumptions, the objectives and scopes of this project are outlined.

1.8 Objectives and Scopes

Based on the literature review which done, the aims of this project are outlined. It is to investigate the flexural behavior of SFRC hollow beam subjected to Variable percentage of hollows; in this stage variable size of hollow will be used in order to determine the ideal size; the judgment will be under serviceability limit state and different volume fraction fibers in order to provide safe, efficient and economical beam design. The following objectives have been identified for investigating the above statement:

1. Investigate the effects of the existence of hollow part on flexural and behavior of hollow beams under load.
2. Investigate the effects of the steel fiber (S.F) dosage on mechanical properties of concrete mixture and structural behavior of solid and hollow beam.
3. The longitudinal rebar resistant on SFRC hollow beams under combined shear and flexure
4. Discuss the results of experimental work (compressive and splitting tensile strength, the load-deflection behavior, the ultimate loads capacity, the first crack loads and crack patterns) according to Standard of Specification according to of Concrete Structures for Design and Construction.

In addition, in the research, variable parameters will be investigated, among these parameters, the steel volume fraction, the percentage of the hollow area to the total cross-sectional area, and the strength of concrete. The judgment will consider the ideal percentage of steel fiber used, in the lighted beam, and based on the flexural test of beams model and molds under standards codes provisions (cylinders and prisms).

1.9 Thesis Layout

The current research is presented in five chapters with this chapter as follows:

Chapter 2, included the literature review on basic knowledge of SFRC as a composites and hollow member in concrete structures in addition that, a brief review on the previous researches related to the present study is given.

Chapter 3, a brief of the experimental work details as well as the used construction materials

Chapter 4, present and discuss the results of the experimental work.

Finally, Chapter 5, the brief of conclusions which obtain from this work and the recommendations for future studies.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The concrete structural stays the lowest cost/strength ratio, with low tensile strength, limited ductility, and heavy weight of the concrete members and remains the main challenges that face the designers like beams, columns, and slabs especially in multi-story structures, and there were many studies to improve the concrete specifications. One of the best and low-cost improvement is by using fibrous materials, for enhancing these deficiencies, different kind of fibers are used. Adding steel fibers (SF) to concrete mix will contribute significantly to improve the following properties of concrete: tensile strength, strain capacity, shear strength, limiting crack width, hence the strength against impact load, increase the resistance against twisting (torsional capacity and increase a ductile), on the other hand the heavy weight issue in structural engineering can be solved by using the hollow section. In order to improve the concrete matrix properties, the SF are widely used for this purpose. It is shown that the SF has a positive effect on the toughness and energy absorption capacity, and also, to enhance the ductility and transfer the stress between the two edges of the cracks by bridging, also improved durability (Inoue, 1996).

In turns, increasing the shear resistance and controlling shear cracking of RC members, many researches had been conducted on this technic, it they shows that include the fibers materials are delay the initial cracks by reducing the stress intensity, which affect the first cracking, and dissipated the energy which increase the number of cracks and crack propagating (Guleria, 2014). Using SF reinforcement in beams (up to 1.2 % volume fraction) mobilizes in tension zone much more effectively to resist the external load, Moreover fiber reinforcement achieves the tensile cracks distribution in the beams and minimizes the penetration of the shear cracks into the compression zone (Romualdi, 1963).

Experimental studies by Swamy (1979) showed that SF significantly improves the ultimate load capacity and post-cracking stiffness, but decrease ductility approximately 27% - 54% higher load carrying capacity and 13% - 73% lower ductility are obtained specifically, when the inclusion of 2% volume of SF.

The heavy mass of RC stays the unlikely adjective especially in precast concrete members. Therefore, the reductions in the member's weight is important in large-span beams, among one of various solution is to remove the parts of zero stress core of the beam. When the construction of the required materials are reduced the weight this led to decrease the dead load on the other structure's members, which in indirectly reduce the other member's construction materials. Rectangular section RC hollow beams have circular opening with diameter less than 44% of the depth (h) of beam which exerted no effect on the capacity of ultimate load, in addition, circular openings section with a diameter by about 44% of (h) decrease the ultimate load capacity by about 34.29% (Hafiz , 2014).

Because of the complex behavior of hollow beam, it need a different analysis for structural, where the section of this type consist of two types of sub-members, two webs and flanges, each of these type have a different structural behavior, the behavior of top flange as a plate monolithically connected with two walls, while the behavior of web as a wall fixed by two ends and exposed to axial forces. Many researches had conducted on direct design method for evaluating the capacity of these beams (Alnauimi and co-workers, 2004 and 2008). They found that the hollow beam is failed close to design load, while the direct design applying to the solid beam is more conservative. In addition to, the ultimate load resistance of hollow beam is less than the solid. Among these materials, SFRC with hollow section remains a good option.

2.2 Solid and Hollow Section Beams Behavior

Looking back into the history, the natural behavior of the concrete is strong in the compression zone and weak in tension. In addition to that the brittleness and heavy weight plays an important role in affecting the design and behavior of major structural engineering members like beams.

Generally, many comparisons between the reinforcement concrete solid and hollow section beams (with same outer geometry and same reinforcement) approved that the solid beam higher resist for load than the hollow one. The hollow beam was it nearest for the design loads filer than the solid one, while the solid beam failed much more than the design loads, the hollow beams behaved softer than the solid ones (i.e., more displacement and more steel strain under the same load value), All beams failed in a ductile manner with steel yielding before concrete crushes (Ali, 2008).

2.3 Hollow Beam with Opening

In the last period, the hollow sections in structural engineering have been increasingly used, because the hollow sections save many services like uses for passing the electrical and mechanical utilities, and for reducing the materials cost and quantity.

According to the study done by Sarah, (2016) on hollow beams subjected to flexural load, the results of displacement for all tested hollow beams showed reduction about 10 times compared with the control solid beam (see Figure 2.1). Also, the ductility of the control solid beams was 8.2, whereas the results of hollow beams (beam with square opening 100 mm^2, 200 mm2 and 300 mm^2) were the same degree of ductility were 4.2.

In addition, the results of ultimate load capacity of hollow beam have opening 100 mm^2 showed reduction by about 24% whereas the hollow beam have 200 mm^2 and 300 mm^2,the ultimate load was reduced by about 30% and 49%, respectively. Therefore, during the flexural loading, the openings in beams effectively were reduced the capacity of ultimate load of beams. Meanwhile, the results indicated that the capacity of load was decreased in beams with square opening 200 and 300 mm^2

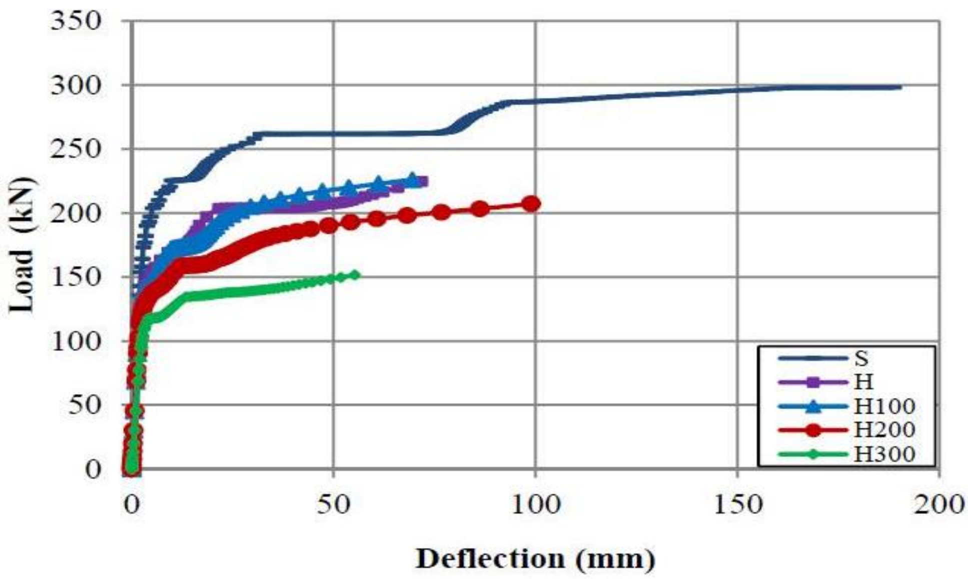


Figure 2.1 Load-deflection curve for hollow beams (Sarah, 2016)

In addition, the openings in RC beams which were without special reinforcement on the opening zone have effect on the behavior of beam. In the shear and flexural zone, the maximum effect of opening with diameter 40 mm was an increase in the deflection 4% and 1.5% respectively, and the decrease in the ultimate failure load capacity was 26 % and 6% respectively compared with control beam. (Hafiz 2014)**.**

2.4 SFRC Shear Behavior

The behavior of the SFRC beams were compared with that of the RC beam with stirrup reinforced which meets the minimum requirement in the ACI Code. On the other hand, the steel fiber can be used in place of the minimum stirrup reinforcement required by ACI Committee 318, when use the hooked steel fibers, with a recommendation that: a volume fraction was greater than or equal to 0.75%. Also, this volume fraction led to an improvement the inclined cracking pattern (multiple cracks) and enhanced shear strength in beams without reinforcement for stirrup, equal or greater than l to $0.33\sqrt{f'c}$ MPa, (Hai, 2010).

Specifically, the usage of 0.5% or more volume of steel fibers in the concrete mixture of SFRC deep beams changes the failure mode from brittle shear to ductile flexure. Rather than, by increasing the aspect ratio of the fiber from 60 to 100 it was observed and improved by about or up to 32% of the ultimate shear strength of SFRC beams, as shown in Figures 2.2 and 2.3, also it was observed by increasing the fiber's length from 30 to 60 mm. The ultimate shear strength of SFRC beams was increased. The fiber's length enhances the flexural strength more than its shear strength of the SFRC beams. Also it observed for most types of fibers (straight, crimped and hooked fibers) have a similar effect on the shear strength of SFRC beams (Yassir, 2016).

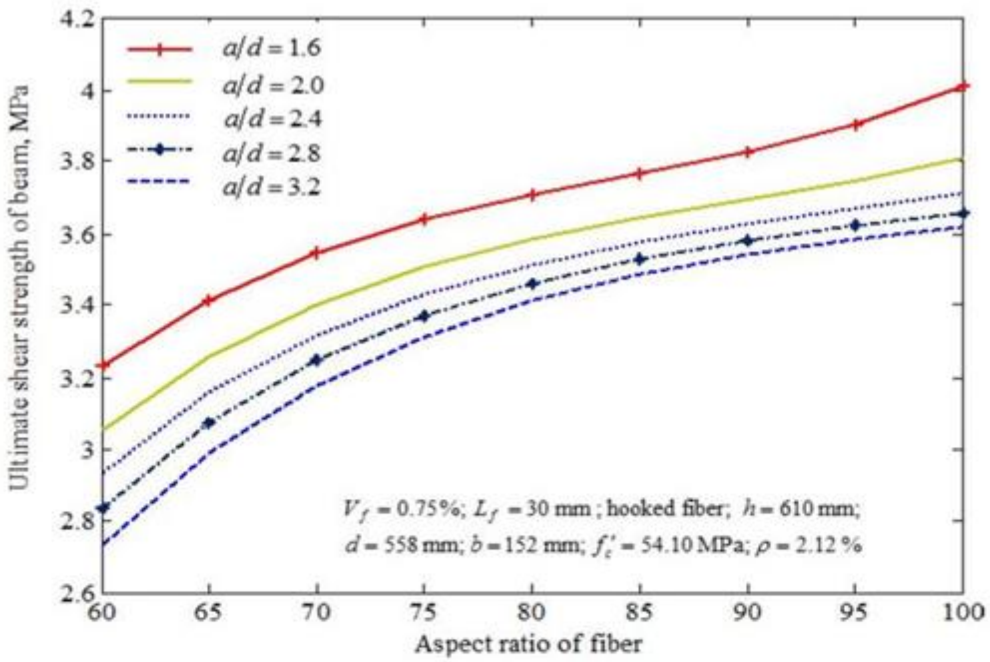


Figure 2.2 Effect of length of fiber on the ultimate shear strength of SFRC beams without web reinforcement (Yassir, 2016)

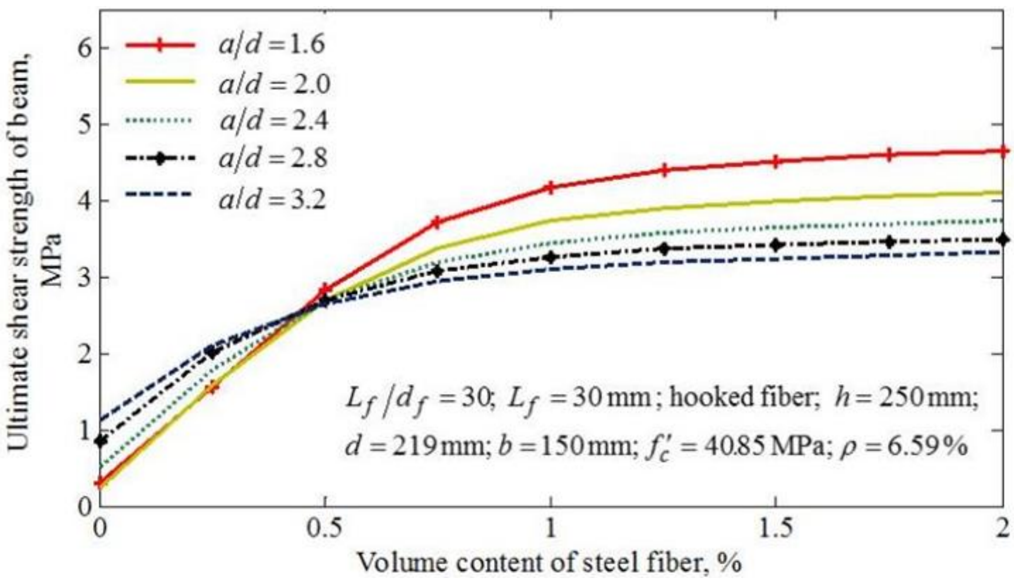


Figure 2.3 Effect of volume content of fiber on the ultimate shear strength of SFRC beams without web reinforcement (Yassir 2016)

More importantly, the addition of steel fibers for a concrete mixture of beams increased the peak capacity and yielding capacity. As expected, the SFRC beams had ductile behavior regardless of the bar type, moreover one cracks initially emerged in these beams were showed. The influence of rebar bond for concrete was less effective in SFRC beams (Dhakal, 2006).

Also was observed by adding the fibers which significantly reduce the scale effects in RC elements under shear, specifically, usage fibers can influence to replace the minimum quantity of transverse and the skin reinforcement required to control the propagation of cracks and give visible warning before the collapse in structural, needless to mention, fibers allow the shear cracking to grow gradually although more the overall deflection to become visible before the collapse (Minelli et al, 2007).

2.5 Advantage of Hollow Cross Section

The advantages of hollow sections can be noted below:

- Reduction in the weight, and thus, affect significantly on the cost of transport and handling
- Fundamental reduction the quantities of material, in most cases, the usage required materials are almost much more less than that usage for other conventional systems and, with the above advantages of contributing relatively simple formwork (Nimnim, 1993).

The existence of hollow cavity in RC beams substantial to reduce the load carrying capacity approximately by about 37.14% to 58.33% and contribute to increase the deflections by about 71.6% (with hollow ratio 7.4%) to 75.5% (with hollow ratio 14.8%) for same applied load compared with the same properties solid beams, also observed when increasing the hollow ratio from about 7.4% to 14.8% the load carrying capacity is reduction and increased by about 28.5% and 14% for the deflection respectively with the same other properties (Ahmad et al, 2014).

2.6 Steel Fiber

Concept use fiber as reinforce in concrete is not new, fiber from many years use as reinforcement since ancient time, historical used as a reinforcement in brittle material like mortars of clay with different kinds of fibrous material to made bricks or as a reinforcement in sunbaked bricks also the ancient people using horsehair as a choice type of fibrous for reinforcing the masonry mortars, the term of SFRC called when the steel fiber mixed with the mixture of concrete. And in present time there are many engineering industry becoming use the fiber as composite material in construction project.

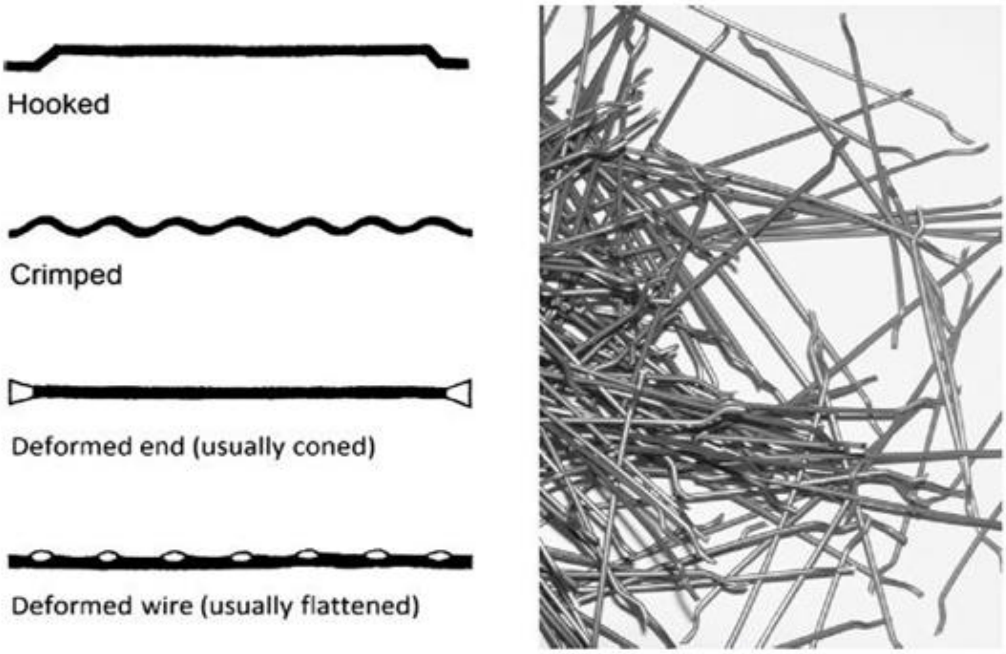
2.6.1 Shapes and types of fibers

One of the common types are steel fibers which had square, circular, rectangular, and irregular cross-sections The shape of steel fibers is so important to increase the anchorage of fibers and strengthens the bonding in the concrete mix, and thus, the last 40 years, the produced were hooked, flattened, spaded, surface-textured, twisted, crimped, conned, and melt-cast steel fibers (Figure 2.4a (Maidl, 1995)) and Figure 2.4b explain the geometric shapes of commonly used steel fiber and an example of popular fiber type-"hooked" (Katzer, 2006).

There are many types of fibers:

1. Steel fiber (hooked, crimped, coned and mechanically deformed),
2. Mircro synthetic fiber,
3. Macro synthetic fiber,
4. PVA fibers,
5. Glass fibers,
6. Specialty fiber (ex. carbon, Kevlar) and other blend.

(a)



(b)

Figure 2.4 Fibers (a) Various types of fibers (Maidl, 1995), (b) Geometric shapes of commonly used steel fiber (Katzer, 2006).

2.6.2 Application of steel fiber reinforced concrete

SFRC has many uses and applications such as in the following construction:

- Rocking slope stabilization and supporting of excavated foundations, often in conjunction with rock and soil anchorage systems.
- Channel linings, protect bridge abutments and stabilize debris flow prone creeks.
- Industrial floorings, bridges, warehouse, ports/Airports, road pavements, and warehouses floorings, usually imposed with heavy loading.
- Support of underground openings in tunnels and mines.
- Rehabilitations of RC structures.

However, steel fibers are also commonly used in shotcreting, commercial and industrial floors where heavy loadings are imposed on.

2.6.3 Background of engineered steel fiber

The long history of inventing modern SFRC started in 1874, the idea patented of strengthening concrete when Bernard in California with addition of steel splinters. This was supposed to improve the homogeneity by using the thick wire in concrete reinforced. In 1918 in France, by modifying the concrete to increase tensile by adding long steel fibers strength of concrete (Naaman, 1985).

2.6.4 Development of steel fiber

In fact, there are more than 30 major producers of steel fibers which were not only confined in a developed country like Europe, USA, and the UK, but also in other countries like Republic of South Africa, Australia, Japan, and Malaysia. They have different over 100 types of fiber with different specifications and requirement for purpose of modifying the concrete properties (Odelberg, 1985).

Unfortunately, the oldest and most basic type of steel fibers are straight fibers which were predicted from that cut out from the smooth wire. This type of fiber does not provide strong anchorage between the concrete matrix and steel fibers due to weak bonding, and this can be consider a material wastage in term of tensile. Nowadays, over 90% of present produced fibers are deformed in shape after the enhancement from the previous weakness.

2.7 Effect the Steel Fiber on Concrete Mix Behavior

2.7.1 Fiber and concrete matrix interaction

By adding steel fibers this will help to bridge the formed cracks and control the undergo pull out processes. The steel fibers were added stretch more than the concrete During the loading; therefore, the composite system of SFRC is assumed to work as there was no fiber reinforced until the start of the first crack strength reaches. When the first crack appears, the steel fiber will take over the role to hold the concrete together for controlling and preventing further occurred cracks, see Figure 2.5 (Brown et al, 2002).

Figure 2.5 Steel fiber action to hold the concrete together for controlling and preventing further occurred cracks, (Brown et al, 2002)

Generally, by using the steel fiber which decreased the workability of concrete mixtures especially, the workability of the RC mixture, and the unit weight of concrete is increased with using fibers. This increase varies with the aspect ratio and volume of fibers, also the usage of steel fiber in concrete will accrue smoothly increasing in the compressive strength of concrete by about 4-19%, also increasing the split tensile and flexural strength of concrete about (11-54%), finally when added the steel fiber, there is a little effect of compressive strength than flexural strength and split tensile strength (Yazici et al, 2007).

Using the steel fibers in plain concrete, transforms the inherently unstable and uncontrolled tensile cracking into a slow, and even a small amount of steel fibers reduce the suddenness failure, also When used in conventional RC.

Steel fiber reinforcement in beams (up to 1.2 percent) mobilizes the tension zone much more effectively to resist the external load. Also Fiber reinforcement achieves better the tensile cracks distribution in the beams and minimizes the penetration of the shear cracks into the compression zone (Swamy et al, 1979).

2.7.2 The optimum aspect ratio and volume fraction effects

The very important factors that effect on the SFRC properties are the aspect ratio (l/d ratio) and the volume fraction (V_f %) of the fibers, Generally, l/d ratios of steel fibers which are used in concrete mix are mostly between 50 and 100, also the V_f has more effects on the workability of concrete, where increasing V_f will reduce the workability. Commonly, the most recommended suitable V_f values are equal to 0.5% and 2.5% by volume of concrete for concrete mixes (Yazici et al, 2007) However, the l/d ratio spouse to not be higher than 150 to avoid the reduction in workability of the SFRC mixtures, hence will cause many problems during the concrete cast process (Katzer, 2006).

The studies of the structural performance of Ultra-High Performance Concrete (UHPC) beams with different steel fibers, reported that steel fibers improved on the load carrying capacity, cracking response and post-cracking stiffness, but unfortunately decrease the ductility. However are obtained when usage steel fiber with 2% of volume, may high the load capacity by about 27%-54% and low the ductility by about 13%-73%. In addition, an increase in the length of steel fibers and the use of twisted steel fibers improve the post-peak response and ductility; however, length and type of steel fiber effect on Cracking response is in significantly accordance (Yoo and Yoon, 2015).

Specifically, there was no problem in mixing when adding fiber (30, 50 and 60 mm length) up to (120 kg/m^3) of fibers, because distribution of fibers was found to be uniform, moreover the hooked-end fibers type are very influential to improve the toughness, also fiber content in the range of (30 to 60 kg/m^3) is more sufficiency for obtaining ductile behavior, in addition, for hooked end fibers, the length of the fibers do not affect toughness (Balaguru et al, 1992).

2.7.3 Effect the steel fiber of workability or slump test results

It has been observed that the slump tests give us good indicators for the workability and consistency of the concrete mix. The efficiency of SFRC mixes are dependent upon a uniform distribution achievement of the fibers in the concrete, their interaction with the cement matrix and the ability of cast or sprayer the concrete successfully, The change in slump depend upon the different type of fiber content and form (see Figure 2.7).

Coincidentally, the fibers that contribute more effect on the mechanical performance of the composite which make the workability has difficulties, also for the content and the aspect ratio (aspect ratio can be defined that, the ratio between fiber length and the diameter of the circle which equals the cross section of the fiber). So, the effect of steel fiber is negatively on the fluidity of the concrete mixtures, (Hannant 1978).

Usage fiber volume fraction within 0.5% to 1.5% may reduce the concrete mix workability and will cause more difficult to separate by vibration (Ganesan et al, 2010).

It is observed that the workability of SFRC gets reduced as the percentage of steel fibers increases (Mohod, 2012).

It has been observed that the workability-reducing effect of mixtures fibers depends approximately fully on fiber content and fiber aspect ratio. Aspect ratio of steel fiber is the ratio length to diameter, or equivalent fiber’s diameter of noncircular cross section, and is defined for monofilaments of fibers.

One test that assesses, the workability of FRC mixture under vibration is the ASTM –C995-Test Inverted Slump Cone Method of Flow time for FRC (see Figure 2.6).

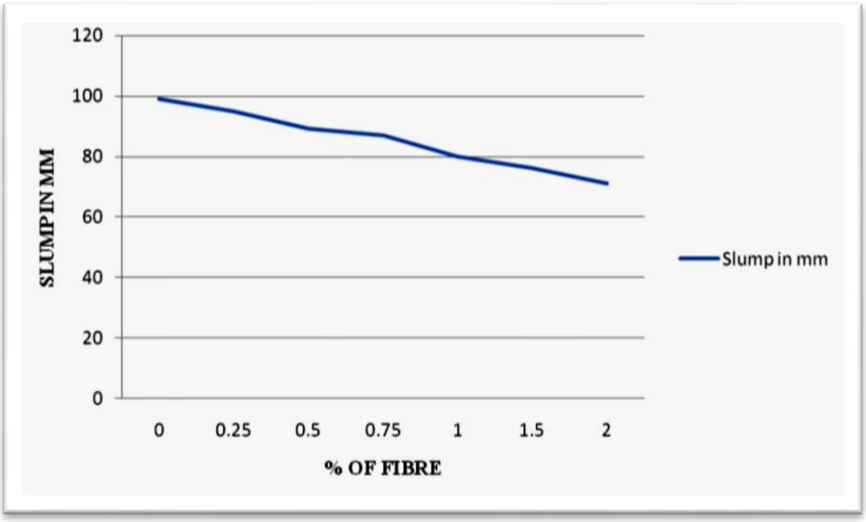


Figure 2.6 Variation in slump of concrete with respect to % of fiber content (ASTM, C995)

Both the inverted slump cone and Vebe test results correlate closely (see Figure 2.7), and the essential linear relationship passed through the origin suggests that both are measured primarily the same rheological characteristic; namely, the mobility or flow of FRC under vibration (Johnston, 1984).

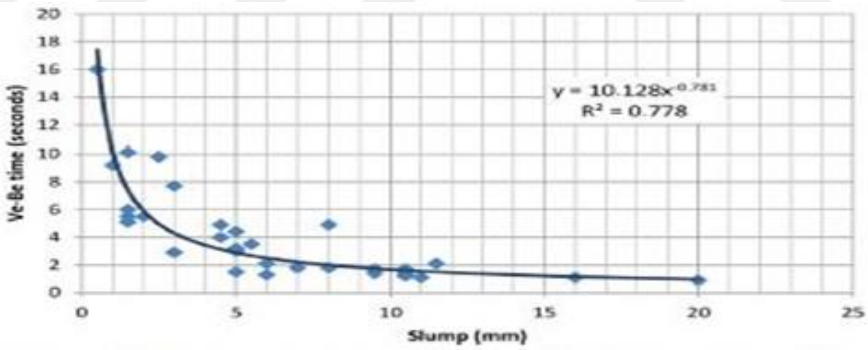


Figure 2.7 Correlation between all the slump values higher than zero and the Ve-Be time (Johnston, 1984)

The inclusion of fibers in plastic concrete mix altered its mobility, The loss of mobility which is happen at primarily by the fibers which reduce or block the relative movement of the aggregates and reduce the hardened FRC post-crack strength. The best solution could be by reducing the maximum of aggregate's size or increasing the mortar content in the mix of concrete. Needless to mention, the Ve-Be test is not applicable to evaluate the concrete mixtures under conditions in which the mix of concrete is more fluid and its slump is more than 100 mm, for a lower volume of fibers. This condition typically occurs by about below 0.7% by volume (55 kg/m^3). As expected, for fiber contents which exceeded this value, the slump applicability is so difficult (Johnston, 1984).

As recommended in ACI 544, 3R-08, the volume fraction of SFRC supposed to be 0.5% to 1.5% as the usage of fiber in concrete mix may reduce the workability (Ganesan et al, 2010).

2.7.4 Effect of the steel fiber on compressive strength of concrete

The compressive strength of concrete with steel fibers 0.25%, 0.50%, 0.75% and 1% (for the cubes test) is higher than of cubes without steel fibers. This fact may be due to that the steel fibers improved and holed the micro cracks for mass of concrete. According a study done by Mahadik et al (2014). The increasing in the compressive strength with variable percentage of steel fiber 0.25%, 0.50%, 0.75% and 1% compared with the without steel fibers are 11.56%, 21.05%, 24.15% and 10.52% respectively. The maximum percentage increase in compressive strength of concrete with steel fibers is 0.75% by volume of concrete (+19.50%), see Table 2.1, therefor it was recommended that using steel fibers 0.75% for concrete to obtain maximum benefit for increasing the compressive strength of concrete (Mahadik et al, 2014).

Table 2.1 The Effect of the steel fiber of compressive strength (Mahadik et al, 2014).

Detail of beam	**Size of bean in** (**B×D×L**) mm	**Average failure load in** kN	**Average compressive strength in** N/mm^2	**% increase /decrease in compressive strength**
0% (plain concrete)	150×150×150	931.95	41.42	-
0.25 %steel fiber	150×150×150	1039.86	46.21	11.56
0.5% steel fiber	150×150×150	1128.15	50.14	21.05
0.75 %steel fiber	150×150×150	1128.15	51.45	24.15
1.0% steel fiber	150×150×150	1030.05	45.78	10.52

As shown in Figure 2.8. The increasing of Compressive strength which was obtained by an increase in steel fiber percentage, the optimum value of content for SFRC was found to be 1% (Mohod, 2012).

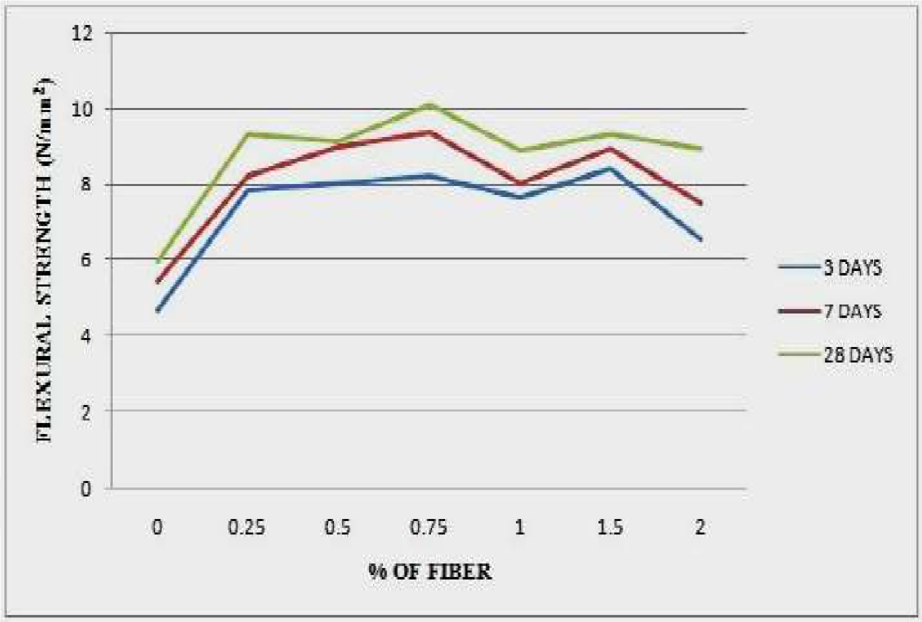


Figure 2.8 Variation of compressive strength with respect to % of fiber content (Mohod, 2012)

Finally, we can be summarized the benefits of adding the steel fibers for plain concrete as follows:

1. Delay the growth of cracking
2. Improve the resisting of the tensile load after cracking by fibers bridging across cracks and fibers resisting pullout.
3. More increase in flexural and shear strength
4. Enhance fatigue strength under cyclic loading and impact resistance
5. Reduce of the creep and shrinkage.

The influence of the volume fraction of steel fiber is more significant on compressive strength results of concretes mixtures with the aspect ratio of 65, and it observed the increase in the fiber volume fraction (V_f) by about from 0.26% to 0.64% cause relatively increase of 30 % in the compressive strength.

2.7.5 Effect the steel fiber on splitting tensile strength

According to Yazıcı et al (2007), the splitting tensile strength was 4.1 for plain control concrete MPa, and for aspect ratio (l_s/d_s ratio) of 45,60 and 80,0 the minimum tensile strength was 4.50MPa, 4.51MPa, and 4.58MPa, respectively, While the obtained maximum splitting tensile strength was 5.69, 6.26, and 5.90 MPa,. As shown in Table 2.2, the results approve that the SFRCs tensile strengths were about 11%–54% more than the control specimen. Finally, the behavior of the fiber with the aspect ratio of 80 (l_s/d_s= 80) is not applicable because it was broken into two parts. In fact, The obtained results might be due to their larger cross sections for the fibers with aspect ratio 65 of the fiber volume fraction compared to that of fibers with l_s/d_s=*80* (Eren and Celik, 1997).

Table 2.2 Split tensile properties of concrete mixture (Yazıcı et al, 2007)

Mixture code	l_s/d_s ratio	V_f (%)	f_{st}(MPa)	**Relative** f_{st}(%)
CC	-	-	4.01	100
SFRC1	45	0.5	4.5	111
SFRC2	45	1.0	4.69	116
SFRC3	45	1.5	5.69	140
SFRC4	65	0.5	4.51	111
SFRC5	65	1.0	4.77	117
SFRC6	65	1.5	6.25	154
SFRC7	80	0.5	4.58	113
SFRC8	80	1.0	5.18	128
SFRC9	80	1.5	5.9	145

2.7.6 Effect the steel fiber on flexural strength

The flexural strength of concrete for beams with variable percentage of steel fibers (0.25%, 0.50%, 0.75% and 1%) is better than that of beams without steel fibers. This issue gives us a good indicator on the fact that the steel fibers effectively hold the micro cracks in the mass of concrete. The increasing in the flexural strength for the beams with variable percent of steel fibers which are compared with beam without steel fibers are +27.92%, +38.33%, +43.29%, and +34.19% respectively, (see Table 2.3). This results are due to recommend to use steel fibers 0.75% by volume of concrete to get the maximum improving for flexural strength in concrete that are from the RC beams (Mahadik et al, 2014).

Table 2.3 Effect the steel fiber on flexural (Mahadik et al, 2014).

Detail of beam	**Size of beam in (B×D×L)mm**	**Weight of beam in** kN	**Average flexural strength in** N/mm^2	**% change in flexural strength**
0% (Plain concrete)	150×150×700	39.800	25.94	-
0.25% steel fiber	150×150×700	39.850	33.26	27.92%
0.5% steel fiber	150×150×700	40.050	36.14	38.96%
0.75% steel fiber	150×150×700	42.250	37.22	43.29%
1.0% steel fiber	150×150×700	40.600	34.90	34.19

also, The flexural strength behavior of concrete going ahead on increasing with the increase in fiber content (see Figure 2.9). The optimum value of SFRC for flexural strength was found to be 0.75% (Mohod, 2012).

Figure 2.9 Variation of flexural strength with respect to % of fiber content (Mohod, 2012).

2.8 Bridging Action

Pullout resistance of steel fibers is very important in term of efficiency. Pullout strength of steel fibers significantly enhances the post-cracking tensile strength of concrete. When an SFRC is loaded, fibers bridge the cracks, in addition bridging action provides the SFRC with greater larger toughness, ultimate tensile strength, and better energy absorption.

By using SFRC, the addition of steel fibers will be bridging the cracks formed and pullout processes. That's refer to the deformation can only be continued with which are the further applied load. During the loading, this mean that the steel fibers added pond more than the concrete; hence, the composite system of SFRC will work as if it were not FRC till reaches the first crack and after appearing the first crack, the steel fiber will hold the concrete together to prevent further cracking growth (Brown et al, 2002).

When fibers are properly bonded during the hardened state, the interaction with the matrix at the level of micro-cracks accuse and effectively bridge these cracks by providing stress transfer and that delays their growth. In fact, for high volume fraction fiber composite, reported increases in the tensile/flexural strength over the plain matrix. The tensile capacity of the composite is reached, and the bridge will conversing of micro-cracks to macro-cracks, the length of fibers and bonding characteristics continue, may play an important role to restrain crack opening and crack growth by bridging across macro-cracks (Banthia, 2012).

2.9 Effect the Steel Fiber on Crack Pattern

According to the studied of the crack pattern in beams by Kwak et al (2002), the steel fibers in concrete are highly affecting the observed cracking patterns for beam with a/d = 2. As shown in Figure 2.10, three beams are identical for the addition of steel fibers in their concrete mixture.

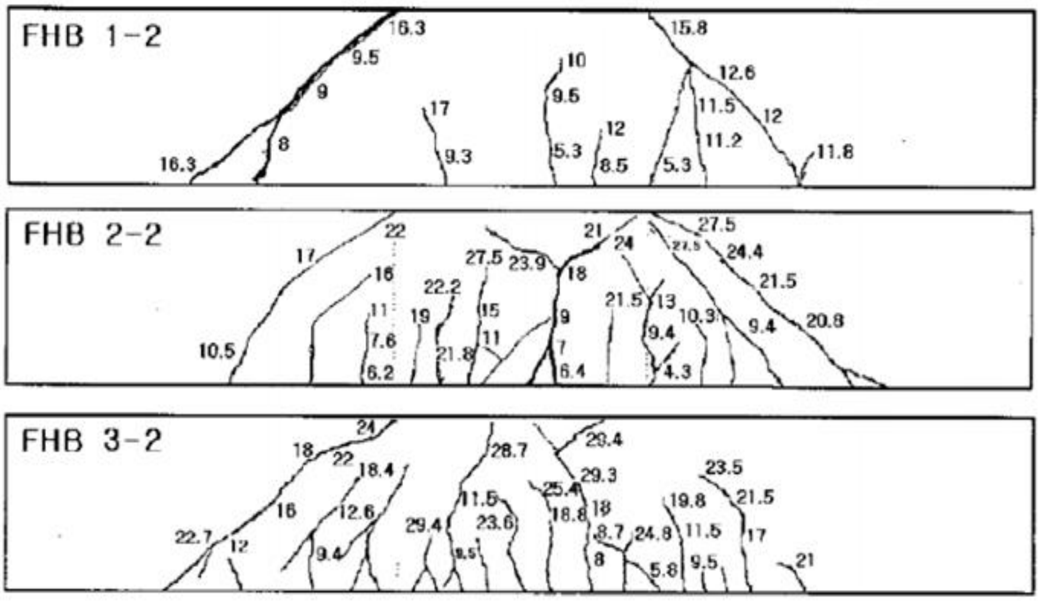


Figure 2.10 Typical crack patterns ($a/d = 2$) (Kwak, 2002)

The results in Table 2.4 refer to the load beside to the cracks. Beam (FHB 1-2), that had not included steel fibers in concrete mixture, the flexural cracks are formed firstly within the middle of the span. Then, two shear cracks show within the areas of constant shear. Therefore the beam failed along a single shear crack suddenly.

Moreover, when the V_f increased to 0.50% and 0.75 %for specimen FHB 2-2 and FHB 3-2, the failure mode is changed from shear failure to a collection of shear and flexure. Also both happens diagonal shear cracks and vertical flexural cracks (Kwak et al, 2002).

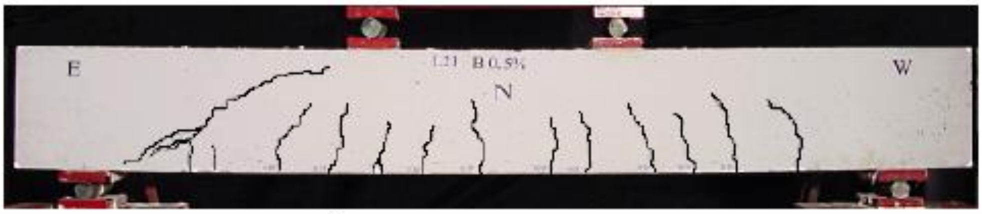
Table 2.4 Failure mode of concrete beam influence by V_f (Kwak et al, 2002)

Beam designation	Fiber volume fraction V_f (%)	Shear span/ depth ratio a/d	Concrete compressive strength f'_c(MPa)	Average shear stress		Ultimate displacement mm	Failure mode
				V_{cr} MPa	V_uMPa		
FHB1-2	0.00	2.0	62.6	1.67	3.02	6.08	Shear
FHB2-2	0.50	3.0	63.8	1.94	5.09	16.50	Shear-flexure
FHB3-2	0.75	4.0	68.6	2.22	5.44	34.35	Shear-flexure
FHB1-3	0.00	2.0	62.6	1.48	2.53	9.68	Shear-flexure
FHB2-3	0.50	3.0	63.8	1.67	3.09	18.20	Shear-flexure
FHB3-3	0.75	4.0	68.6	1.80	3.40	33.59	Shear-flexure
FHB1-4	0.00	2.0	62.6	1.26	1.98	13.86	Shear-flexure
FHB2-4	0.50	3.0	63.8	1.54	2.41	28.49	Shear-flexure
FHB3-4	0.75	4.0	68.6	1.57	2.74	43.87	Shear-flexure
FNB2-2	0.00	2.0	30.8	1.30	4.04	8.93	Shear
FNB2-3	0.50	3.0	30.8	1.11	2.55	10.18	Shear
FNB2-4	0.75	2.0	30.8	1.70	2.00	41.07	Shear-flexure

Also, according to study which were done by (Hassan, 2007), the addition of steel fibers to concrete mixture of beams enhance the ductility and crack control. Figure 2.11 shows a comparison of the crack patterns of the two tested specimens included variable dosages of hooked SF (0.5and 1.0%) in their concrete mixture with 0.0% steel fiber (specimen don't include steel fiber in concrete mixture).

0% fibres	- Large crack widths - Large spacing between cracks

0.5% fibres	- Reduced crack widths at equivalent load stages - Similar spacing between cracks



1% fibres	- Reduced crack widths at equivalent load stages - Development of flexural cracks in a steady and stable manner - Reduced spacing between cracks - "forking" cracking patterns

Figure 2.11 Comparison of cracking patterns at failure for the specimens (Hassan, 2007)

CHAPTER THREE

EXPERIMENTAL WORK

3.1 Introduction

The usage of steel and concrete members with hollow part sections have been widely increasing in the new construction of structural buildings and bridges, the advantages of hollow members are for extending the electrical cables and passing the mechanical runs or other utilities in addition to reduce the cost of construction materials and weight of member.

For hollow concrete members especially of smaller cross-sectional size, the longitudinal and shear rebar (stirrups) reinforcement to place it may be convenient in one layer only near the external face of the cross section and not tie the concrete through the wall thickness, This leads to a simpler arrangement of reinforcement, but the concrete near the inside face of the hollow section is unconfined and the behavior of the flexural failure may be brittle. Therefore, the subject of this study focuses on the issue of enhancing the ductility and the ultimate strength of hollow RC members could be increased through treating the deficiency by adding additive materials, among these materials, ideas for using the (steel fiber) with concrete mixture for increasing their flexural and shear capacity under loading.

The current study, the concrete mixture which are used with high fine aggregate content is used to construct twelve beams, some of these beams have a different steel fibers dosages.

The presence of high percentage of fine aggregates is participating in good distribution of stress. In addition to the binder surfaces' area is increased many times because of using the silica fume, moreover, enhancing the bond between the steel fibers and the coarse aggregate, and early strength, because of the high contact particles area. All previous improvements led to enhance the post-behavior of the beams .

3.2 General

The experimental work was carried out in the Mechanic Structure Lab of the Civil Engineering Department for Gaziantep University. The purpose of the experimental program and test are to study the structural behaviors of the hollow section beam with SFRC and investigate the deflection, cracks and also to the flexural element behavior under static loading conditions to determine the different limits at state behavior and mode of failure for RC hollow beams with and without included steel fiber in their concrete mixture.

Briefly, this section explains more than the outline of the research methods; it will explain what are the materials which are used and also give us a good idea about the test setup issue. In addition to, the experimental work can be properly referred to the way of theoretical analysis of the appropriate methods to the field of study.

In the current chapter, the ultimate load capacity and deformation of (SFRC) hollow beams section are investigated and compared with the solid beams which have same properties of the concrete mixture. In this study the beams which are tested were square beams section (width $b = 150$ mm, High $h = 150$ mm, and the length $L = 750$ mm) simply support under two points load.

Twelve concrete beams models were poured in this research including four solid beams and the others hollow beams were poured with a variable square open (80×80, 60×60 and 40×40 mm along the beam of 750 mm) with and without included steel fiber in their concrete mixture. The effect of opening size, the dosage of steel fiber and longitudinal steel reinforcing are investigated to evaluate the response of beams to cry the applied load. The experimental behavior based on load-deflection was measured at mid span of beam and tension zones.

Furthermore, in this chapter will refer to the materials used in this project as well as the test setup for the experiment work and the procedures involved.

3.3 Scope of Work

In order to study the structural behavior and ultimate load capacity of hollow beam section with SFRC under static load. A longitudinal opening is used to construct the hollow core beam which is a cast in site and a total of twelve specimens included two beams hollow and solid beam as controlling. All the beams were made from single mixture properties (Cement: Sand: Gravel) with a water/cement ratio 0.43 in order to obtain consistent workability, and also all beams were designed to have the same dimensions, also we can add, the holes of hollow beams section which are made by square steel pipes with variable dimensions (40×40, 60×60 and 80×80 mm) along the beam section. As per the ACI-11.6.1.2, the beam is consider as a thin- walled beam if the thickness (t) of the wall is equal or less than (x/10), the term of x means a shorter dimension of the beam. All dimensions of our specimens were 150×150×750 mm among the big hole specimens were cast with (35 mm thick wall) which 80×80 mm opening size that means thick wall section. Also, this chapter includes information regarding details of construction materials, casting, curing and test beams. Rather than, instrumentation, experimental setup and testing procedures are adopted throughout this investigation and presented as indicated in Figure 3.1.

Figure 3.1 Structural elements prior to their test and concrete cylinders

3.4 Considered Parameters

The total of twelve specimens included two beams hollow and solid beam as controlling as detailed in Table 3.1 are studied. In the present investigation, four group's parameters were chosen to study the behavior and flexural failure of hollow beams and to collect as many data as possible on the effect of steel fibers in concrete beams when applied the static load as detailed below:

Group one (hollow beams without steel fiber): Consists of three specimens, hollow section with opening (40×40, 60×60 and 80×80 mm), without steel fiber in their mixture and with constant longitudinal bars (2Ø8 mm top and bottom) and with stirrups of (Ø6mm @ 7.5cm c/c), for investigating the hollow part size effect.

Group two (Solid beams with steel fiber): Consists of three specimens were solid section (150×150×750 mm) includes variable steel fiber (0.5%, 1.0%, and 1.5%) volume of fraction and with constant longitudinal bars (2Ø8 mm top and bottom) with constant stirrups of (Ø6 mm @ 7.5cm c/c). for investigating the steel fiber effect

Group three (Hollow beams with steel fiber): Consists of three hollow specimens, with constant a hollow section (80×80 mm), includes variable steel fiber (0.5%, 1.0% and 1.5%) volume of fraction and with constant longitudinal bars (2Ø8 mm top and bottom) with constant stirrups of (Ø6 mm @ 7.5cm c/c) for investigating the steel fiber effect).

Group four (Hollow beams with steel fiber and variable flexural bars): Consists of three hollow specimens, with constant opening (80×80×750 mm), includes constant steel fiber (1.0%) volume of fraction and with variable longitudinal bars (constant 2 Ø8 mm top and 2Ø8, 3Ø8 and 4Ø8 bottom) with constant stirrups of (Ø6 mm @ 7.5cm c/c) for investigating the effect of steel bars on tension failure.

Table 3.1 The parameters of groups.

Parameter groups	Beam code	Section properties	Opening ratio %	Bottom rebar mm	Top rebar mm	Stirrups reinforcing mm	Steel fiber ratio %
Group One	H40-0-2	Hollow	7.10	2Ø8	2Ø8	Ø6@75	0.00
	H60-0-2	Hollow	16.00	2Ø8	2Ø8	Ø6@75	0.00
	H80-0-2	Hollow	28.40	2Ø8	2Ø8	Ø6@75	0.00
Group Two	S-0.5-2	Solid	_	2Ø8	2Ø8	Ø6@75	0.50
	S-1-2	Solid	_	2Ø8	2Ø8	Ø6@75	1.00
	S-1.5-2	Solid	_	2Ø8	2Ø8	Ø6@75	1.50
Group Three	H80-0.5-2	Hollow	28.40	2Ø8	2Ø8	Ø6@75	0.50
	H80-1-2	Hollow	28.40	2Ø8	2Ø8	Ø6@75	1.00
	H80-1.5-2	Hollow	28.40	2Ø8	2Ø8	Ø6@75	1.50
Group Four	H80-1-2	Hollow	28.40	2Ø8	2Ø8	Ø6@75	1.00
	H80-1-3	Hollow	28.40	3Ø8	2Ø8	Ø6@75	1.00
	H80-1-4	Hollow	28.40	4Ø8	2Ø8	Ø6@75	1.00
Control specimen	S-0-2	Solid	-	2Ø8	2Ø8	Ø6@75	0.00
	H80-0-2	Hollow	28.40	2Ø8	2Ø8	Ø6@75	0.00

And Table 3.1 shows the detail of the specimens classified according to the following symbols:

Hx-y-2 = H: Refer to Hollow Beam section & x: refer to hole size which (40×40, 60×60 and 80×80×750 mm), y: refer to steel fiber dosage which (0.5,1.0 and 1.5 %), number 2 refer to longitudinal bars (2Ø8 mm in bottom). Finally, the symbols S: refer to the solid beam.

3.5 Material

The materials used in manufacturing the test specimens are:

Cement: Ordinary Portland cement (type TS EN 197-1) produced in Turkey was used in this study. It was stored in a dry place to avoid exposure to different atmospheric conditions.

Sand: Natural graded river sand of 4.75 mm maximum size was used as fine aggregates, the sieve analysis for the used sand is shown in Table 3.2 and Figure 3.2.

Gravel: Crushed stone with maximum size of 9.5 mm was used. As seen in Table 3.3, the aggregate size between particles of 4.75 and 9.5 mm,

Reinforcing bars: Deformed steel bars were used in this study with a nominal diameter of 8.0 mm as longitudinal reinforcing bars and 6.0 mm as stirrups for shear purpose

Water: Tap water was used for casting and curing all the specimens.

Square steel pipes: Square steel pipes were used with dimensions of (80×80, 60×60 and 40×40) mm × 850 mm to form the hollow core of the concrete beams.

Silica fume: Micro Silica fume has SiO_2 content of at least 90% with a mean particle size of less than 0.1 micron.

Super plasticizer: Super plasticizers, also named high range water reducers, type Glenium 51 was used. The used super plasticizer conforms to the requirements of ASTM C494 Types A.

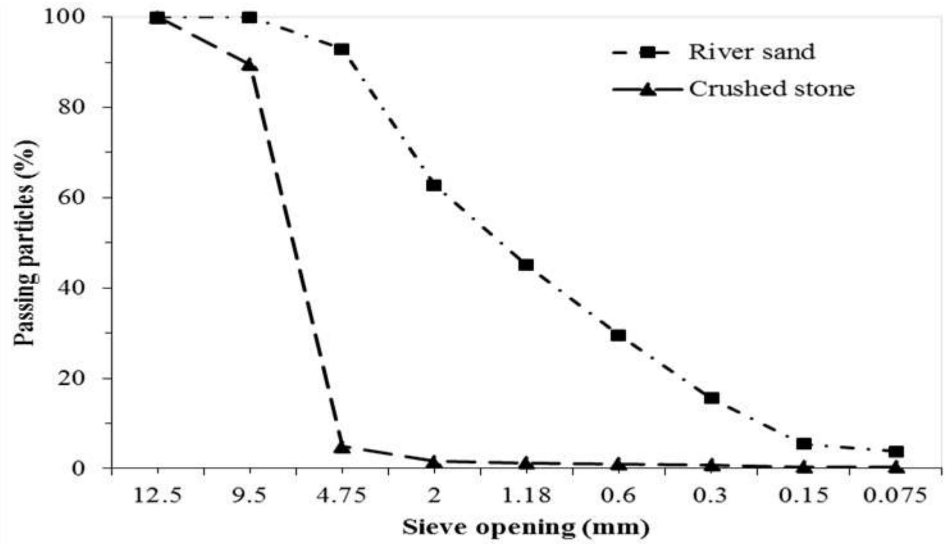


Figure 3.2 Sieve analysis.

Table 3.2 Grading of fine aggregate (river sand).

Sieve opening (mm)	**Retained weight** (g)	**Passing** (%)
12.5	0	100
9.5	0	100
4.75	104.7	93
2	554	63
1.18	816.5	45
0.6	1048.7	29
0.3	1255.4	16
0.15	1407.4	5
0.075	1431	4

Table 3.3 Grading of coarse aggregate (crashed stone).

Sieve opening (mm)	**Retained weight** (g)	**Passing** %
12.5	0	100
9.5	186.6	89
4.75	1690.8	5
2	1749.7	2
1.18	1754.9	1
0.6	1758.5	1
0.3	1763.8	1
0.15	1770	0
0.075	1770	0

3.5.1 Additional materials

The used steel fibers were 3D (hooked end) type with length of 30 mm and diameter of 0.55 mm (aspect ratio = 55) and were manufactured by Kemerix. The used fibers have yield strength of 512 MPa, ultimate tensile strength of 1500 MPa, modulus of elasticity 210 GPa, and density of 7850 kg/m^3, as shown in Figure 3.3. The steel fibers are made from normal low carbon bright steel. The applied water soluble glue that collates the steel fibers will not affect the performance of the SFRC cast as the steel fibers will be evenly distributed and dispersed during the mixing process.

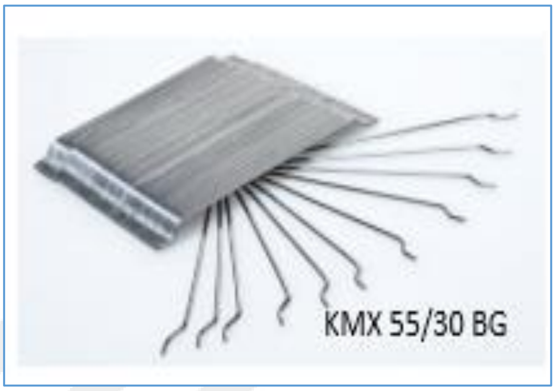


Figure 3.3 Steel fibers.

3.6 Concrete Mix

Table 3.4 includes the details of the concrete mix that was used in this work. Three cylinders (100×200 mm) for each beam were cast to evaluate the compressive and the splitting tensile strengths of concrete. All specimens were kept under water and lab conditions for 28 days and were tested at the same day.

Table 3.4 Concrete mix properties per one cubic meter.

Gravel kg	**Sand** kg	**Cement** kg	**Silica fume** kg	**Water** kg	**Water reducer** kg	**Steel fiber ratio** %	**W/(C+Sf) ratio** %
680	1170	465	35	216	6.6	0.5-1.5	43

3.6.1 Steel fibers and concrete mixing

Generally, the steel fiber was added with the variable volume fraction of (0.5, 1.0 and 1.5) and tried to avoid collated steel fibers tend to have a balling effect and ensure that no balling will occur to avoid over mixing because the ACI Committee 544 (1993) recommends that.

No balling was occurred for the used fibers during the mixing process. This is because the used steel fibers are glued into bundles in strips of about 30 to 50 steel fibers, making the dosing and mixing process easy and reliable. The water soluble glue would guarantee that the steel fibers are uniformly dispersed and distributed during the mixing. The water soluble glue that used to collate the steel fibers would be softened by the mixing water. Hence, it is very important that the fibers are added at the right timing in the mixing sequence. The most important thing to remember is not to add the fibers before the aggregates during the mixing process. The fibers should be added while the mixing machine is rotating at full mixing speed.

3.7 Formwork

For solid section beams, the formwork which is used in this study is15 mm thickness waterproof plywood is used as the mold formwork for the beams specimens, the dimensions of the formworks needed are (150×150×850) mm.

For hollow section beam, the formwork for the construction of the hollow section consists of two parts: an internal core and an open external box. The internal core was made up for square steel pipes (with variable dimensions (40×40, 60×60 and 80×80 mm) hollow sections, and these pipes are covered by Nylon layers that have papules.

This type of Nylon will be so easy for removing pipes during the removing the formwork. The external box was made for 15 mm thick waterproof plywood with internal clear dimensions of 150×150×850 mm, see Figure 3.4. The initial preparation for construction of the specimen consisted of assembling the internal core, erecting the longitudinal and traversing the reinforcing bars around the internal core and encasing the internal core with the steel cage inside the external box. For the purposes of casting the solid beams, the internal core was canceled.

Figure 3.4 Formwork

3.8 Structural Tests

3.8.1 Fabrication of test specimens

The structural tests were used to investigate the behavior of SFRC hollow beam. In addition to investigations of cracking, deflection and strain levels were intended to be recorded for the different types of hollow beam specimen's behavior which is necessary to ensure a good coverage of flexural elements. Although more, SFRC were used as additional flexural reinforcement, while steel rebar was used for the main flexural reinforcement see Figure 3.5

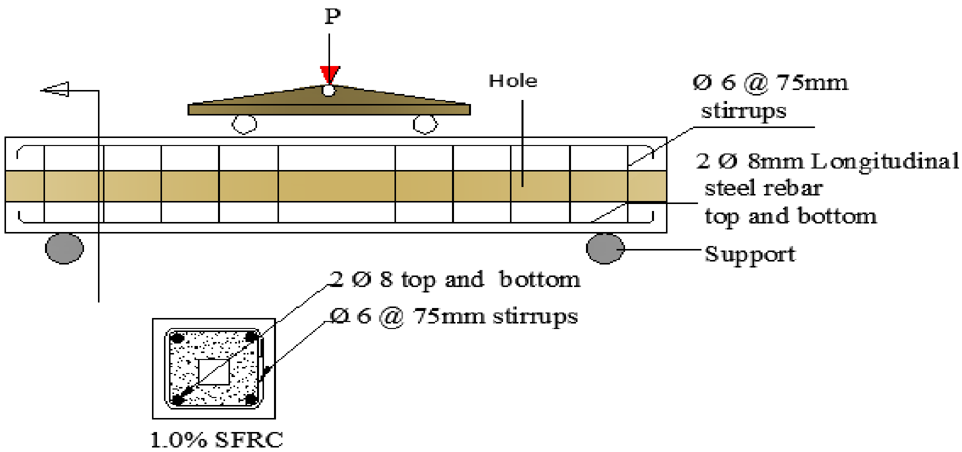


Figure 3.5 The structural test for specimens.

The beams were tested under two-point static loading. The span between the supports was 750 mm. The shear span was 250 mm, and the distance between loads being 250 mm, also a constant two of 8 mm steel rebar's was used as top and bottom reinforcement within the shear span to hold the stirrups. All the hollow beams clear concrete cover to the main flexural rebar at the bottom was set as 15 mm, to avoid splitting bond failure. Also, the designed hollow beam sections group were under-reinforced, near balanced or over-reinforced, with failure expected to occur either by rupture of rebar or crushing of concrete. The specimens of solid beam section (control beam) was designed to have an approximately equal flexural capacity to their hollow section group; therefore, they have calculated load carrying capacity similar to that of hollow sections group. Finally, more specifically, 3ø8 and 4ø8 mm steel rebar were used for hollow sections as tension reinforcement.

3.8.2 Beams geometry

All beams with a dimensions of (150×150) mm section were used in this work, two beams were considered as control specimens, one was solid and the second was hollow with (80×80) mm opening to study and evaluate the effect of a steel fiber on the behavior and capacity of a hollow beam which subjected to two point loads. The total twelve reinforced beams were poured and tested, the beams had a clear span (750) mm, depth (150) mm, and width (150) mm and all beams are reinforced constant longitudinal bars (2Ø8 mm top and bottom with yield strength 503 MPa) with constant stirrups of (Ø6.3 mm @ 7.5cm c/c with yield strength 400 MPa), included one group is constructed in a different way, which construct by increase the bottom longitudinal rebar (3Ø8 mm and 4Ø8 mm) as detailed in Table 3.1 (group four). Figure 3.6 shows the dimensions and geometry of the beams, and Figure 3.7 shows the steel fiber content dosages.

In order to construct the hollow in the beams, 40×40, 60×60 and 80×80 mm iron section is used, fixed inside the two smaller side plywood shutters, so that the percentages of volume were removed from the solid beam is 7%, 16% and 28 % respectively. The main problem that the authors concerned with is that when removing the inner steel section without applying undesirable stresses during the first hours of the concrete hardening, the problem is aggravated due to concrete shrinkage and/or consolidating. The iron section was covered by a bubbled plastic sheet of 4 mm bubble height, moreover, the contact area between iron sections and the plastic sheet and area between the sheet and the poured concrete were lubricated.

The mechanical properties of three volume fraction of hooked ends SF are 0.5, 1.0, and 1.5 %, were the length of the fiber of is 30 mm and diameter D_f is 0.55 mm, also the l_f / D_f is equal to 55, hence the ultimate tensile strength is 512 MPa, the density about 7850 kg/m^3, modulus of elasticity 210 GPa, yield strength f_y of 500 MPa are used by.

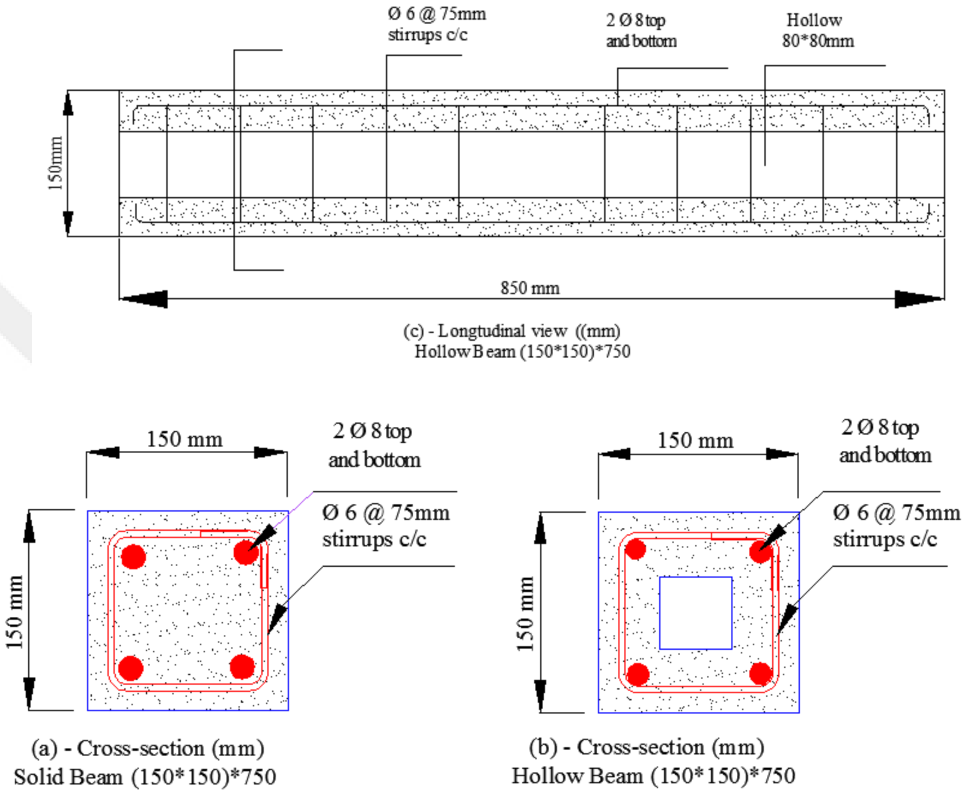


Figure 3.6 Reinforced concrete beam with solid and hollow section.

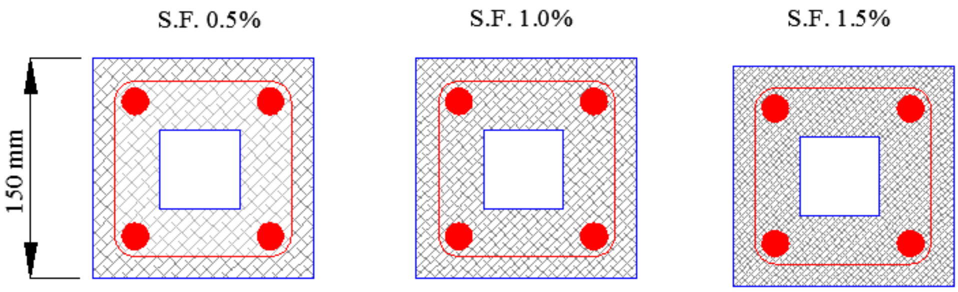


Figure 3.7 Steel fiber content (Vf %).

3.9 Objective of the Research

The aims of this project are outlined to investigate the flexural behavior of SFRC hollow beam which is subjected to Variable percentage of hollows; in this stage variable size of hollow will be used in order to determine the ideal size; the judgment will be under serviceability limit state and different volume fraction fiber in order to provide safe, efficient and economical beam design.

In addition, in the proposed research, variable parameters will be investigated, among these parameters, the steel volume fraction, percentage of hollow area to the total cross-sectional area, and the strength of concrete. The judgment will be considered the ideal percentage of steel fiber used, and based a flexural test of beams model and molds under standards codes provisions (cylinders and prisms).

3.10 Experimental Parameters

The Hollow section beam with Steel fiber reinforcement concrete (SFRC) is used to investigate the effects on the mode of failure, ultimate failure load, cracking tension stiffening, and deflections compared with the solid section.

3.10.1 Mixing procedure

The following mixing procedure was applied for this project:

1. The coarse and fine aggregates were first added to the drum mixer for 5 minutes.
2. After the coarse and fine aggregates were thoroughly mixed, the quantity of silica fume was adding and mixed in the dry state with the cement. This operation was continued five minutes to ensure that silica fume powder was thoroughly dispersed between particles.
3. The mixing water was added slowly to the drum mixer, all ingredients were mixed together in the mixer for another two minutes before the fiber was added, and the water-reducing (super plasticizer) were added. The whole mixture was mixed for two more minutes. The total mixing time was twelve minutes.
4. Finally, fibers were uniformly distributed and added into the mix in slow way for 5 minutes during mixing process (ACI committee 544,1993) recommend

that fibers should be added to the concrete mix as the final ingredient after all other mixing has completed, the mixing of one batch requires approximately seventeen see Figure 3.8.

Figure 3.8 The concrete mixture.

External vibration is recommended for SFRC to prevent damage to the fibers. In this study, a variable frequency-vibrating table was used to consolidate the specimens. And it was externally vibrated.

3.10.2 Curing process

After 24 hours are past the mold was removed and the samples were taken in to the curing water tank with a heater to start the curing process with a temperature by about 23 °C and it remains there for 28 days. As shown in Figure 3.9

Figure 3.9 Curing of specimen.

3.10.3 Compressive strength

The compressive strength test for the used mixtures was accordance with (ASTM C39,1997) cylindrical specimen (D = 100 and H = 200) mm. The test was carried out at 28-days. Three specimens were used and each concrete type (normal and SFRC) the average value was calculated from the test results. The specimens were cured in a water bath until they were tested. A compression machine was used for loading the specimens and all specimen prepared before the test which were made by capping and were used to get leveling for surfaces and to ensure uniform load distribution. The loading rate on the compression machine was (1.5 kN/m^2) and kept constant. The specimen was loaded until failure and recorded the ultimate load. Figure 3.10 the compression strength test setup.

Figure 3.10 The compression strength test setup.

3.10.4 Splitting tensile strength

The splitting tensile strength test was carried out on (D=100 and H=200) mm cylindrical specimens according to ASTM C 496-02(2004), these tests were made on three cylinders' specimen cast with every mix used for casting the beams, see Figure (3.11). The splitting tensile strength was calculated by using the following formula:

$$f_{sp} = \frac{2P}{\pi D_c l} \qquad \text{Equation (3.1)}$$

where:

f_{sp}: splitting tensile strength (MPa)

P: applied load in (N)

D_c: Diameter of cylinder (mm)

l: length of cylinder (mm)

Figure 3.11 Splitting tensile test.

3.10.5 Slump test

The slump test for the concrete mixture is used to determine the consistency of fresh concrete, it is used to give us a good indicated about the activity of concrete mixture by measure the workability of concrete. The results of slump test for this work were as detailed in Table 3.5, which shows that the effect of adding the steel fiber on workability, the relation between the workability and percentage of steel fiber is inverse.

Table 3.5 Slump test results.

Specimen	**Slump test result** (mm)
N (normal concrete)	95
S0.5 (steel fiber 0.5%)	78
S1.0 (steel fiber 1.0%)	65
S1.5 (steel fiber 1.5%)	54

3.11 Test Setup and Instrumentation

All beam specimens were tested under a static two-point load to study their flexural behavior and to compare the experimental results between the hollow and control solid beams. A universal testing machine (BESMAK) with a capacity of 250kN, is a closed loop servo hydraulic testing system computerize controlled, the experiments were executed in load control with manually data monitoring. The rate of the load was slowly about 0.4 kN/Second to register the evolution of cracks, strains and the deflections the beam. Also, an optical micrometer to measure crack widths, the crack pattern was remarked and drawn on the front face of the beam to make easy the position and identification the growth of cracks during and after the test. The crack pattern was studied and additional photographs were taken, also used a dial gauge having a travel of 50 mm to record the vertical deflection at the edge The mid-span deflections were obtained by using two high precision Linear Variable Displacement Transducer (LVDT) that were placed on the bottom near of the mid-span of the beam each side of the specimen. A rectangular steel plate fastened to the specimen was also used to hold the LVDT in place. The behavior of the beams was watched carefully from beginning the failure. All specimens were placed on the testing machine by aligning the marked support and loading locations. The loading was applied at a constant rate. The location of the damage on the tension surface of the specimen was also checked to see it was limited to the middle third of the test specimens, also was recorded the appearance of the first crack, the development and the propagation of cracks during the increase of load. After the initial cracking, the loading was continued and was stopped when the beam was just on the collapse stage.

Finally, the beam was removed from the testing instrument and the concrete surface was checked at different locations, Figure (3.12) shows the setup and test instrumentation. All tests were made in the Laboratory of Mechanic of Structures in Gaziantep University, College of Engineering, Gaziantep, Turkey.

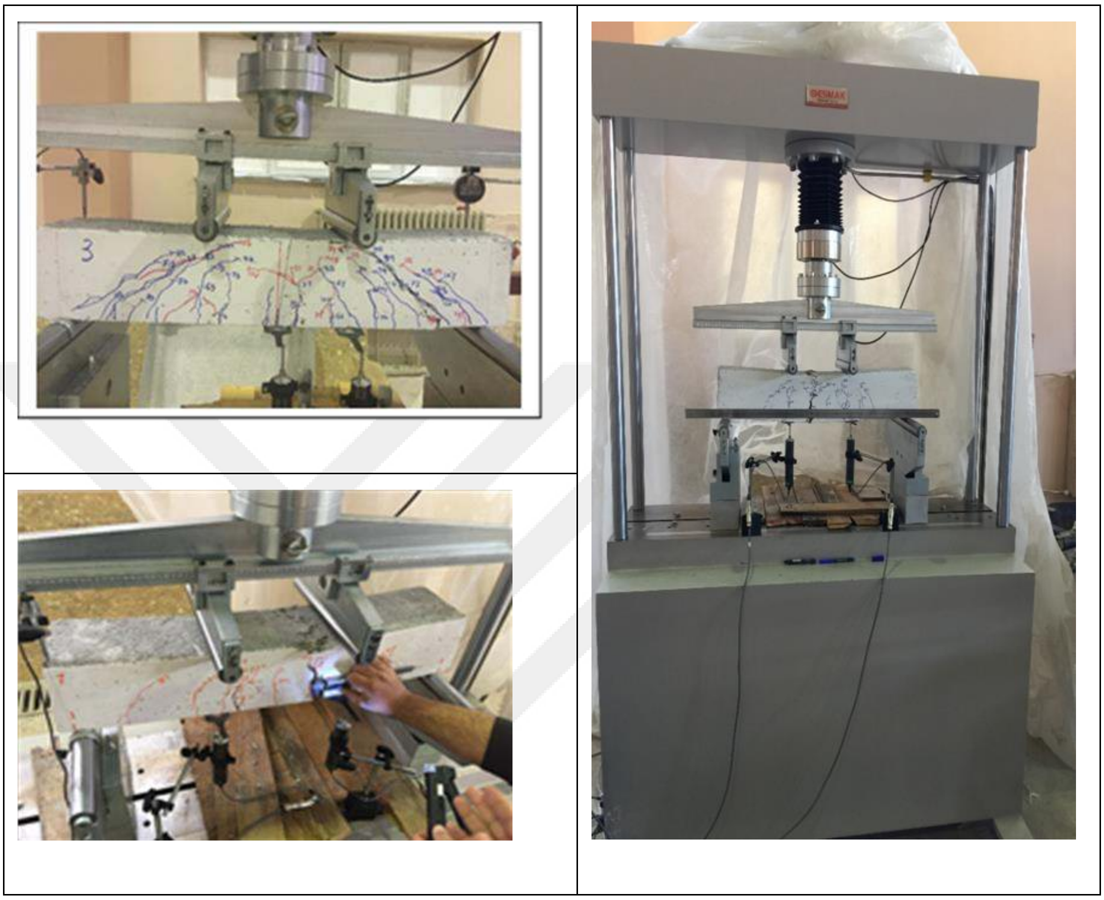


Figure 3.12 The flexure test setup and instrument.

3.11.1 Crack width

An optical micrometer was used to measure crack widths, for all beam specimens. And for clear visibility, all beams surfaces were painted with white color to make it easy to see the small crack and measure the width; see Figure 3.13.

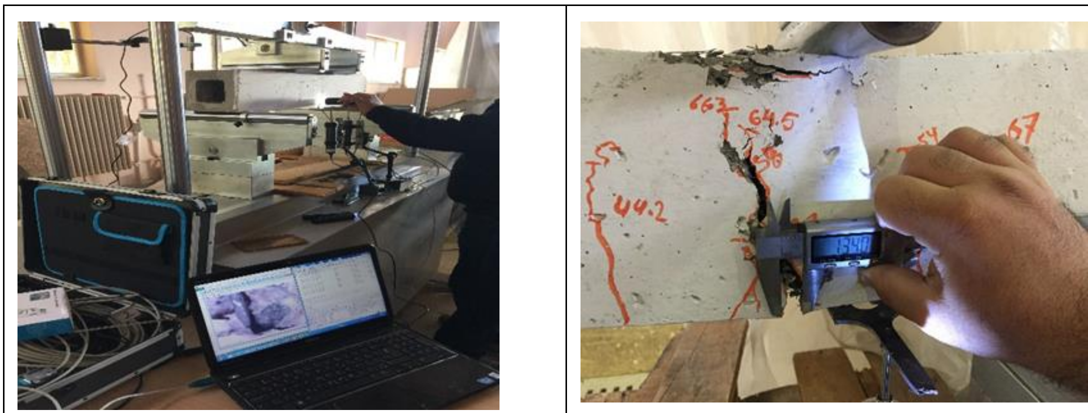


Figure 3.13 The measurement of crack width**.**

CHAPTER FOUR

EXPREMANTAL RESULTS AND DISCUSSION

4.1 General

The main objective of this research is to examine the material properties and structural behavior of SFRC hollow beams. In this chapter, the results of experimental work are discussed. The results are summarized and discussed in many titles, which is load deformation behavior, material properties, effect of steel fiber dosage on the ultimate beam strength and effect of steel fiber dosage on beam tensile strength. In addition, the deflections at the mid-span of the beam and the cracks width were examined and recorded during the failure stages.

The experimental work was classified into four groups (group one, group two, group three and group four) each group included three beams and all groups are compared with control beam which was solid and without steel fiber. The four groups are detailed in Table 4.1.

4.2 Results of Control Test Specimens

Two control tests were adopted in this research to evaluate the compressive and tensile strengths of concrete. The compressive strength (f'_c) was evaluated by using standard 100 mm diameter cylinders based on ASTM C39(ASTM C39,1997). On the other hand, the splitting tensile strength (f_{sp}) was carried out on similar cylinders based on ASTM C496 (ASTM C496, 2004) to evaluate the tensile strength.

Table 4.1 The results of compressive and tensile tests for concrete cylinders.

Group	Specification code	f'_c (MPa)	f_{sp} (MPa)	Steel fiber ratio
One	H40-0-2	68.92	4.26	0.00%
	H60-0-2	64.3	4.81	0.00%
	H80-0-2	67.7	4.48	0.00%
Two	S-0.5-2	73.48	5.13	0.50%
	S-1-2	79.55	5.88	1.00%
	S-1.5-2	74.39	5.22	1.50%
Three	H80-0.5-2	74.56	5.5	0.50%
	H80-1-2	78.30	6.10	1.00%
	H80-1.5-2	69.82	5.52	1.50%
Four	H80-1-2	78.30	6.10	1.00%
	H80-1-3	79.55	6.32	1.00%
	H80-1-4	78.10	6.40	1.00%
Control	S-0-2	68.92	4.20	0.00%
	H80-0-2	64.3	4.48	0.00%

4.2.1 Compressive strength

The experimental results of compressive cylinders showed that the addition of SF to concrete mixture slightly enhanced the compressive strength of concrete (f 'c) as showed in Table 4.1.

For Group two, the use of steel fiber with volume fractions of 0.5, 1.0 and 1.5% enhance the compressive strength by approximately 6.6, 15.4, and 7.9%, respectively. However, using 1.0 % of steel fiber gave a good enhancement in compressive strength, the values and (%) enhancing in compressive strength shown in Figure 4.1and 4.2 respectively.

For Group three, the use of steel fiber with volume fractions of 0.5, 1.0 and 1.5% enhance the compressive strength by approximately 8.2, 13.6, and 10.3%, respectively. This means that the best results in this group were obtained when 1.0% steel fiber was used, the values and (%) enhancing in compressive strength shown in Figure 4.3and 4.4 respectively.

For Group four, the use of steel fiber with volume fractions of 1.0% significantly improved the compressive strength (f 'c) for the tested cylinder by approximately 12.6, 15.4 and 13.3. The average value in this group was obtained is 13.8%, the values and % enhancing in compressive strength shown in Figure 4.5 and 4.6 respectively.

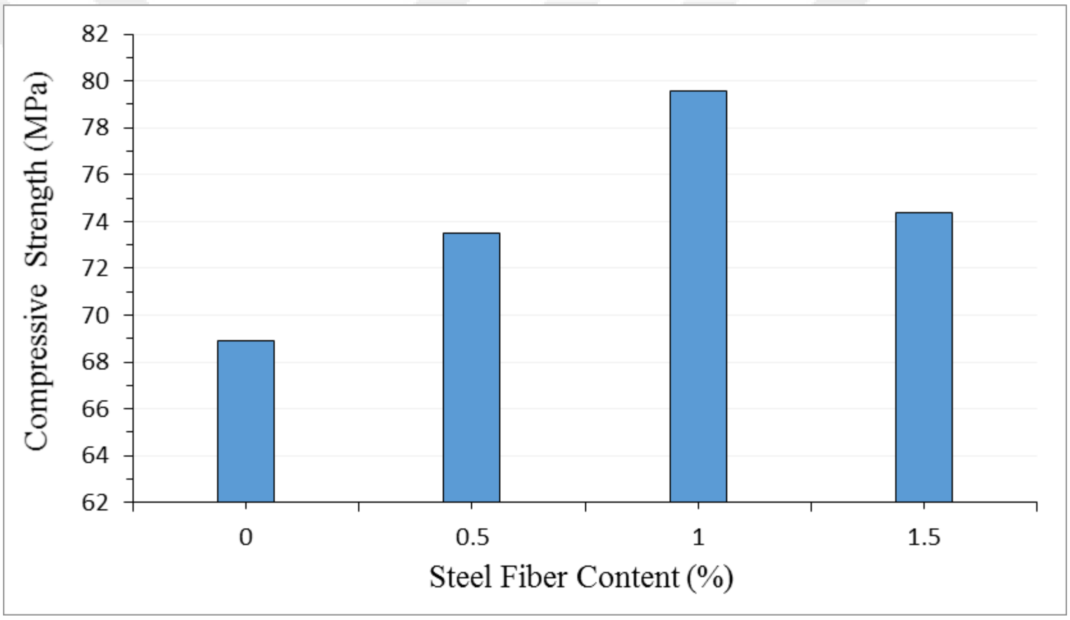


Figure 4.1 The effect of steel fiber content on compressive strength (Group Two).

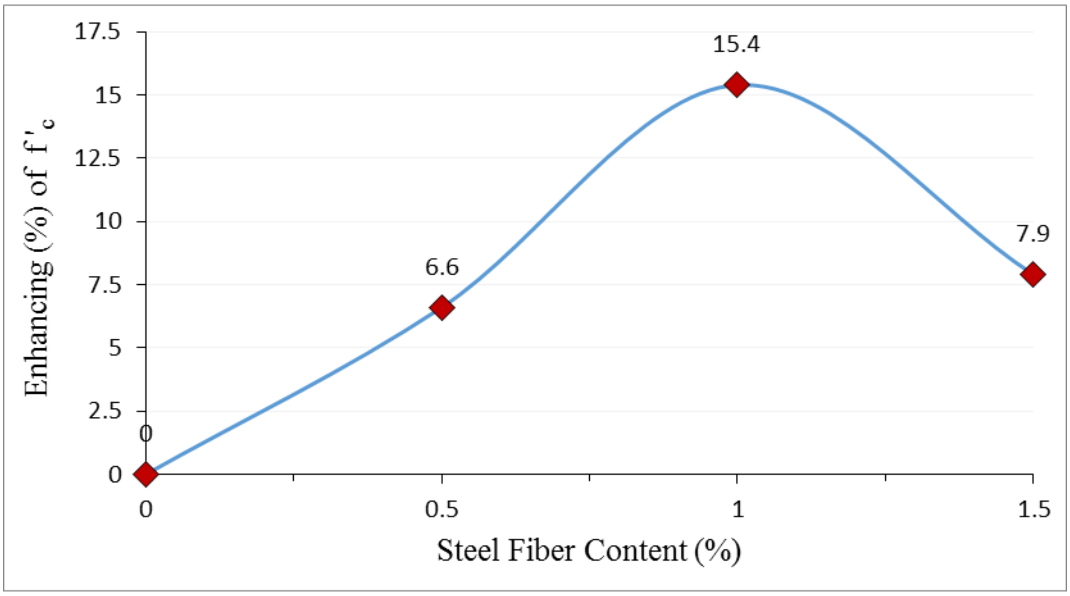


Figure 4.2 Enhance (%) of the compressive strength (Group Two).

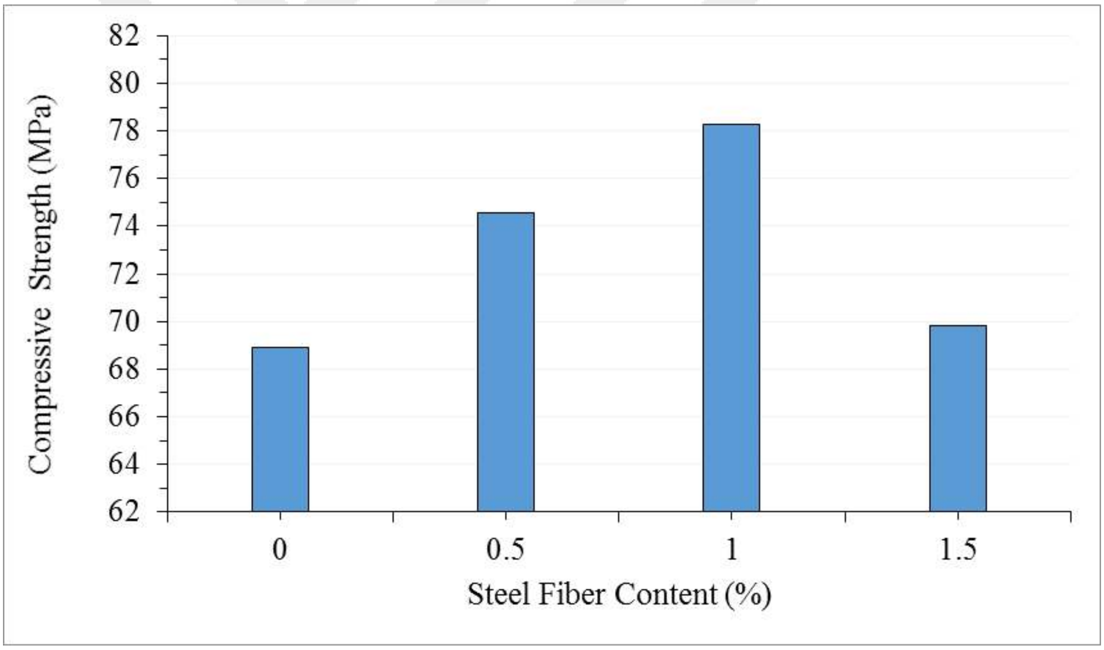


Figure 4.3 The effect of steel fiber content on compressive strength (Group Three).

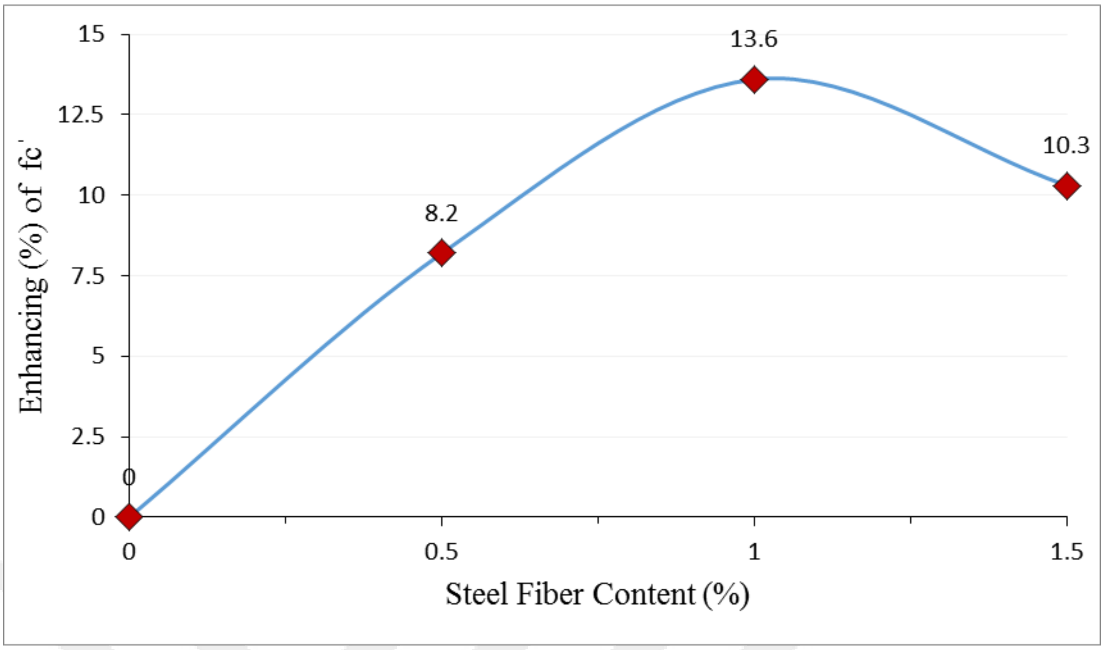


Figure 4.4 Enhance (%) of the compressive strength (Group Three).

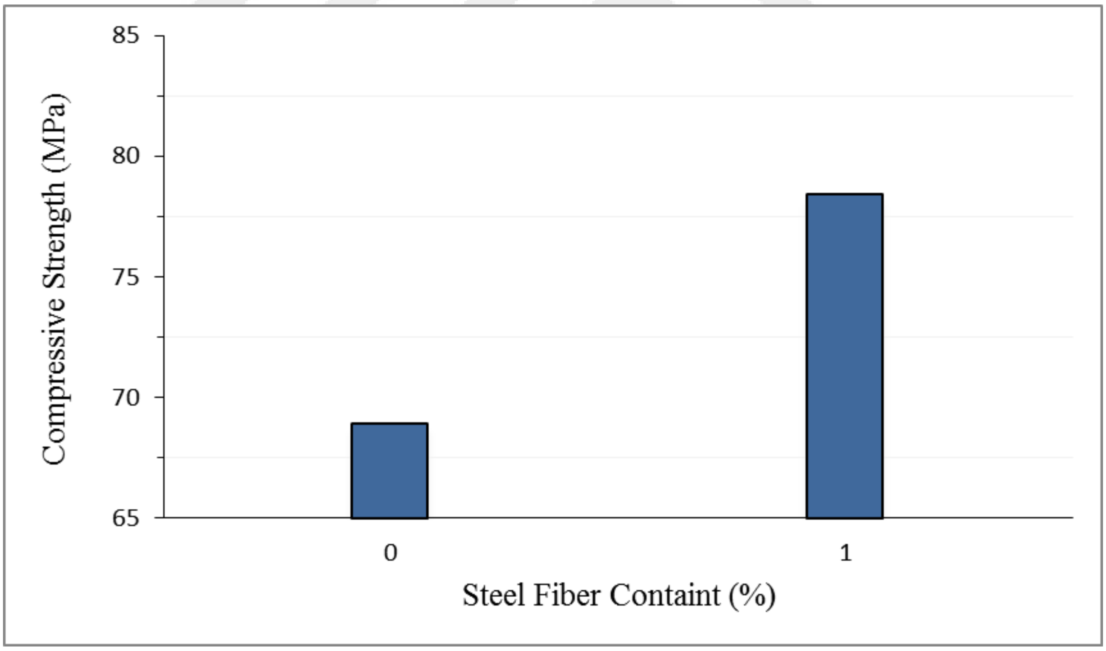


Figure 4.5 The effect of steel fiber content on compressive strength (Group Four).

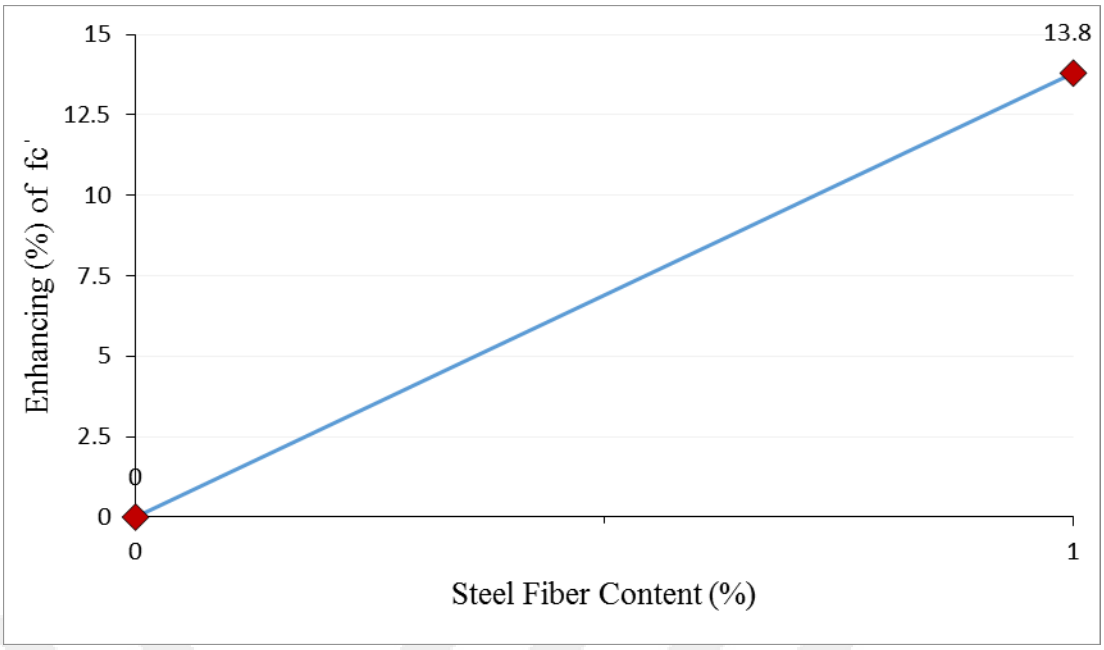


Figure 4.6 Enhance (%) of the compressive strength (Group Four).

4.2.2 Splitting tensile strength

As it is shown in Table 4.1, only the second and third groups consist of specimens which having different fiber contents. Therefore, the purpose of comparison purposed of the fiber addition effect, only the results of the second and third groups are considered.

For Group two, the use of steel fiber with volume fractions of 0.5, 1.0 and 1.5% enhance the splitting tensile strength by approximately 22, 40, and 24%, respectively. However, using 1.0 % of steel fiber increases the splitting tensile strength significantly, the values and % enhancing in splitting tensile strength shown in Figure 4.7 and 4.8 respectively.

For Group three, the use of steel fiber with volume fractions of 0.5, 1.0 and 1.5% enhance the splitting tensile strength by approximately 31, 45 and 32%, respectively. This means that the best results in this group were obtained when 1.0% steel fiber was used, the values and % enhancing in splitting tensile strength shown in Figure 4.9 and 4.10 respectively.

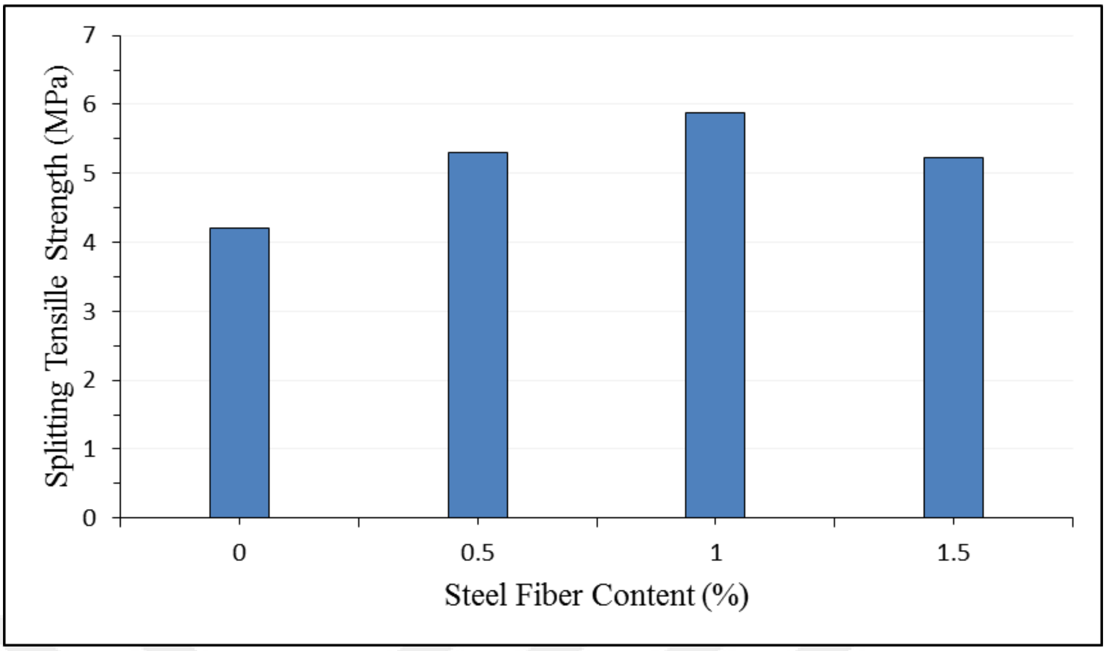


Figure 4.7 The effect of steel fiber content on compressive strength (Group Two).

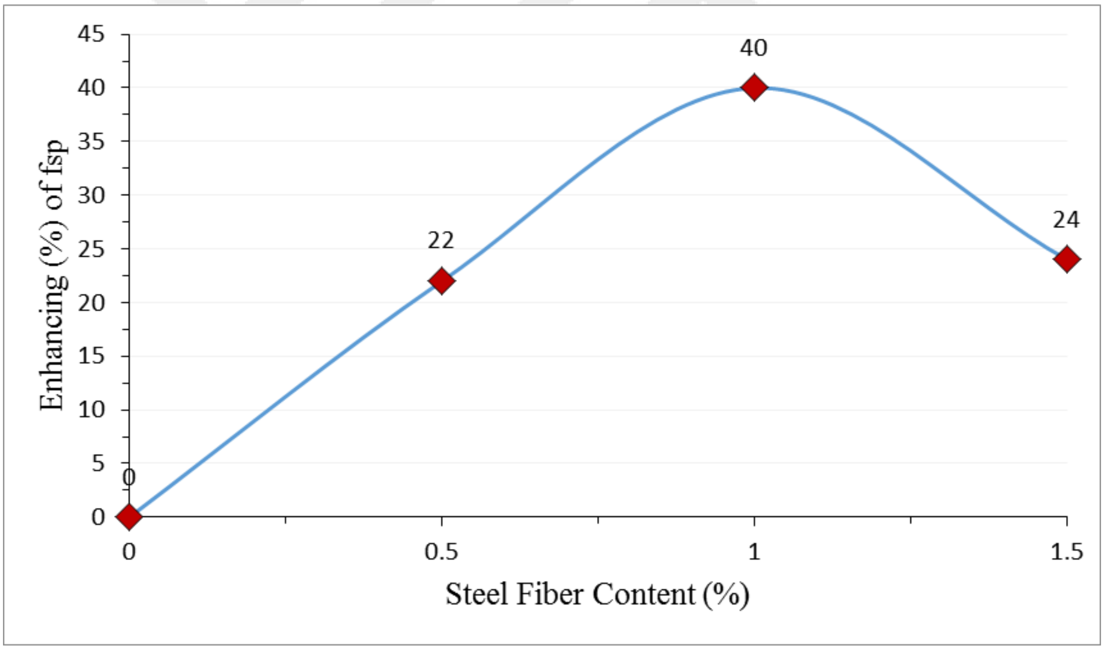


Figure 4.8 Enhance (%) of the splitting tensile strength (Group Two).

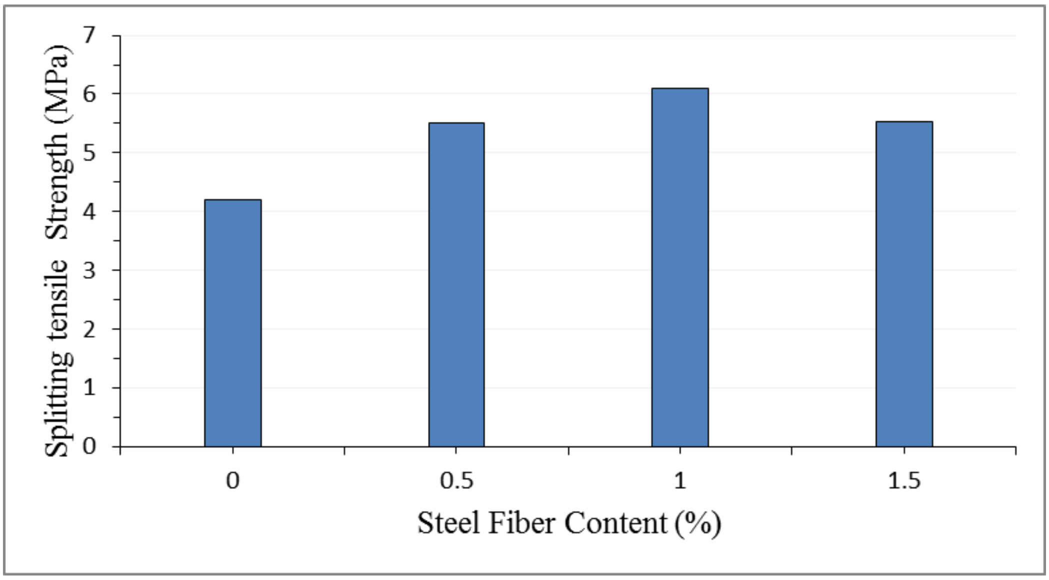


Figure 4.9 The effect of steel fiber content on splitting tensile strength (Group Three).

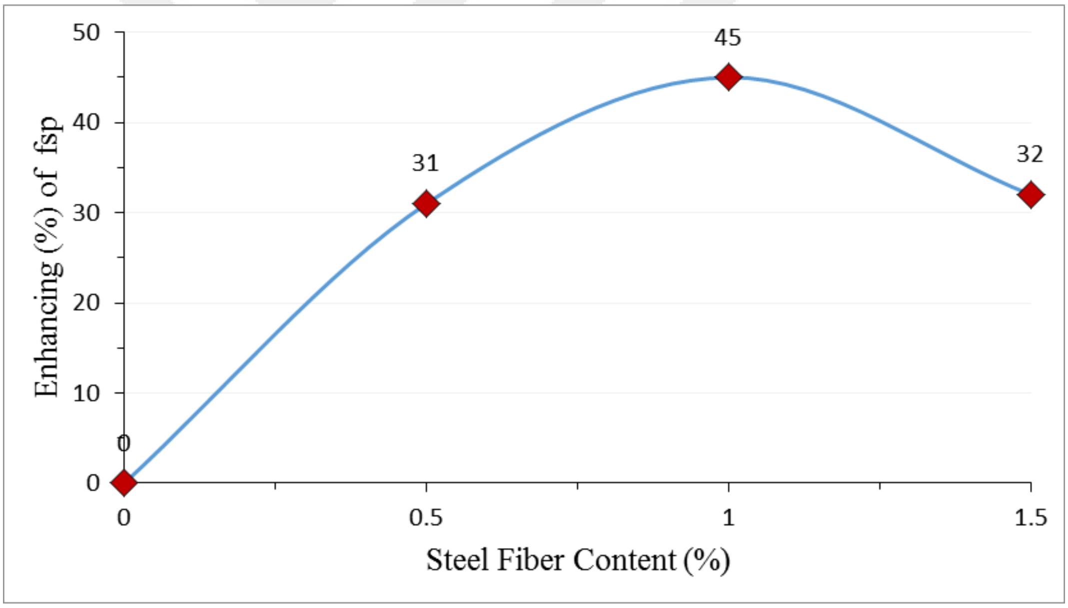


Figure 4.10 Enhance (%) of the splitting tensile strength (Group Three).

4.3 Crack Pattern and Failure of the Beams

Generally, the RC beam flexural behavior is governed by the properties and amount of longitudinal reinforcement. According to the provided reinforcement ratio, the beams can be classified into three grades. In the first, only two 8 mm diameter bars were used as tension reinforcement. This case is the most general one as listed in

Table 4.1. On the other hand, the specimens of group four were reinforced with 2, 3 and 4 tension bars having the same nominal diameter of 8 mm.

In the current work, as it was designed, all beams failed in flexure. Cracking started at the flexural zone between supports, which was then accompanied with the yielding of steel bars as the load increased. In most cases, the failure of the specimens was similar to above discussed case where one main flexural crack was obvious with few smaller cracks. In general, the first visible flexural cracks were noticed at 17 to 51% of the failure load as listed in Table 4.2 and shown in Figure 4.11. The mode of failure was less affected by the steel fiber content than by the longitudinal steel ration.

Table 4.2 Ultimate load capacities and first crack load.

Group	**Specification code**	**Cracking load P_{cr} (kN)**	**Ultimate load P_u (kN)**	**P_{cr}/P_u %**
One	H40-0-2	22.96	70.41	0.33
	H60-0-2	20.54	62.17	0.33
	H80-0-2	22.58	51.67	0.44
Two	S-0.5-2	28.19	79.14	0.41
	S-1-2	19.22	81.73	0.27
	S-1.5-2	23.22	78.32	0.34
Three	H80-0.5-2	22.29	59.13	0.38
	H80-1-2	21.03	69.23	0.30
	H80-1.5-2	25.22	73.73	0.34
Four	H80-1-2	21.03	69.23	0.30
	H80-1-3	26.02	105.54	0.25
	H80-1-4	29.02	117.67	0.25
Control	S-0-2	11.79	69.40	0.17
	H80-0-2	22.58	51.67	0.44

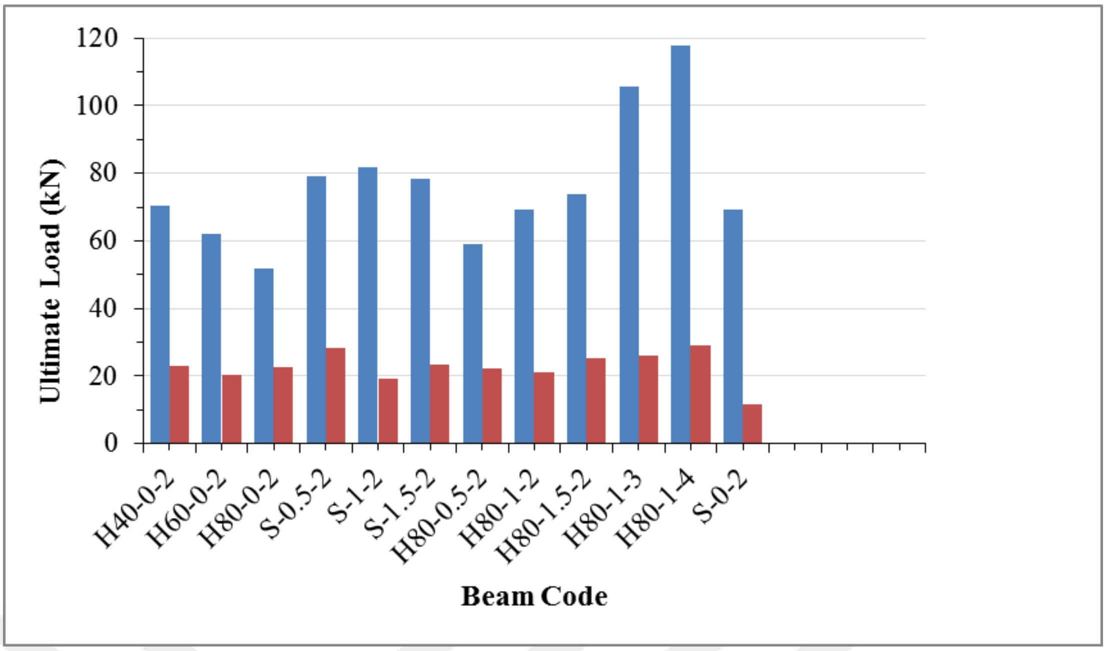


Figure 4.11 Ultimate and cracking load behaviors.

The 1% S.F content that was used led to both reductions in crack widths and crack spacing, Furthermore, the addition of S.F. led to a more diffused for cracking pattern. In addition to the reduction in crack patterns and crack widths, there are many secondary cracks are growing and developing out of the primary cracks. The cracking patterns are bridging action of the S.F and reductions in crack widths. Furthermore, the beam was still resisted the load due to the capacity of the S.F which tried distributions the stresses between all cracks, this leads to increase the shear capacity of the member until the maximum flexural resistance of the beam was occur.

For The tested hollow beams (group three) which loaded up to failure, and which causes a wide central flexural cracks, Figure 4.12 shows the cracks patterns for the flexural and shear, because the high shear capacity which is compared to the flexural capacity all cracks doesn't reach the top flange, increasing the steel fiber dosage which decreases the number of cracks, this is not expected behavior. Moreover, the shear cracks for all hollow beams which include steel fiber in their concrete mixture are started from the distance (a / 2) from the supports, while the shear crack for plain concrete hollow beam are started at the support which is an expected cause failure near the support of beam due to high stress on the bottom flange.

For the tested hollow beams (Group four), the shear cracks failure is so clear near the support as shown in Figure 4.13.

Figure 4.13 shows the effect of the longitudinal steel ratio on the cracking pattern. Noting that the three beams contain 1.0% of steel fiber. It is obvious in the Figure that the inclusion of one additional steel bar does not significantly affect the cracking pattern, while both the first crack and failure load increase noticeably with percentage increases of approximately 24 and 52%, respectively. On the other hand, the inclusion of 4 bars led to better cracking behavior as a multi-crack failure was obvious. The first crack load was increased by approximately 38% as 4 bars were used instead of 2 bars. On the other hand, the failure load was increased from 69.23 kN to 117.67 kN with a percentage increase of approximately 70%.

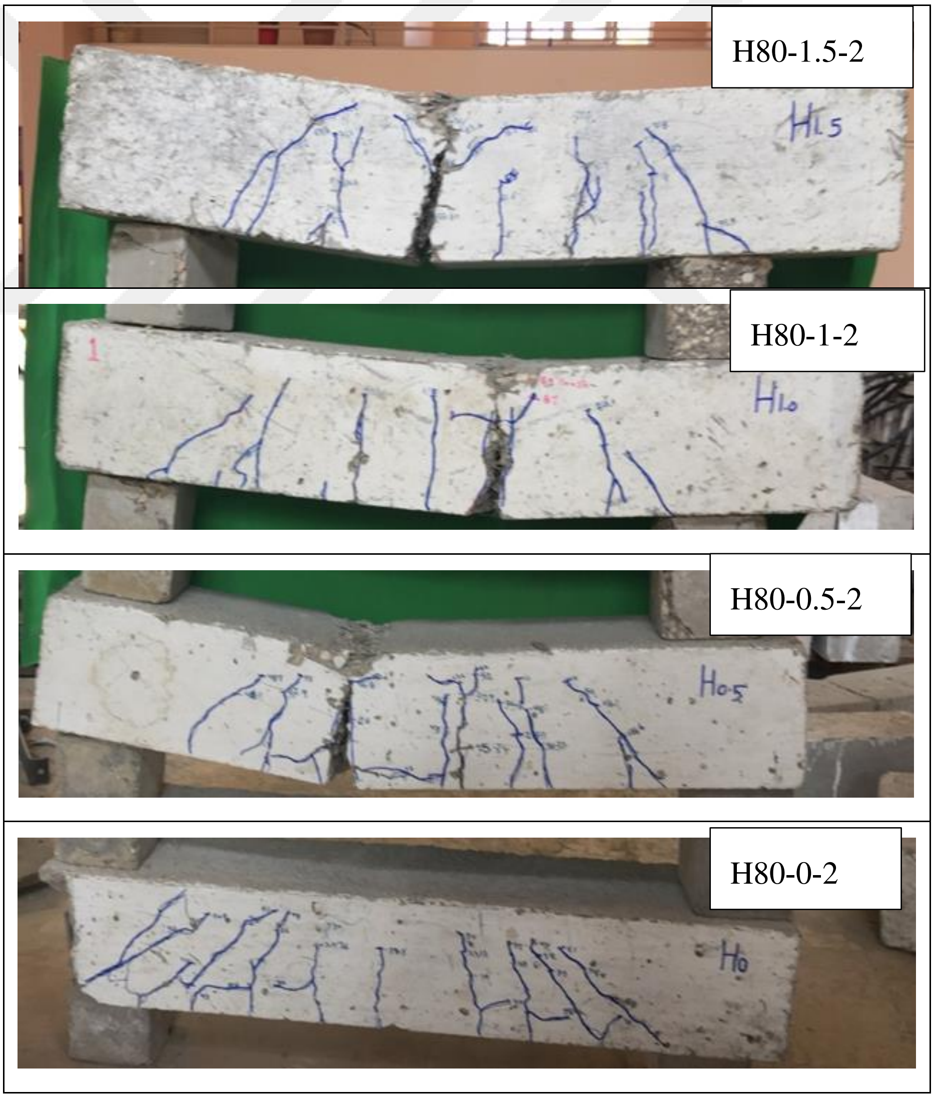


Figure 4.12. Cracks patterns of tested hollow beams.

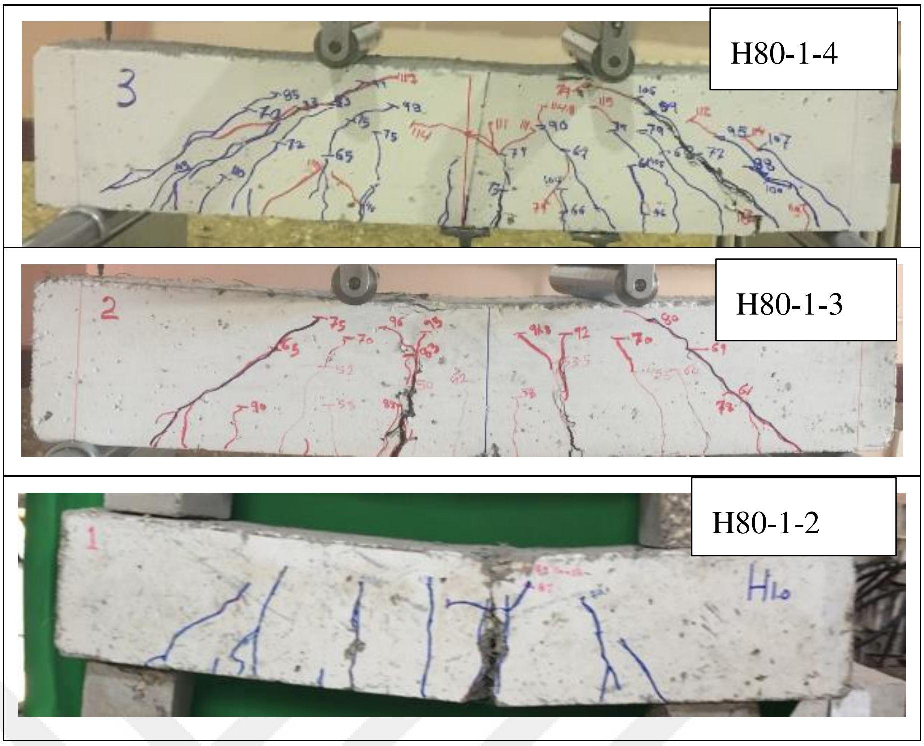


Figure 4.13. Cracks patterns of tested hollow beams.

4.4 Load-Deflection Behavior

The monotonic load was applied by two rollers to avoid the moment resistance which induced from friction load. The clear span between the two supports was 750 mm, and the distance between the point loads was 250 as shown in Figure 4.14. All tested beams were loaded till failure. The central deflection of the beam was measured directly by using the built-in displacement sensor in the loading machine. The beam loading was displacement controlled with rate of 0.4 mm/min. The discussion of this section was divided into four sections to discuss the effect of four different parameters on the load-deflection behavior of the beams.

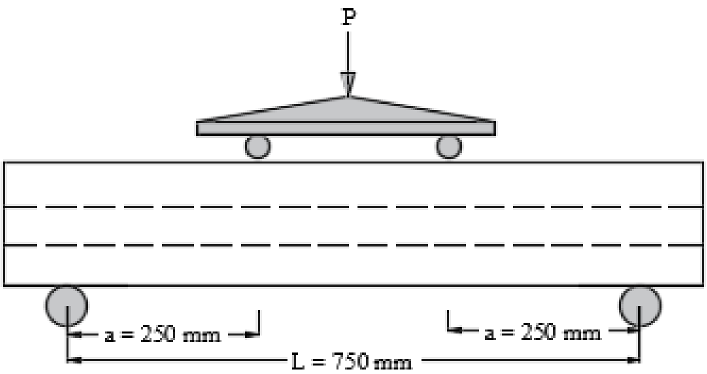


Figure 4.14 The location of two points load.

For all tested beams, the deflection behavior was remarked and studied. The experimental curves showed larger deformations for lower steel fiber ratios.

For group one which includes hollow specimens with variable square cavities (40×40, 60×60 and 80×80 mm) and without steel fiber, the deflection and ultimate load results are shown in Table 4.3 and Figures 4.15 and 4.16. The results indicate that the deflection values at failure load of hollow beams have opening sizes of 40×40 and 60×60 mm were higher in comparison with the solid control beam, which has same mixture properties, while the deflection values of hollow beam has opening size of (80×80 mm) were lower.

Figure 4.16 shows the development stages of deflection with the applied load. Generally, the load-deflection curve is summarized in three main stages. The first portion is elastic or semi-elastic where the load-deflections curve is approximately linear up to the first crack, which occurs due to the increase in applied load. At the second stage, the load-deflection curve continues linearly, yet one of the reinforcement bars is yielded. After all bars are yielded, the curve becomes nonlinear and the displacement hardening plateau shown up to ultimate load, except the specimen (H80-0-2), which failed in a brittle stage. At the next stage, the load starts decreasing due to the low resistance until failure. In addition, below that is a load of 50 kN, the curve of the specimen (H80-0-2) showed extra displacements.

Table 4.3 The load deflection results of Group One.

Group	**Specification code**	**Ultimate load P_u (kN)**	**Displacement δ_{pu} (mm)**
One	H40-0-2	70.41	14.9
	H60-0-2	62.17	13.7
	H80-0-2	51.67	5.02
Control	S-0-2	69.4	8.9

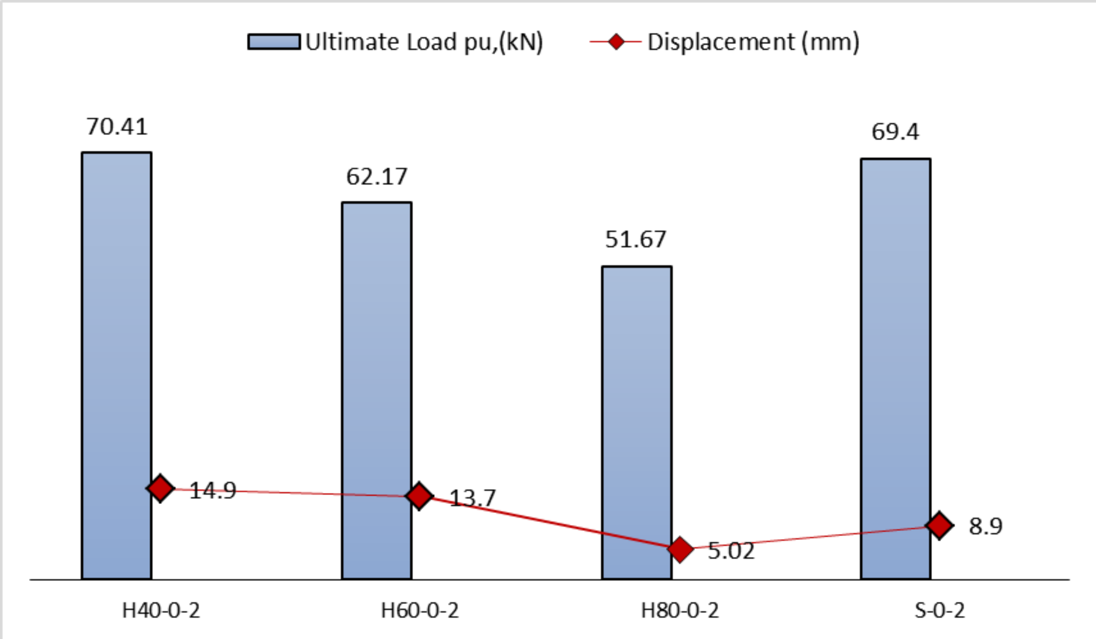


Figure 4.15 Effect the opening on displacement.

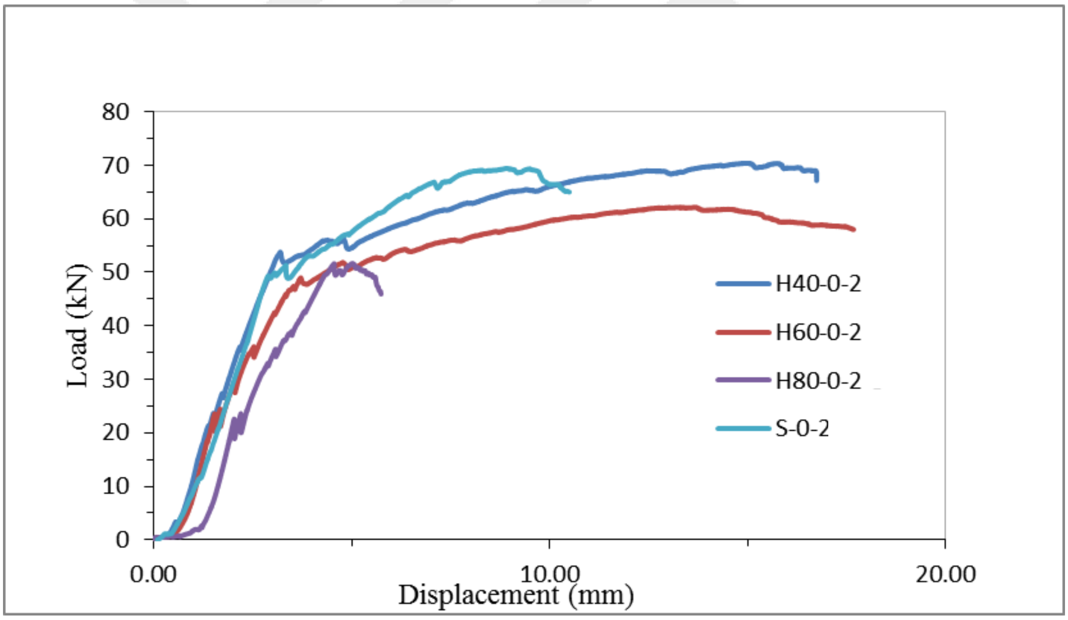


Figure 4.16 Load-deflection of Group One.

For group two, which consists of solid specimens include variable content of steel fibers (0.5, 1.0 and 1.5%), the deflection results are shown in Table 4.4 and Figures 4.17 and 4.18. These results show that increasing the dosages of steel fiber from 0.5% to 1.0%, the deflection values at failure load become higher, while the increase of the steel fiber dosage to 1.5% leads to lower deflection values compared with the solid control beam.

Table 4.4 Deflection results of Group Two.

Group	Specification code	Ultimate load P_u (kN)	Displacement δ_{pu} (mm)
Two	S-0.5-2	79.14	11.76
	S-1-2	81.73	11.52
	S-1.5-2	78.32	7.24
Control	S-0-2	69.4	8.9

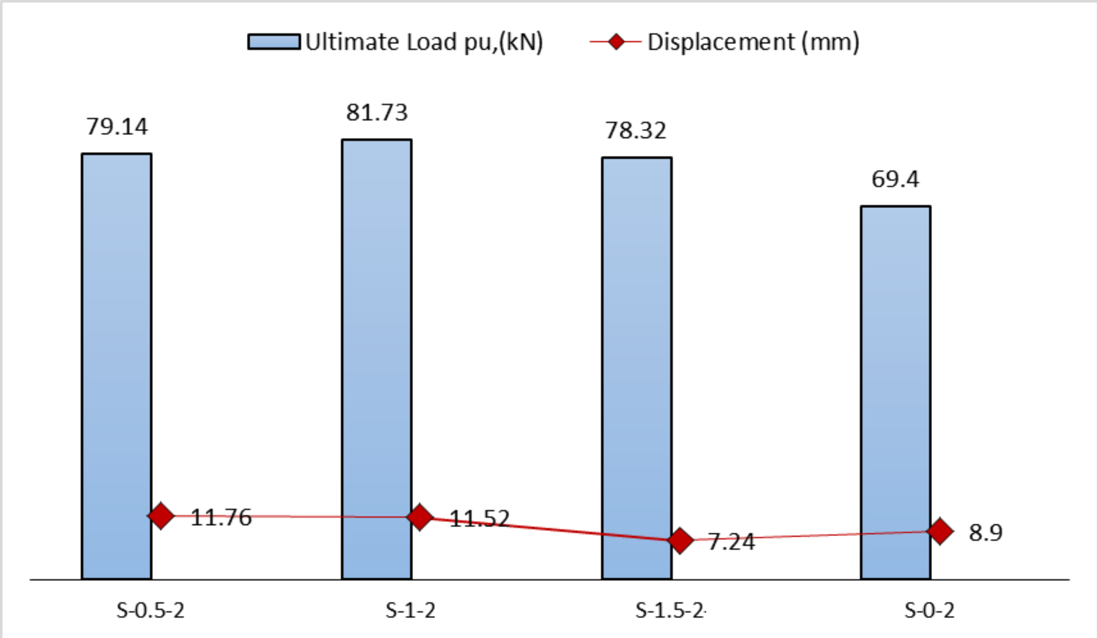


Figure 4.17 Effect the steel fiber on displacement of Group Two.

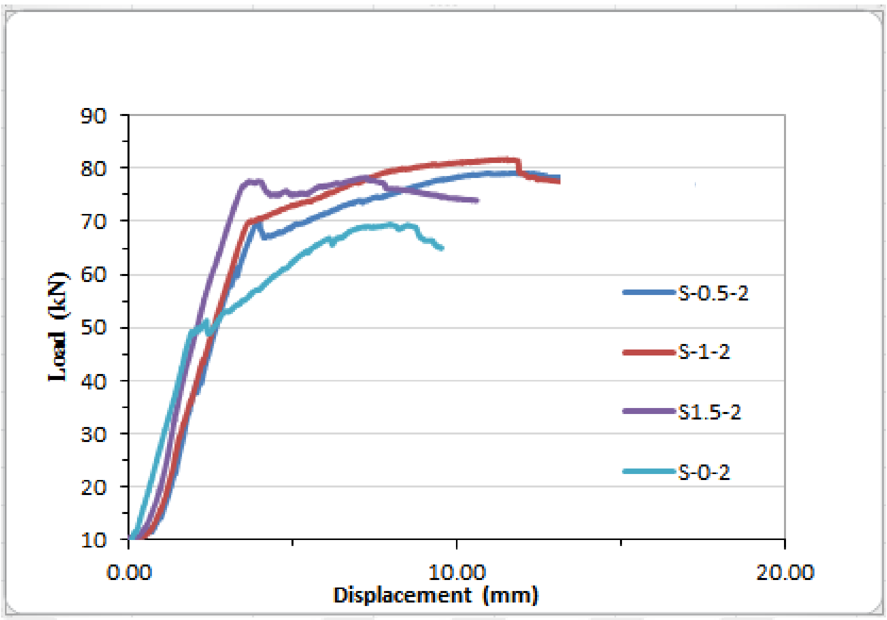


Figure 4.18 Load-deflection of Group Two.

Group three which included hollow specimens have constant size square cavity (80×80) mm and included variable volume fraction steel fibers of 0.5, 1.0 and 1.5 in their concrete mixture. The load and deflection results are shown in Table 4.5 and Figure 4.19 and 4.20. The load listed in the table and shown in Figure 4.20 are the ultimate loads, while the displacements are the corresponding central deflections at the ultimate load stage. On the other hand, Figure 4.20 shows the full load-deflection curves of the tested beams. The loads listed in the table indicate that when increasing the dosage of SF from 0.5% to 1.0% and 1.5% the deflections of the three fibrous beams jumped to approximately twice that of the beam without fiber (0.0%). However, the difference in deflection which was minor with a maximum of approximately 20%. On the other hand, the effect of the use of steel fiber in this group on the ultimate load are discussed in details in the next section.

The Figure 4.20 shows that the same behavior for all hollow beams from applied the load till occur of the first crack was achieved. Beyond the first crack, the curve of specimen (S-0-2) shows much lower final deformation than (H80-1-2) and (H80-1.5-2). This is an expected result as the absence of fibers eliminates the advantage of crack bridging that increases the plastic region by increasing the deflection after the ultimate load stage. It is also shown in the figure that the curves of the three fibrous beams are approximately parallel along the nonlinear stage.

Table 4.5 Deflection results of Group Three.

Group	Specification code	Ultimate load P_u (kN)	Displacement δ_{pu} (mm)
Three	H80-0.5-2	59.13	12.26
	H80-1-2	69.23	9.94
	H80-1.5-2	73.73	10.62
Control	H80-0-2	51.67	5.02

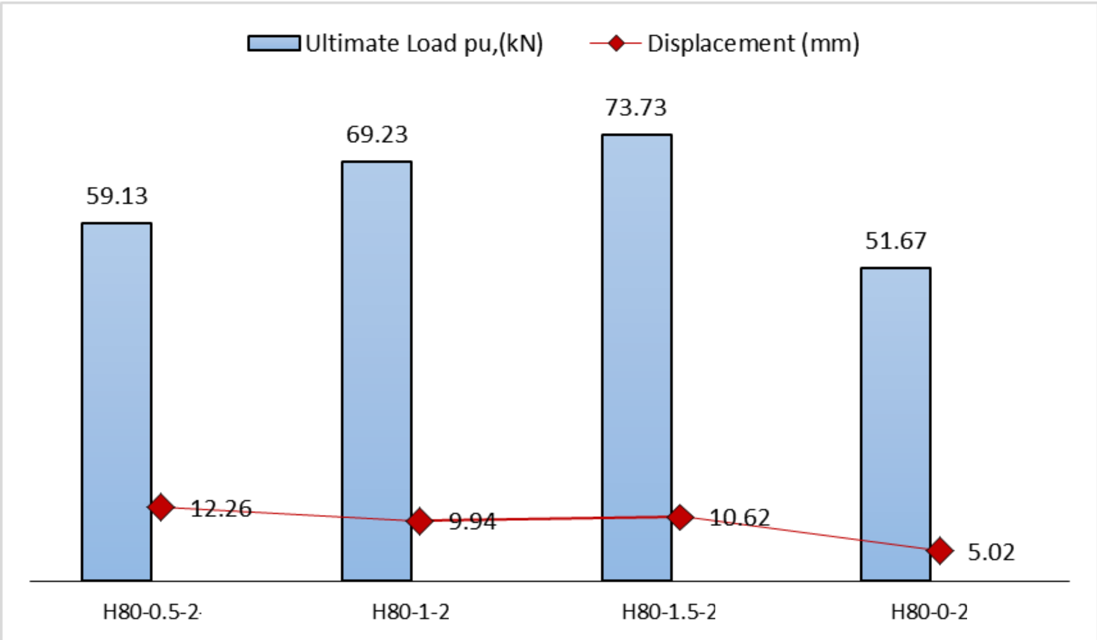


Figure 4.19 Effect the steel fiber on displacement (Group Three).

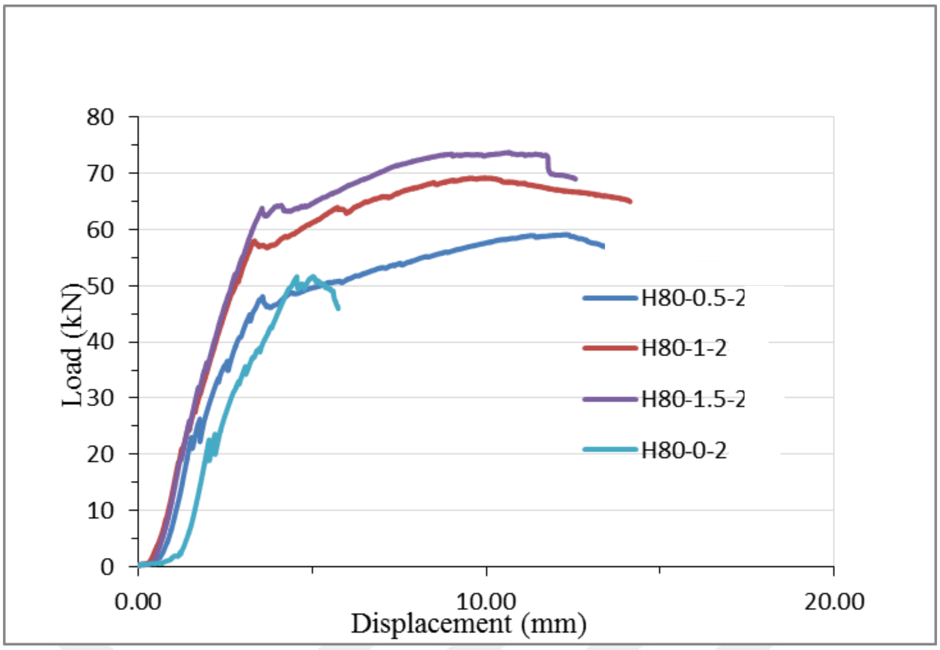


Figure 4.20 Load-deflection (Group Three).

Group four included hollow specimens with constant size square cavity (80×80) mm and included constant volume fraction of steel fibers (1.0%) in their concrete mixture. The deflection results are shown in Table 4.6, Figure 4.21 and 4.22, which indicate that when increasing the longitudinal reinforcement bars, the ultimate load will be increased while the deflection remain nearly same in comparison with control beam.

Table 4.6 Deflection results of Group Four.

Group	**Specification code**	**Ultimate load** P_u (kN)	**Displacement** δ_{pu} (mm)
Four	H80-1-2	69.23	9.94
	H80-1-3	105.54	10.61
	H80-1-4	117.67	8.73
Control	S-0-2	69.4	8.9

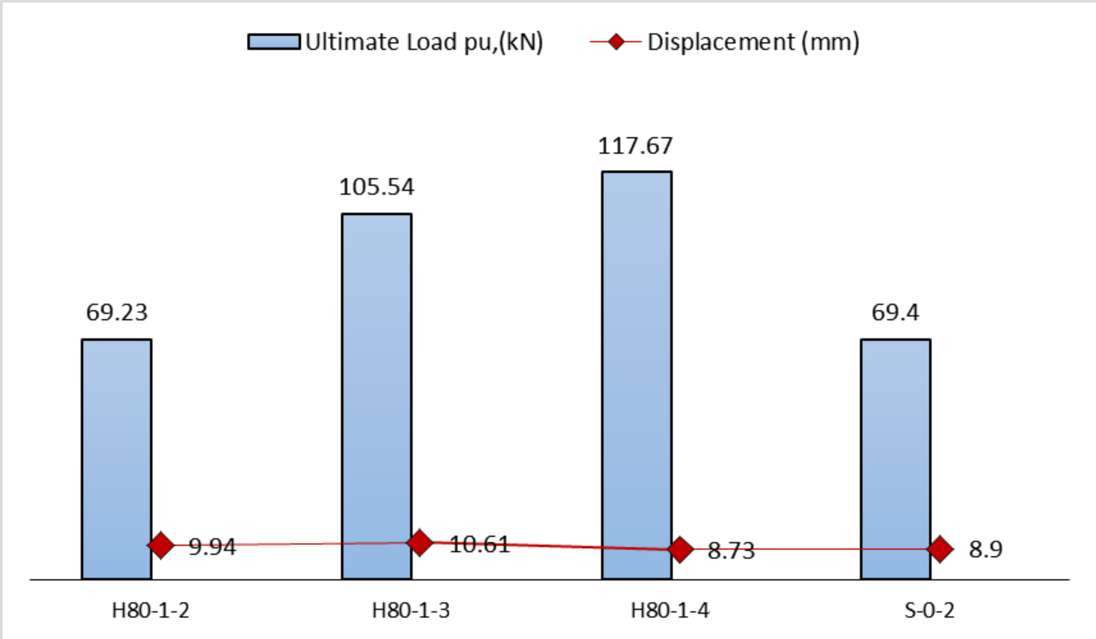


Figure 4.21 Effect of the flexural rebar on displacement.

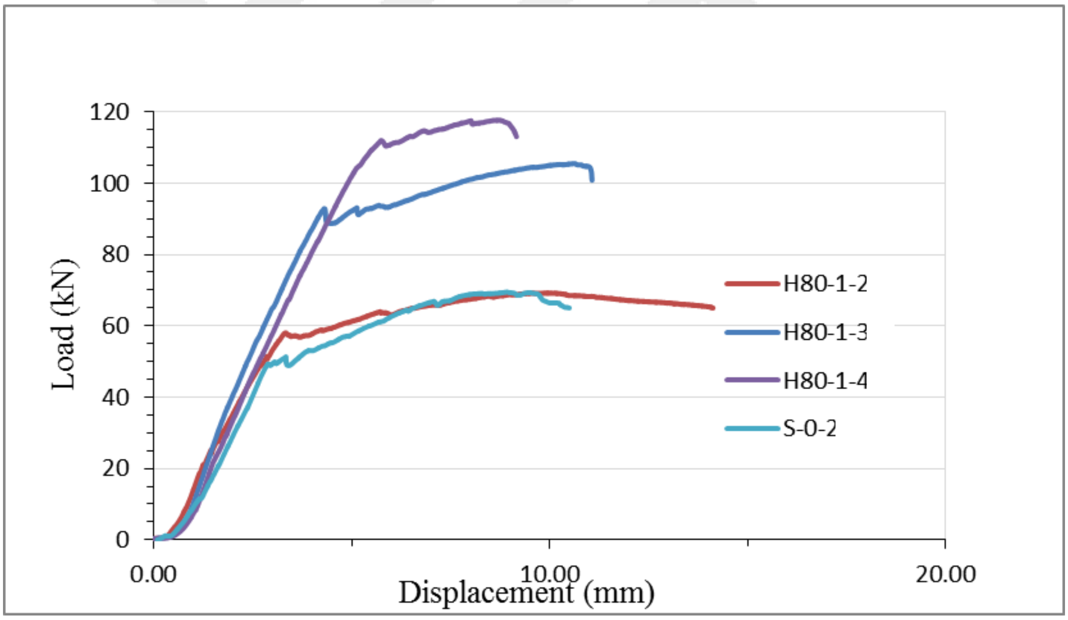


Figure 4.22 Load-deflection of Group Four.

4.5 Ultimate Load Capacity of Beams

Generally, the beam can be classified a thin or thick walled beam according to the wall thickness, if the thickness (t) is less than or equal (x/10), the beam is considered as thin walled and if greater than (x/10) the beam consider as a thick wall. The symbol (x) refers to the shorter dimension of the cross section of the beam. In the current study fifteen beams were fabricated and purred, ten beams were hollow section, eight with opening (80×80) mm from all groups were cast with (35 mm thickness of wall) and two beams with opening (one with opening size (60×60) mm and second was (40×40) mm and the, the thickness of wall were 45 and 55mm respectively, the cross section of specimens were (150×150) mm, that's mean it is possible to consider all hollow beam specimens as a thick walled section. All beams (solid and hollow section beam, with and without included steel fiber in their concrete mixture) are tested flexural under two-point load. The experimental results are compared with solid beams of plain concrete as a control specimen, the calculated section moment capacity for the control beam was 6.22 kN.m. Based on this model, the equilibrium of internal resisting forces gives:

$$F_c = F_s \tag{4.1}$$

And hence, the ultimate resisting moment (M_u) is:

$$Mu = \rho b d^2 f_{sc}(1.0 - 0.539\rho f_y/f'_c) \tag{4.2}$$

Where, $\rho = A_s/b \times d$, when

A_s: is tension steel area, b: is the width of the beam.

d: is the net height of beam between the bottom (tensile) and the top (compression) steel bars,

f_y: is the characteristic tensile strength of steel

f_c': is the characteristic compressive strength of concrete.

The tested ultimate moments for all beams are summarized in Table 4.7. The tested ultimate moment (M_u) is calculated as,

$$M_u = \frac{P_u a'}{2} \qquad \text{Equation (4.3)}$$

Where a' the shear arm as shown in Figure 4.14, and P_u is the resistance of ultimate load of the beams.

Table 4.7 The Ultimate moment capacities and EAC.

Group	Specification code	Ultimate load P_u (kN)	Ultimate Moment M_u kN.m	EAC† kN.mm
One	H40-0-2	70.41	8.80	757.59
	H60-0-2	62.17	7.77	668.91
	H80-0-2	51.67	6.45	601.94
Two	S-0.5-2	79.14	8.64	743.81
	S-1-2	81.73	8.96	771.36
	S-1.5-2	78.32	8.54	735.20
Three	H80-0.5-2	59.13	7.39	552.68
	H80-1-2	69.23	8.65	518.03
	H80-1.5-2	73.73	9.21	599.24
Four	H80-1-2	69.23	8.65	518.03
	H80-1-3	105.54	13.19	1135.52
	H80-1-4	117.67	14.70	1265.52
Control	S-0-2	69.4	8.67	746.41
	H80-0-2	53.10	6.63	570.77

† EAC refers to energy absorption capacity

4.5.1 Effect the size of opening on the ultimate beam strength

To investigate the effect of opening size of the hollow section on the ultimate beam strength, three hollow beams are fabricated and poured with three different-size square cavities of 40×40, 60×60 and 80×80 mm.

Group one specimens in Table 4.9 details the included specimens, while Figure 4.23 shows the ultimate loads obtained from the test for these specimens. By comparing the results which shows that removing 16% (opening size 60×60 mm) and 28% (opening size 80×80 mm) of the cross-sectional area decreases the ultimate load (Pu) by 11.62% and 36%, respectively. Moreover, the results clarified that the ultimate strengths of the solid control beam and that with opening size (40×40) mm were approximately the same as shown in Figure 4.24.

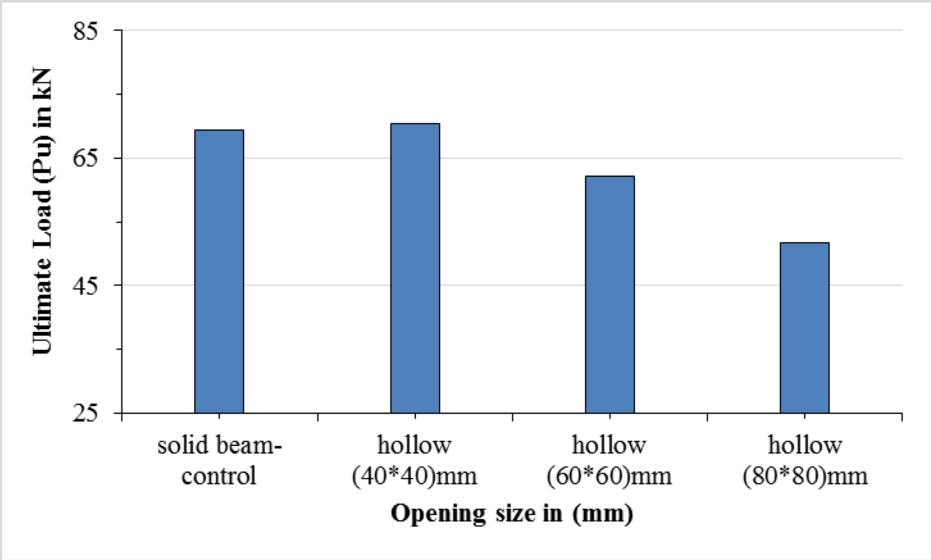


Figure 4.23, The Effect of opening size on ultimate load of beam (Group One).

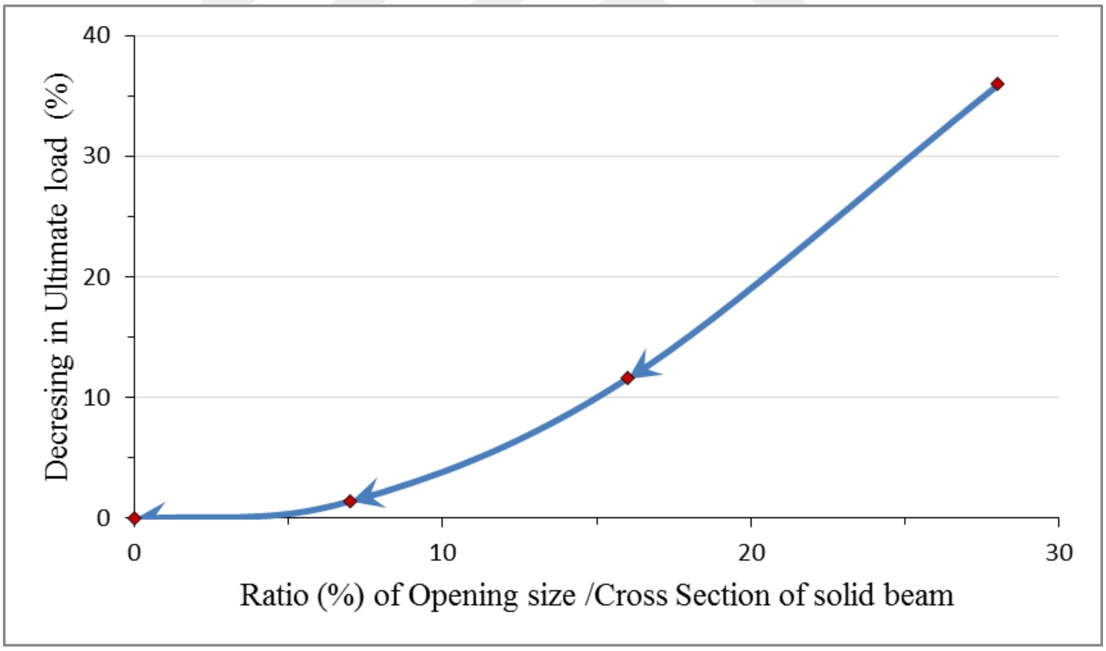


Figure 4.24 The Effect of opening size on ultimate load of beam.

4.5.2 Effect of steel fiber content on the ultimate strength of beams

In this section, the effect of steel fiber content on the ultimate strength of the tested beams is studied by using both solid and hollow beams. Three different dosages of steel fiber were adopted, which were 0.5, 1.0, and 1.5%.as detailed in Table 4.8.

For Group two (solid beams), the use of steel fiber with volume fractions of 0.5, 1.0 and 1.5% enhance the ultimate strength of solid beam by approximately 14, 18, and 13%, respectively. However by using 1.0 % of steel fiber which gave a good enhancement in ultimate strength as shown in Figure 4.25 and 4.26.

For Group three (hollow beams), the use of steel fiber with volume fractions of 0.5, 1.0 and 1.5% enhance the ultimate strength approximately 14, 34 and 42%, respectively. As shown in Figure 4.27 and 4.28.

In addition to for hollow section, the Energy Absorption Capacity (EAC) is also enhancing by using the SF, but still, less than the solid beam, where increasing the steel fiber dosage from 0.5 % to 1.5% increased the EAC by 8 %. However, the EAC of the solid specimen (S-0-2) is more than the EAC of (H80-1.5-2) by 24 %.

Table 4.8 The ultimate strength results for solid and hollow beams.

Group	**Specification code**	**Steel fiber** V_f (%)	**Ultimate load** P_u (kN)
Two	S-0.5-2	0.50	79.14
	S-1-2	1.00	81.73
	S-1.5-2	1.50	78.32
Three	H80-0.5-2	0.50	59.13
	H80-1-2	1.00	69.23
	H80-1.5-2	1.50	73.73
Control	S-0-2	0.00	69.40
	H80-0-2	0.00	51.67

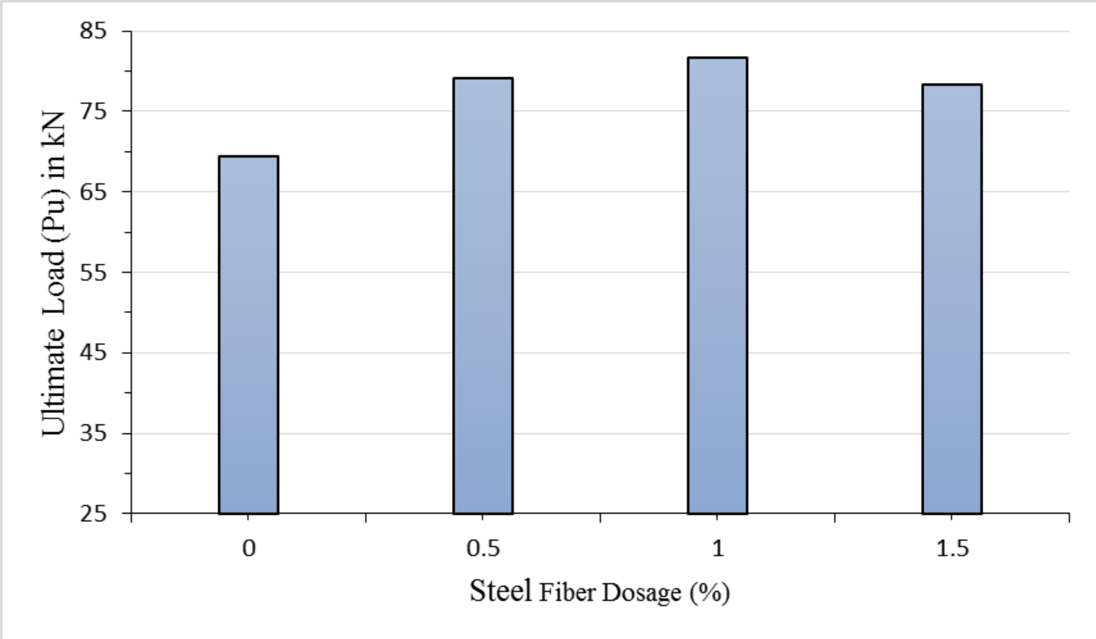


Figure 4.25 The effect of S.F. dosages on the ultimate strength of solid beam.

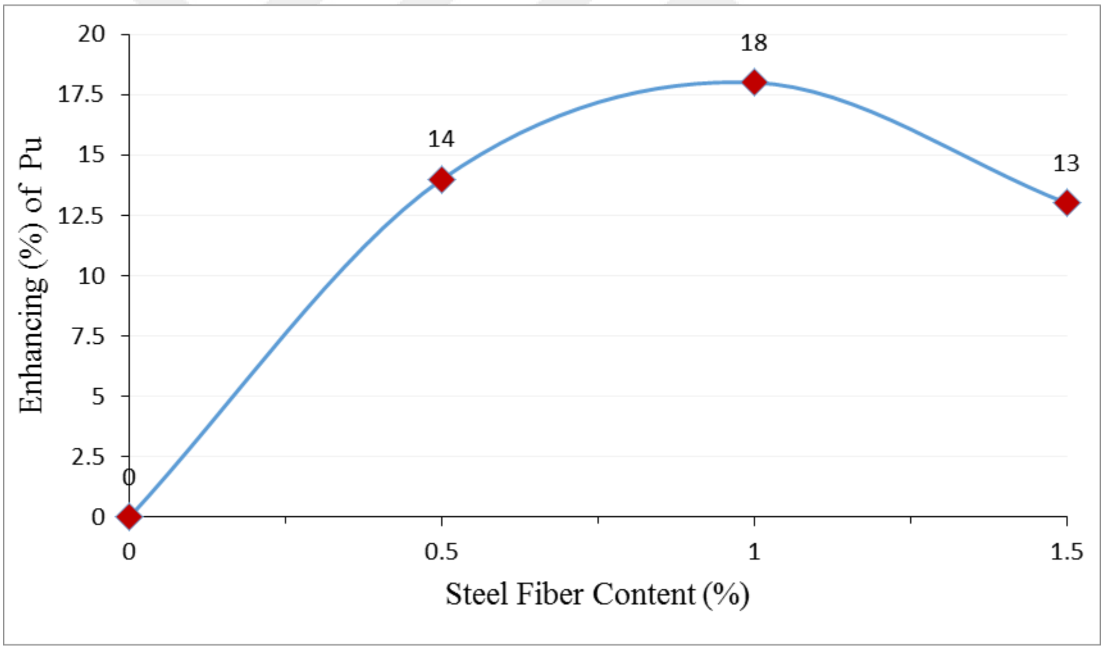


Figure 4.26 Enhancing (%) of S.F. dosages on the ultimate strength of solid beam.

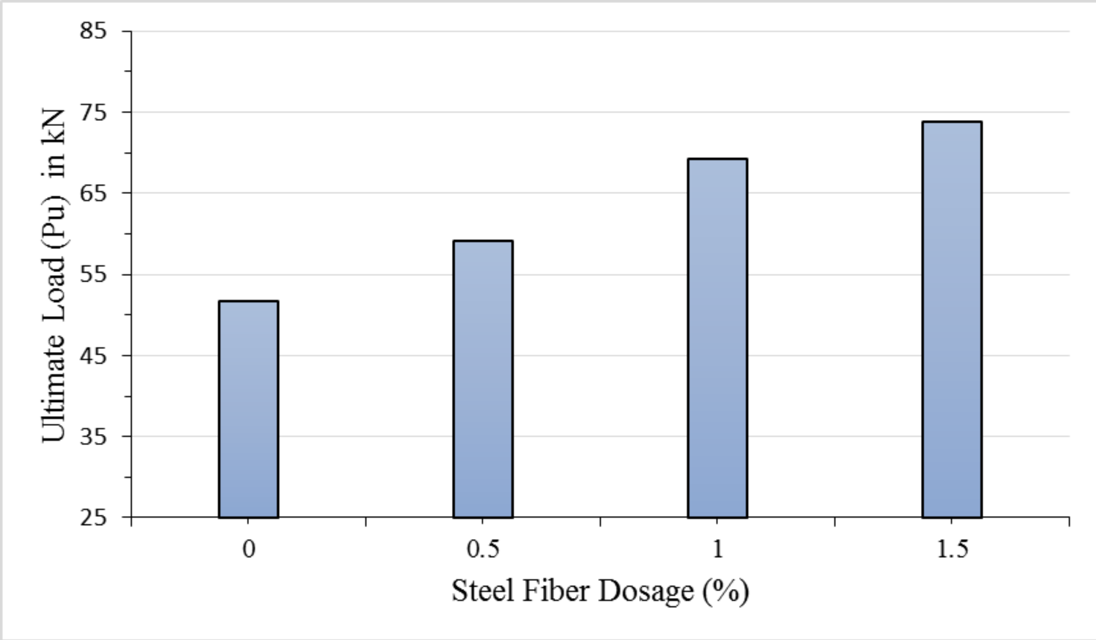


Figure 4.27 The effect of S.F. dosages on the ultimate strength of hollow beam.

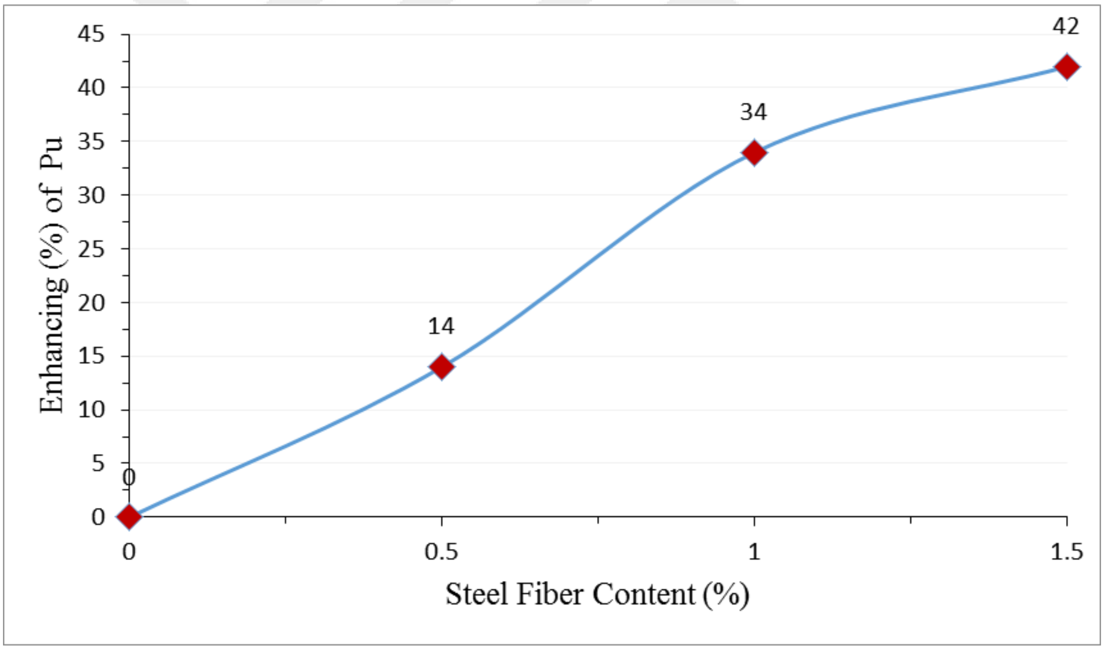


Figure 4.28 Enhancing (%) of S.F. dosages on the ultimate strength of hollow beam.

CHAPTER FIVE

CONCLUSIONS AND FUTURE RECOMMENDATIONS

5.1 Conclusions

In this chapter and based on the results of the experimental work and the discussions in the previous chapter, the most important conclusions are drawn. Moreover, recommendations for future corresponding works are given in this chapter.

In this study, the effects of variable sizes of square openings on the behavior of hollow square beams were investigated under monotonic loading. The effects of the use of different dosages of steel fiber on the load-deflection behavior, the ultimate load capacity and cracking patter were also investigated in this research. Moreover, the influence of the variation of the amount of the conventional reinforcing steel was studied in the presence of steel fibers. The experimental results of this study led to the following conclusions:

1. The incorporation of steel fibers did not noticeably affected the compressive strength of the used concrete mixture where the compressive strength values were approximately the same for concrete cylinders having 0, 0.5, 1.0 and 1.5% steel fiber. On the other hand, significant increase in splitting tensile strength was recorded as the percentage fiber increased. The average splitting tensile strength of different groups of specimens having 0.5, 1.0, and 1.5% were 5.3, 6.0 and 5.4MPa compared to 4.2 MPa of cylinders without steel fiber. However, using 1.0 % of steel fiber gave a good enhancement in splitting tensile strength.
2. Compared to the control solid beam, the hollow beams resulted in lower ultimate load, which was decreased as the opening size increase. The percentage decrease in the ultimate strength of the hollow beams with opening sizes of 80×80 and 60×60 mm were approximately 25% and 10%,

respectively, while no such load decrease was noticed for the hollow beam with opening size of 40×40 mm.

3. The incorporation of steel fiber to the used concrete matrix led to better flexural behavior and increased the ultimate load capacity. This effect was clear for both solid and hollow beams. The percentage increase in the ultimate load capacity for solid beams containing steel fibers with volume fractions of 0.5, 1.0 and 1.5% were 14, 18 and 13%, respectively, compared to similar beam without fiber. On the other hand, the percentage increase sequence for hollow beams with opening of 80×80 mm were 14 , 34 and 42 % for the same sequence of steel fiber content, respectively.
4. The increase of the longitudinal steel bars number (increase of the area of the conventional flexural steel) has significantly enhanced the cracking behavior of the beams. The beams with higher steel reinforcement ratio (0.0093 and 0.0124) exhibited narrower crack widths with larger number of cracks distributed along the flexural tension zone between point loads. This behavior is more ductile than that the beam reinforced with two bars only (steel ratio = 0.0062), which exhibited lower number and wider cracks. It should noticed that all the beams of this group were hollow with opening size of 80×80 mm.
5. Inclusive the SF with 1.5 % for beam enhanced the energy absorption capacity by 24 % compared with control beam (0 % SF).

5.2 Recommendations for Future Studies

Within the limits of the studied parameters in this study and based on the above drawn conclusions, the following titles can be suggested as projects of future studies:

1. Experimental study on the behavior of hollow concrete beams including different types and lengths of steel fiber.
2. Experimental study on the behavior of SFRC concrete hollow beams under cyclic loading and impact loading.
3. Experimental study of the effect of the geometrical shape of the hollow part on the structural behavior for SFRC hollow beams.

REFERENCES

American Concrete Institute ACI 318-14, (2014). *Building Code Requirements for Structural Concrete.* American Concrete Institute, U.S.A.

ACI committee 544, (1993). *Guide for Specifying, Proportioning, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete*. ACI Committee U.S.A.

ASTM C39, (1997). Standard test method for compressive strength of cylindrical concrete specimens. *Annual book of ASTM standards,* 4,20-24.

ASTM C496. (2004). Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete Specimens. *ASTM International.,* 1.

Abbas, Y. M., & Iqbal Khan, M. (2016). Influence of Fiber Properties on Shear Failure of Steel Fiber Reinforced Beams Without Web Reinforcement: ANN Modeling, *Latin American Journal of Solids and Structures*, **13**(8), 1483-1498.

Alnauimi, A. S., and Bhatt, P., (2004). Direct design of hollow reinforced concrete beams. Part II: experimental investigation, *Structural Concrete*, **5**(4), 147-160.

Alnuaimi, A. S., Al-Jabri, K. S. and Hago, A., (2008). Comparison between solid and hollow reinforced concrete beams, *Materials and Structures*, **41**(2), 269-286.

Alshimmeri, A. J. H. and Al-Maliki, H. N. G., (2014). Structural Behavior of Reinforced Concrete Hollow Beams under Partial Uniformly Distributed Load, *Journal of Engineering*, **20**(7), 130-145.

Balaguru, P., Narahari, R., & Patel, M. (1992). Flexural toughness of steel fiber reinforced concrete. *Materials Journal*, *89*(6), 541-546.

Banthia, N. (2012). FRC: Milestone in international research and development, *Proceedings of FIBCON2012,* Nagpur, India, 13-14.

Batson, G., Ball, C., Bailey, L., Landers, E. and Hooks, J., (1972). Flexural fatigue strength of steel fiber reinforced concrete beams. *Journal Proceedings* **69**(11), 673-677.

Brown, R., Shukla, A. and Natarajan, K. R.. (2002). *Fiber reinforcement of concrete structures* URITC FY99-02,, Final Report, University of Rhode Island, Kingston.

Chanh, N.V. (2005). *Steel fiber reinforced concrete*, Ph.D Thesis, Faculty of Civil Engineering, Ho Chi Minh City University of Technology.

Dhakal, R.P., (2006). Post-peak response analysis of SFRC columns including spalling and buckling, *Struct Eng Mech,* **22** (3), 311-330.

Dinh, H. H. (2009). *Shear behavior of steel fiber reinforced concrete beams without stirrup reinforcement,* Ph.D dissertation, University of Michigan.

Eren, Ö., and Celik, T. (1997). Effect of silica fume and steel fibers on some properties of high-strength concrete, *Construction and Building Materials*, **11**(7-8), 373-382.

Ganesan, N., Indira, P. V., & Rajendra Prasad, S. (2010). Structural behaviour of steel fibre reinforced concrete wall panels in two-way in-plane action. *Indian concrete journal*, *84*(10), 21-28.

Hannant, P. J., (1978). *Fibre cements and fibre concretes*, Chichester; New York: Wiley.

Hafiz, R. B., Ahmed, S., Barua, S., and Chowdhury, S. R. (2014). Effects of opening on the behavior of reinforced concrete beam. *Journal of Mechanical and Civil Engineering*, **11**(2), 52-61.

Hassan, A., (2007). *Structural Behaviour Of Steel Fibre Reinforced Concrete Members*, Ph.D thesis, Department of Civil Engineering and Applied Mechanics, McGill University, Montreal, Quebec, Canada.

Inoue, S., and Egawa, N. (1996). Flexural and Shear Behavior of Reinforced Concrete Hollow Beams under Reversed Cyclic Loads, *Proceedings of 11th World Conference on Earthquake Engineering,* Acapulco, Mexico, 23-28.

Jabbar, S., Hejazi, F., and Mahmod, H. M., (2016). Effect of an opening on reinforced concrete hollow beam web under torsional, flexural, and cyclic loadings, *Latin American Journal of Solids and Structures*, **13**(8), 1576-1595.

Johnston, C. D., & Zemp, R. W. (1991). Flexural Fatigue Performance of Steel Fiber Reinforced Concrete--Influence of Fiber Content, Aspect Ratio, and Type. *Materials Journal*, **88**(4), 374-383.

Johnston, C. D. (1984). Measures of the workability of steel fiber reinforced concrete and their precision. *Cement, concrete and aggregates*, *6*(2), 74-83.

Katzer, J, (2006). Steel fibers and steel fiber reinforced concrete in civil engineering. Pacific Journal of Science and Technology. 7. 53-58.

Kwak, Y. K., Eberhard, M. O., Kim, W. S., & Kim, J. (2002). Shear strength of steel fiber-reinforced concrete beams without stirrups, *ACI Structural Journal*, **99**(4), 530-538.

Mahadik, S. A., Kamane, S. K. and Lande, A. C., (2014), Effect of Steel Fibers on Compressive and Flexural Strength of Concrete*, International Journal of Advanced Structures and Geotechnical Engineering*, **3**(4), 388-392.

Maidl, B. R., (1995). Steel fiber reinforced concrete. Berlin, Germany: Ernst & Sohn,

Minelli, F., Plizzari, G. A., and Vecchio, F. J. (2007). Influence of steel fibers on full-scale RC beams under shear loading. *High performance concrete, brick-masonry and environmental aspects. Sixth international conference of fracture mechanics of concrete and concrete structures FRAMCOS6.* Taylor & Francis Group (UK), London/Catania, 1523-1531.

Mohod, M. V. (2012). Performance of steel fiber reinforced concrete. *International Journal of Engineering and Science*, **1**(12), 1-4.

Nimnim, H. T., 1993, Structural Behavior of Ferro cement Box-Beams, M.Sc., thesis, University of Technology.

Naaman AE.(1985) Fibre reinforcement for concrete. *Concr Int Des Construct,* **7**(3), 21-25,

Odelberg, G. (1985, June). Producing and Promoting of Swedish steel fibers to the market. In *Proceedings of steel fibre concrete us-sweden joint seminar. Stockholm*.

Orange, G., Acker, P., & Vernet, C. (1999). A new generation of UHP concrete: Ductal®. Damage resistance and micromechanical analysis. In *Third international workshop on high performance fiber reinforced cement composites (HPFRCC3), Mainz, Germany* (pp. 101-111).

Palermo, A., Pampanin, S., & Carr, A. J. (2005). Efficiency of simplified alternative modelling approaches to predict the seismic response of precast concrete hybrid systems, *fib (Fédération internationale du béton / International Federation for Structural Concrete) Symposium "Keep Concrete Attractive",* Budapest.

Ramakrishnan, V., Oberling, G., & Tatnal, P. (1987). Flexural fatigue strength of steel fiber reinforced concrete. *Special Publication*, *105*, 225-246.

Ramakrishnan, V., Wu, G. Y., & Hosalli, G. (1989). Flexural fatigue strength, endurance limit and impact strength of fiber reinforced concretes. *Transportation Research Record*, *1226*, 17-24.

Romualdi, J. P., & Batson, G. B. (1963). Behavior of reinforced concrete beams with closely spaced reinforcement. *Journal Proceedings*, **60**(6), 775-790.

Rossi, P., Acker, P., & Malier, Y. (1987). Effect of steel fibres at two different stages: the material and the structure. *Materials and Structures*, *20*(6), 436-439.

Sarah Jabbar, Farzad Hejazi, H. Mahir Mahmod)(2016)(Effect of an Opening on Reinforced Concrete Hollow Beam Web Under Torsional, Flexural, and Cyclic Loadings

Swamy, R. N., AI-Taan, S., & Ali, Sami A. R. (1979). Steel Fiber for controlling Cracking and Deflection. *Concrete international 1979. 6, 41-49.*

Swamy, R. N., AI-Taan, S., & Ali, Sami A. R. (1979). Steel Fiber for controlling Cracking and Deflection. *Concrete international 1979. 6, 41-49.*

Yazıcı, Ş., İnan, G., & Tabak, V. (2007). Effect of aspect ratio and volume fraction of steel fiber on the mechanical properties of SFRC. *Construction and Building Materials*, **21**(6), 1250-1253.

Yoo, D. Y., & Yoon, Y. S. (2015). Structural performance of ultra-high-performance concrete beams with different steel fibers. *Engineering Structures*, **102**, 409-423.