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M.Sc. in Civil Engineering

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UNIVERSITY OF GAZİANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

BEHAVIOR OF TWO-WAY CONCRETE SLABS REINFORCED WITH FIBERS

M.Sc. THESIS

IN

CIVIL ENGINEERING

BY

ISRAA SABBAR ABBAS

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M.Sc. Thesis

in

Civil Engineering

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Supervisor

Prof. Dr. Mustafa ÖZAKÇA

By

Israa Sabbar ABBAS

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

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Israa Sabbar ABBAS

ABSTRACT

BEHAVIOR OF TWO-WAY CONCRETE SLABS REINFORCED WITH FIBERS

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M.Sc. in Civil Engineering
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The flat plate-column connection is a structural system, where columns without capitals or drop panels support the slab. This type of connection is governed by its weak strength of two-way shear (punching shear), which shows high brittleness behavior that leads to collapse. Adding the various types of fibers were the most important solution. Moreover, fibers are adding to the dense matrix in order to decrease the brittleness, in turns, increasing the sense of the matrix is increasing the bond with fibers and increasing the post-cracking strength. Fibers used in Reinforced Concrete (RC) that randomly oriented making the concrete behave as composite materials, which improve the residual strength of the members.

Behaviors of the flat plate-column assembly of ten reinforced slabs were investigated. Synthetic fibers (Polypropylene and two aspect ratio of polyvinyl alcohol) were added to the dense concrete that includes 63 % of fine aggregate. Ten square slabs of same reinforcement ratio (0.9 %) and same dimensions (500 × 500 × 60 mm) were used in investigation. The main parameters was the effect of different fibers type and volume fraction of the fiber. Where, two types of fiber are used, with three percentages of volume fraction, fibers are used (0.5, 1.0, and 1.5 %), compared to normal concrete slabs.

The obtained result were compared with the proposed equation by ACI318-14, where the maximum ultimate load obtained from experimental work was higher than that ultimate punching shear load by 186 %. This result was reached by adding 0.5 % of PVA of 6 mm length. The test results shows that, adding fibers to the dense concrete are increased compressive strength by 74 %, moreover, increasing the load resistance gradually as the fiber content increases. The enhancement of the ultimate resistance load can reach 45 %. In the same manner, adding fiber, increased the first crack resistance load up to 59 %, and reduced the deformation of the slabs compared to the normal concrete.

Key Words: PVA and PP fibers reinforced concrete, residual punching shear strength, conventional steel reinforcement.

ÖZET

ELYAF KATKİLİ BETONARME İKİ YÖNLÜ DOSEMELERİN DAVRANİSİ

ABBAS, Israa Sabbar
Yüksek Lisans Tezi, Insaat Mühendisliği
Tez Yöneticisi: Prof. Dr. Mustafa ÖZAKÇA
Aralik 2017
72 sayfa

Döşeme kolon bağlantısı yapısal bir sistemdir, burada kolon sütun başlığı veya levha panel olmadan döşemeyi desteklemektedir. Bu tür bağlantı, çökmeye neden olabilecek yüksek kırılganlık davranışını göstermektedir. Çeşitli elyafların eklenmesi bu problem için en önemli çözümlerden biridir. Kırılganlığı azaltmak için elyaf yoğun matrise eklenmekte, buda matrisin liflerle olan bağını ve çatlama sonrası mukavemeti arttırdığı görülmektedir. Rastgele yönlendirilmiş lifler kompozit malzemeler gibi davranarak betonların mukavemetini artırmaktadır.

On tane betonarme döşeme kolon bağlantısının davranışı araştırılmıştır. % 63 oranında ince agrega içeren yoğun beton üzerine sentetik lifler (Polipropilen ve iki boy oranı polivinil alkol) eklenmiştir. Araştırmada % 0.9 donatı oranına ve aynı boyutlara (500 × 500 × 60 mm) sahip on kare döşeme deneysel olarak incelenmiştir. İncelenmen temel parametreler, farklı lif tür ve boyuları ile hacim fraksiyonunun etkisi idi. İki tür lif ve (0,5, 1,0 ve 1,5%) hacim fraksiyonunda üretilen lifli döşemeler normal beton döşemeler ile kıyaslanmıştır.

Elde edilen sonuçlar ACI318-14 tarafından önerilen denklem ile karşılaştırılmıştır. Burada deneysel çalışmadan elde edilen maksimum nihai yük, son zımbalama makası yükü standarta göre% 186 daha yüksektir. Bu sonuca 6 mm uzunluğunda% 0.5 PVA ilave edilerek ulaşılmıştır. Test sonuçları, yoğun beton üzerine elyaf eklenmesinin, basınç dayanımı % 74 oranında arttığını ve ayrıca, lif içeriği arttıkça yük direncinin kademeli olarak arttığını göstermektedir. Nihai direnç yükünde % 45'e varan artışa ulaşılmıştır. Aynı şekilde, fiber eklenerek, ilk çatlama direnci yükü % 59'a kadar yükselmiş ve döşemelerin normal beton ile karşılaştırıldığında deformasyonunu azaltmıştır.

Anahtar Kelimeler: PVA ve PP lifli betonarme, artık zımbalama mukavemeti, konvansiyonel çelik takviye.

To my Parents, I am grateful to God for having parents like you. Your unconditional love and support made my every achievement possible.

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LIST OF SYMBOLS/ABBREVIATIONS

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
A	Area
BS	British standards code
Lf/df	Aspect ratio of fiber
CFRC	Carbon Fiber Reinforced Concrete
CFRP	Carbon Fiber Reinforced Polymer
f'_c	compressive strength of concrete
f_{ct}, f_{sp}	Tensile strength for concrete
FR	Fiber Reinforcement
f_y	Yield stress of steel
GFRC	Glass Fiber Reinforced Concrete
GFRP	Glass Fiber Reinforced Polymer
HSC	High Strength Concrete
NFRC	Natural Fiber Reinforced Concrete
SEM	Scanning Electron Microscope
SFRC	Steel Fiber Reinforced Concrete

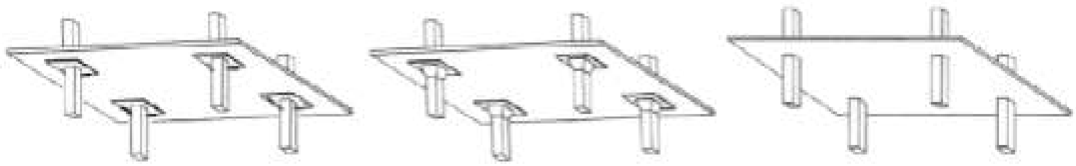
SNFRC	Synthetic Fiber Reinforced Concrete
δ_u	Deflection at ultimate
δ_{pcr}	Deflection at first crack
P_u	Ultimate load
ρ	Reinforcement ratio
d	Effective depth
ϱ	Tension reinforcement ratio
JSCE	Japan Society of Civil Engineering
PC	Portland Cement
P_{flex}	Ultimate flexural capacity
m_R	Moment capacity
b_o	Perimeter of critical shear crack
c	Column dimension
V_f	Fiber volume fraction
v_c	Factored nominal shear stress
v_s	Shear reinforcement
v_n	Nominal shear strength
v_u	Ultimate shear force
V_u	Punching shear nominal strength
V_b	Vertical fiber pull out stress along inclined crack
LVDT	Linear variable displacement transducers

CHAPTER 1

INTRODUCTION

1.1 General

One of the most common structural components is Reinforced Concrete (RC) floor slabs. Concrete floor slab systems have taken many forms since their first constructed, but one of the most economical types of slabs is a beamless floor system supported directly by columns, generically indicated to as flat slab or flat plate. However, different types of beamless slabs utilized for RC buildings such as flat slab with drop panels, flat slab with both drop panels and column capitals, and a slab without column capitals and drop panels, more commonly referred to them as flat plate (see Figure 1.1). Flat-plate construction is frequently used in residential and office buildings where gravity loads are low and relatively short spans are utilized. Regions with high seismicity require the flat-plate system to be constructed according to gravity load-carrying system (see Figure 1.2) or (Park and Gamble, 2000).



a) Flat slab with drop panels　　b) Flat slab with drop panels and column capitals　　c) Flat plate

Figure 1.1 Types of slab-column connection (Park and Gamble, 2000)

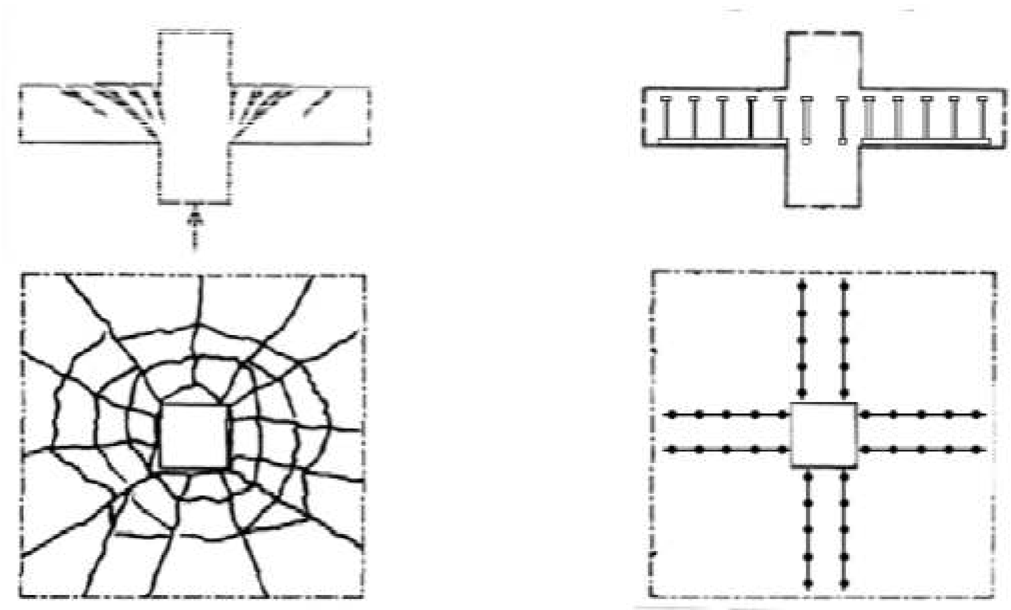
Without depends on beams as a support member, a flat plate inherently has low vertical stiffness; consequently, the clear span for a flat plate building is generally limited to 6 m, roughly corresponding to a span-to-depth ratio of 30. Post-tensioning can be used to increase this ratio to approximately 45 (Xia, 2008). The slab thickness of flat plates is commonly controlled by design code provisions according to the two-way shear resistance or deflection serviceability.

Figure 1.2 Flat plate apartment building with shear walls as lateral load-resisting system (Delray Engineering Inc., 2015)

Commonly a reinforcement ratio less than 1.0 % is used for slab resisting negative bending moment at a slab-column connection (Sherif and Dilger, 1996). Slab bottom reinforcement, which is resisting positive moment, is usually governed by the minimal reinforcement demands with an even lower reinforcement ratio.

The failure of flat plates is generally guarded by punching failure of the slab at columns. Furthermore, punching shear as shown in Figure 1.3a is defined as an event where the highly concentrated slab bending moment and shear localized at a column creates a shear failure cone that breaks through the slab.

Punching shear can be brittle and, although it is a local failure, the surrounding connections will need to carry additional gravity loads initially held by the failed slab-column connection. If the surrounding connections are unable to bear the redistributed loads, the reaction from punching failure over the all integrated floor ought to trigger, resulting in a large-scale or even complete collapse of the building. This type of failure is catastrophic because no external, visible signs can be seen prior to the occurrence of the failure. Punching shear failure disasters have occurred several times in the last decades. On June 30, 1995, a five-story department store in South Korea collapsed due to punching shear failure. In this disaster, 500 people were killed and almost 1000 people were injured, see Figure 1.4.



a) Punching failure b) Shear stud reinforcing

Figure 1.3 Punching failure and typically used slab shear reinforcement (Park and Gamble, 2000)

Figure. 1.4 Post-collapse photograph of the Sampoong Department Store

A solution to avoiding punching failure is through the use of shear reinforcement such as shear studs (see Figure 1.3b). Shear studs could be used when the flat plate structure exposed to these following situations:

(1) A large unbalanced moment produced by pattern or lateral loads requirements to be transferred by slab-column connections.
(2) The slab carries heavy gravity loads.
(3) The span length is relatively large.

However, for slabs that have low reinforcement ratios as is common on a flat plate, flexural capacity can govern the design even with large amounts of shear reinforcement (Lips et al., 2012). Moreover, there another active method had been used to control the post-crack strength by using some high tensile strength materials as a normal construction method had been considered in the meantime. However, a good solution to control the post-crack behavior of brittle materials, like ordinary concrete and masonry bricks, is adding fibers to the mixtures.

While the first examples for using fiber as reinforced materials were mud huts constructed by baked clay when the straw used as a reinforced material and in masonry mortar case the animal hair used as a reinforced material also. At this time, there are several and different types, size, shape, and materials of the fiber depends on the purpose of using and the compatibility of those materials. Synthetic fibers are relatively, among of the synthetic fibers, Polyvinyl Alcohol (PVA), and polypropylene (PP). PVA fiber is a comparatively a modern inclusion. Though, PVA fiber in the concrete matrix is admitted to be stable and durable in case of alkali environment existent (Garcia et al. 1997).

According to the high tensile strength high, elastic modulus and a hydrophilic surface the fiber is Classified while the tensile strength between 0.9 GPa and 1.6 GPa and the elastic modulus between 23 GPa and 40 GPa. As result of that mechanical properties, the fiber can make an excellent chemical bond with the cementitous material (Redon et al. 2001). Another fiber type used widely is PP, which is one of the synthetic fibers that used with normal concrete, in order to enhance the distribution the stress through the slabs. In addition, it is less sensitive to the unfavorable chemical reaction compared to the conventional bars (Mehta & Monteiro, 2005). The low tensile strength of the PP (350 MPa) compared to reinforcement bars and other fibers are employing good interaction between the bond and yielding strength of the fibers.

In the cracked section, the concrete matrix cannot resist the tensile strength and then the fibers hold this stresses up to fibers tensile and/or bond strength. Increasing the load, the fibers will transfer the stresses due to the bond stress, if the yield strength is more than the bond strength, additional cracking in the concrete will take place until reaching the fiber tensile strength and/or pull-out. Therefore, the bond between the fibers and the matrix plays important roles to enhance the posting behavior whereas the fiber strength has less effect on this process. Based on these premises, and as a part of series of investigations on the effect of various types of fibers on the behavior of flat plate connection, authors are attempted to use the PP with a matrix of concrete that includes high percentages of the fine aggregate. The main judgment on the level of improvement based on the strength of the section and the toughness of the slabs. According to ACI (ACICT-13, 2013), terminology toughness is defined as "The ability of a material to absorb energy without rupturing"; in the current work, the toughness is calculated as the area under the load-deflection curve up to 50 % of the peak load.

The first studies that dealt with fiber reinforced concrete were named for Romualdi and Batson in 1963 when the studies had been used for industrial construction purpose. At first, the researchers had been concentrated on the mechanical properties of selected material and had been pursued by a number of applications. By modernization in the improvement of materials, many structural applications have been proposed, for example, constriction that made in the car park for Heathrow Airport in London (ACI 544.4R, 1988), and in the constriction process for the foundation slab of Potsdamer Platz in Berlin (Falkner et al., 1997). The new application is generally examined when the roads, concrete floors, and concrete pavements are used, in the precast industry and for tunnel lining. Utilizing fibers in floors, even in case of the low volume fractions when the fractions bigger than one present, fiber can improve the ultimate load and could be used as a substitutional for conventional reinforcement (Cominoli et al., 2006).

FRC is a composite material consisting of concrete (mainly of hydraulic cement), coarse and fine aggregates, and discrete reinforcing fibers (ACI 544.1R, 1997). Fibers have different shapes such as a long slender needle in particles form that are added to cement paste, mortar or concrete matrix. Fibers satisfactory for reinforcing concrete were produced from steel, basalt (BFRP), glass (GFRP), aramid (AFRP) and organic polymers (synthetic fibers). Some of them are comparatively rigid like steel while others have flexible behavior like glass or PP, relying on the shape and type (Naaman et al., 1984). The concrete matrix could be mortars, ordinary proportioned concrete mixtures, or mixes specifically formulated for a specific application. Commonly, the effective size of standard fiber FRC mention as following, the length and diameter do not exceed 76 mm and 1 mm, respectively (ACI 544.1R, 1997).

For brittle material like ordinary concrete is considered to have no important post-cracking ductility. Fibrous composites had been and are being expanded to contribute the improvements of mechanical properties to the differently brittle material. When exposed to a tension force, these brittle matrices without reinforced deform elastically. The elastic deform is followed by micro-cracking, contained micro-cracking, and finally by fracture at comparatively low strains. (Johnston, 2001).

In several applied applications, the matrix first-crack strength is not improved. On these circumstances, the most important improvement from the fibers is the post-cracking composite response. This is very popular estimated and measured through toughness testing (such as measurement of the area under the load-deformation curve).

If properly engineered, one of the highest benefits to be gained by using fiber reinforcement is enhanced long-term serviceability of the structure or product. Serviceability is the ability of the specific structure or part to maintain its strength and integrity and to provide its designed function over its intended service life (Shah, 1992).

1.2 Problem Statements

Using FRC, always focus on the development of ductile critical elements for various structural applications, one of the important structural element is the panels. The problem with the panels' behavior is the fictitious interaction between the shear and moment. This interaction will be more complex when analyzing the two-direction behavior; moreover, during reviewing the literature it is found the panels that subjected to partial lateral force has its unique complexity.

Among wide solutions offered to improve the ductility and increasing the strength of the panels for both shear and moment section strength, fiber concrete is used. For this type of concrete materials, finding the critical volume fraction and aspect ratio of the fibers is the main interesting requirement.

The critical fiber volume fraction is depending on fiber itself in addition to the matrix, this leads to other dependence, which are the fiber/matrix interaction properties.

1.3 Objectives and Scopes

The aim of this research was to investigate the following aspects of fiber-reinforced slabs made;

1. Evaluate the effectiveness of each type of fibers (PP and PVA fibers) on the shear strength of slabs.
2. Investigation of the effect of different types of fibers volume fraction on punching shear capacity.
3. Investigate the failure mode and crack patterns at failure stage.

1.4 Structure of the Thesis

This thesis consists of five chapters, as below:

Chapter 1 where the punching shear problem was defined and the theses outlines are introduced.

Chapter 2 presents the literature review of punching shear behavior for different reinforcement types conducted on flat slabs. This chapter provides a brief description of the FRC materials and their characteristics and presents the equations proposed by researchers.

Chapter 3 describes the experimental work on two-way flat plate slabs. The details of work and specimens are stated. This chapter provides the detail characteristics of the materials used in this research. The details of the test steps and instrumentations are also given.

Chapter 4 presents the results and discussion of the experimental work. The test results are employed to evaluate the accuracy of current equations to predict the punching shear capacity of FRC two-way slabs.

Chapter 5 presents the conclusion and recommendation depending on the experimental of this work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Concrete slab panels are a common structural element of modern building at the same time. The wide diversity of materials and factors that directly affect the behavior of slabs is also varied, therefore; an intensively studies on the factors and characteristics that affect it and how to improve it are always conducted such as adding synthetics fiber to the mix.

This chapter begins with a review of available experimental studies concerned with punching shear in structural slabs reinforced with different types of internal FRC reinforcement. For the sake of comparison and to help understand those aspects of the punching shear behavior of FRC reinforced members that have not been fully investigated yet, literature pertinent to the punching behavior of steel reinforced slabs is subsequently discussed.

This chapter presents an overview of different topics related to this research investigation. There are several types of fiber shapes and materials in the building industry. Synthetic fibers are comparatively new and there are a few-reported research or field experiences on some types of them. Among of the synthetic fibers, PVA, and PP. This fiber is a relatively new inclusion.

2.2 History

Began to use the fibrous material as a reinforcement for brittle material like mud bricks or with mortars before more than 3500 years ago as found in the ancient city of Aqar Quf near Baghdad (Hannant, 2000).

In 1874, the American A. Berard obtained a patent on the idea of combining concrete with fibers. About 30 years later, in the France in 1918, H. Alfsen obtained a patent the development of adding fibers of steel, wood or other appropriate materials in concrete to increase its tensile strength.

New materials to reinforce concrete has been found. The synthetic fiber is one of these materials, synthetic fibers have been developed and used for the past 30 years. Research to find new fiber types to reinforce concrete still continues to the present day.

2.3 Fiber-Reinforced Concrete

Used the Steel reinforcing bars or prestressing traditionally to overcome low strain capacity and low tensile strength at fracture in unarmed concrete. To improve the mechanical properties of concrete can be use different types of fibers unlike reinforcing continuous steel, that is located in specific locations in the structure to enhancement performance, and Intermittent fibers are randomly distributed in the concrete mixture. Fiber properties significantly effect on FCR properties such as strength of bonding between fiber and concrete, volumetric fracture of fibers, fibers type and direction. Figure 2.1 shows the performance of ordinary concrete compared to the FRC under bending, FRC show resistance under the bending load after the first crack compared to ordinary concrete, which does not contain the strength of curvature after the crack, due to the nature of materials (Payrow, 2008).

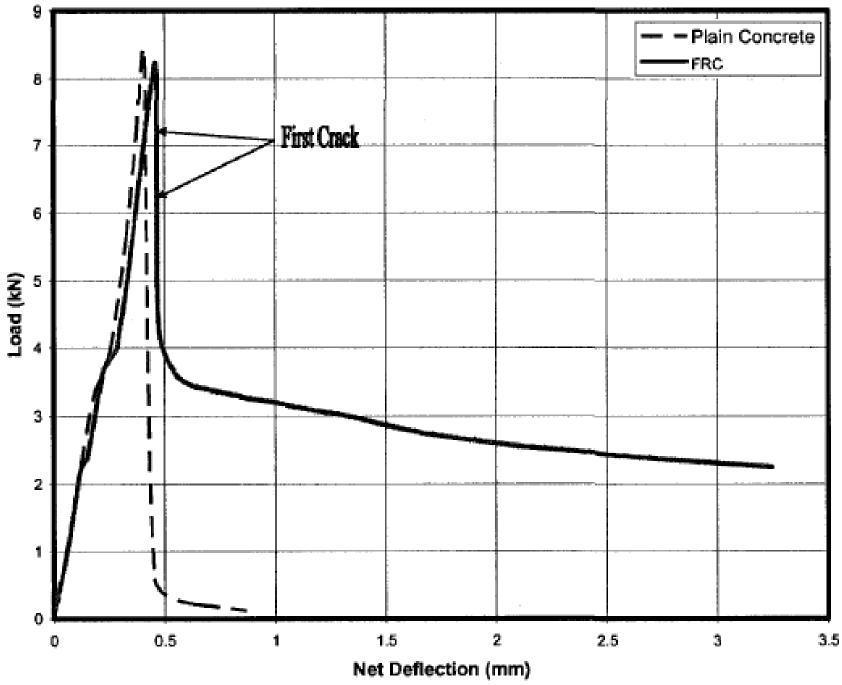


Figure 2.1 Typical load- deflection curves for matrix and FRC in bending (Payrow, 2008)

There are about many different kinds of fiber used as reinforcement. According to ACI 544, there are four FRC based on fiber material type:

- Steel Fiber Reinforced Concrete SFRC.
- Glass Fiber Reinforced Concrete GFRC.
- Natural Fiber Reinforced Concrete NFRC.
- Synthetic Fiber Reinforced Concrete SNFRC.

2.3.1 Polypropylene fibers

PP fiber is a synthetic hydrocarbon polymer. According to ACI 544R-2003, synthetic fibers are fibers that make and develop by human using petrochemical and textile industries. Different sizes and shapes with differing properties are produced from homopolymer PP resin.

Fibers has been developed to increase bonding with concrete by separation and branching of the fibrils in the polymer strand over the mixing stage (Krenchel and Shah, 1985).

It was observed that bonding occurs through chemical reaction and because of the nature of PP fibers; it is not expected to be chemically linked (Rice et al., 1987). The fibers are used for inhabits and controls plastic shrinkage cracks, improving the tensile and flexural strength of concrete

2.3.2 Polyvinyl alcohol fibers

Poly (viny1 alcohol) is adopted from poly (viny1 acetate) which is easily hydrolysed by processing an alcoholic solution with aqueous or alkaline acid, which leads to the structure shown in Figure 2.2 (Feldman 1989). PVA produce a remarkable change in surface bond strength between PVA fibers and the matrix (Xu et al. 2010).

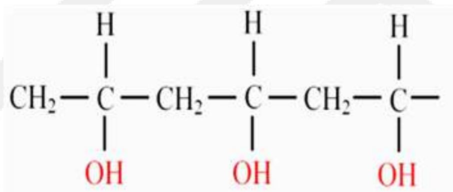


Figure 2.2 PVA fiber structure (Feldman, 1989)

PVA is a white powder with specific seriousness ranging from 1.2 – 1.3 (1200-1300 kg/m3) (Toutanji et al., 2010). This powder is then formed and extruded into a PVA fiber, which is produced commercially. PVA fibers mostly have aspect ratios (L_f/d_f) of 45 to 250 and different cut length varying from 6 to 30 mm to make fibers suitable for different applications. Depending on fiber geometry (length and diameter), elastic (Young's) modulus and the tensile strength of PVA fiber differ. It varies from 1600 to 800 MPa in the case of tensile strength and 40 to 23 GPa with respect to the elastic modulus with an increase in fiber length and diameter. PVA fibers are also available in both resin bundled (oil coated) and virgin (non-coated) type.

PVA fiber has a rough surface. This property significantly enhanced the mechanical interlocking related cohesion capacity of this fiber in a matrix (Felekoğlu et al., 2009). To illustrate the differences in the roughness of the surfaces between the fibers, Scanning Electron Microscope (SEM) images displayed at the same magnification of

PVA fiber versus PP fiber, which has a very smooth surface structure, are presented in Figure 2.3.

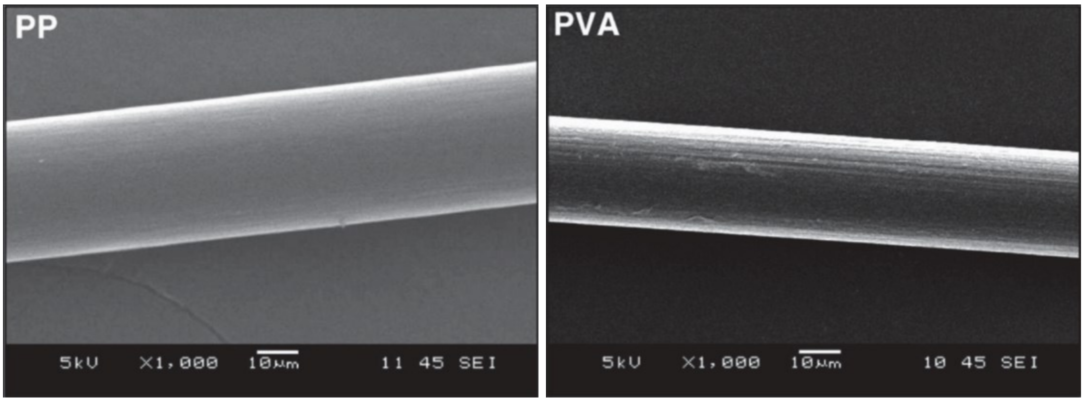


Figure 2.3 SEM images of PP and PVA fibers (Felekoğlu et al., 2009)

PVA fiber serves many advantages when utilized in concrete or composite cement. It has a high ultimate tensile strength, high aspect ratio, comparatively high modulus of elasticity, good chemical compatibility with Portland cement, good affinity with water and no health risks. Since PVA fibers are generally stiffer than the concrete matrix and provide a good interfacial bond with the cement matrix, they mostly have a positive impact on the bending strength and other mechanical properties of their composites.

2.4 Punching Phenomenon

For the slab-column connection, the punching shear strength is define as the net ultimate reaction at the column's contraflexure points and the failure can be mostly categorized as either shear or flexural, depending upon whether the failure is started by yielding of reinforcement, shaped internal diagonal cracking and crushing of concrete.

When a reinforced normal strength concrete flat slab structure is subject to heavy gravity load, punching shear cracks occur at slab tension surface in column vicinity, they propagate at 20°-50° angles through the slab thickness to shape a truncated conical or pyramid failure surface around the column. In additional to vertical loads, the slab-column. Connections may be subject to unbalanced moments, which may be caused for example by unequal spans on both sides of the column or by lateral loadings such as wind or earthquakes. The unbalanced moment is resisted by a combination of stresses in slab flexural reinforcements, the shear strength of concrete, and shear reinforcement in the perimeter of the column (Al-Quraishi and Fehling, 2012).

The punching shear failure mechanism of the normal strength concrete slab under punching shear usually starts with flexural cracking in the tension area directly under the support column. These cracks are distributed in radial and tangential directions with load increasing utill the critical shear cracks open and then are distributed to form the failure cone diameter at the tension area. Shear cracks move towards the compression area through the thickness of the slab to form the whole punching shear cone, see Figure 2.4 (Al-Quraishi and Fehling, 2012)

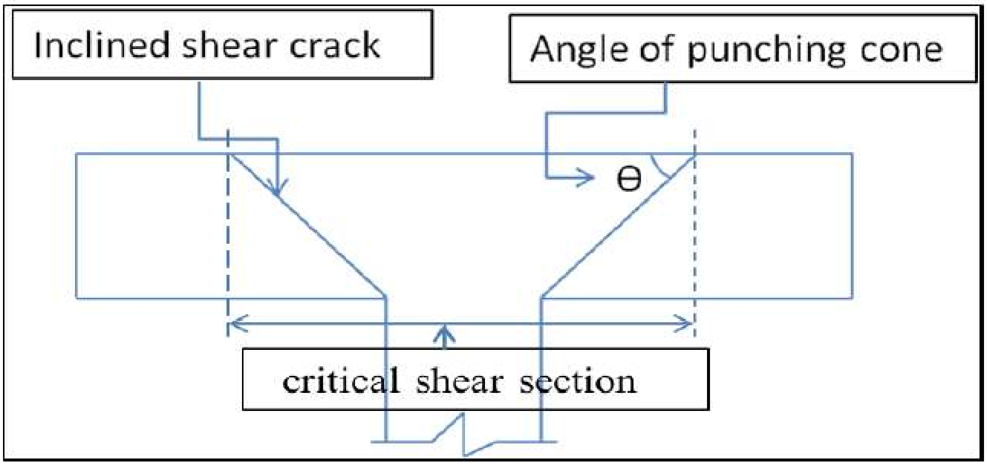


Figure 2.4 Punching shear failure model (Al-Quraishi and Fehling, 2012)

Punching shear depends on the following factors:

Concrete strength: From previous studies, one of the main factors that impact the punching shear resistance is a concrete tensile strength. Exceeding the principle tensile strength of concrete leads to begin concrete cracking. The tensile strength of the concrete is assumed to correspond to the square root of the concrete compressive force. Therefore, increasing the strength of the concrete compressive leads to increased shear punching strength and flexural stiffness of flat plate structure (Al-Quraishi, 2012).

Slab dimensions: The ratio of span length to the effective depth has an impact on the punching shear strength. When this ratio decrease, the punching shear resistance increase (Lovrovich and Mclean, 1990). Furthermore, the increase in the ratio of column size to efficient depth ratio leads to a reduction in the punching shear stress for flat plate members (Moe, 1961).

Reinforcement: Depending on the studies and literature, the increase in reinforcement leads to an increase in shear force punching of the slab. An increase in the proportion of tension reinforcement leads to an increase in the hardness of the slab. There is agreement on the minimal effect of strengthening the compressive force on shear punching in a flat plate.

Column shape: Punching shear in flat plate depends on the column shape. Punching shear with the circular column is greater than the square column because the stress distributes uniformly around the circular column, but in the square column, the stress concentrates near the corners of the column. In addition, the aspect ratio of the column has an impact on the punching shear, when the aspect ratio increases lead to decrease in the punching shear strength.

Openings: In flat plate slabs, the location of the opening affects the punching behavior. There is some application of the openings for various purposes such as electrical, heating, air condition, etc.

2.5 Previous Research

As the years progressed, numerous analysts have had their primary concentrate on expanding punching behavior of slab-column connections. Kinnunen and Nylander (1960) were right on time with the improvement of a way to deal with process the punching behavior in view of mechanical perceptions. Other pioneer researchers tested shear heads (Corley and Hawkins, 1968), while other tested bent-up bars end closed stirrups (Islam and Park, 1976), and shear studs were the main concern (Dilger and Ghali, 1981).

Moe (1961) tested around forty-three 6-foot square slab specimens and reviewed test findings from 260 slabs and footings tested by previous investigators. He suggested that the flexural strength had some influence on the shear behavior of slabs. Moe also summarized that the concentration of the flexural reinforcement does not result in an increase in the shear strength but that it does improve the toughness of the load-deformation response and the load at which initial yielding occurs. He determine the following term for evaluate the ultimate shear strength of slabs:

$$V_u = \frac{v_u}{b\,d} = [15\,(1 - 0.075\,\frac{c}{d}) - 5.25\,Ø_o]\,\sqrt{f'_c}\ \text{(N and mm)} \quad (2.1)$$

Yitzhaki (1966) presented a method for calculating the punching behavior of two-way slabs. The relation between the flexural resistances and the punching shear of the slabs was also presented. He determines that the punching strength depends mainly on the flexural reinforcement strength (f_y) and concrete compressive strength (f'_c). The punching shear strength at distance d from the face of the column can be calculated from:

$$V_u = (149.3 + 0.164\,\varrho\,f_y)\,[1 - (0.5\,\varrho\,f_y) /\ f'_c]\,b_o\,d \quad (2.2)$$

Where; ϱ is the tension reinforcement ratio, b_o is the critical shear perimeter at distance d from the face of the column, d is the effective depth of the slab.

Swamy et al., (1979) implement a test on slab-column connections without or with fibers. The nineteen model were balanced full-scale models of flat slab structures, although five did not have fiber content. To examine different factors, the 19 connections were divided into five groups. In the series, one and three were the attention on the proportion of fiber volume and fiber type, respectively. In the two series, the fiber area was considered and the emotional reinforcement distribution. The reduction of arming and variation of cutting shear was the basic parameter that was considered in the fourth and fifth series, respectively

They assessed that blended fibers were more effective than normal fibers, but less efficient than crumpled fibers. The best-crimped fiber was deformation resistance and increased punching shear capacity, ductility, and energy absorption capability.

Hawkins and Mitchell (1979) reported that in a punching shear failure the shear strength is dependent on the flexural capacity of the slab and that it will decrease as the stiffness of the connection decreases. Accordingly, the ultimate shear strength of connections transferring shear will decrease if significant yielding of the flexural reinforcement takes place. They also noted that concentrating flexural reinforcement in the directly column region slightly increased the capacity of the connection but its decreased ductility.

Swamy and Ali (1982) investigated the effects of FRC on the punching shear behavior of slab-column connections. Similar results were made from the slab-column tests as from their previous research. The results showed that with the addition of 1 % fiber by volume, the specimens showed: an increase of punching shear Load by 40 %, a reduction of deflections by 30 % at service load, a reduction of steel strains, concrete strains, and rotations by 40-50 %, an increase in residual load of 200-300 %.

They also reported that placing FRC a distance 1.5h from the column face is as effective as constricting the entire slab of FRC. The FRC seemed to push the failure surface far away from the column faces, creating a larger failure surface.

Narayanan and Darwish (1987) discussed the effect of fiber reinforcement on the punching shear capacity of micro-concrete slabs by examining twelve simply supported slabs up to failure. The variables studied were the volume fraction of fibers, tension reinforcement ratios, and concrete compressive strength. The results showed that increase fiber content improved the shear resistance adjusted the position of the critical perimeter. They proposed the following equation:

$$V_u = \xi s \,(A\, f_{ct} + B\, \varrho + V_b) \qquad (2.3)$$

Where; ξ_s is empirical depth factor =1.4, A is non dimensional constant =0.24, B is dimensional constant = 16.

Broms (1990) demonstrates a method for calculating the shear strength and deformities at interior columns for flat plates. Failure is assumed to take place when the compression zone of the slab approximately the column is distressed either by a high tangential compression strain or by a high radial compression stress. The effect of the concrete brittleness and Size effect is increased with increased strength are both considered.

Lovrovich and McLean (1990) the results of the experimental investigation of the shear ability of the RC slabs were presented with varying depth ratios. The thickness of the slab was kept constant while the support diameter was changed to reflect different depth ratios was noted that with the reduction of the depth of the slab less than 6, shear resistance increasing to about 5 times greater than the 1983 ACI building code predicted capacity. The higher capacity was a result of smaller span-depth ratios.

Marzouk and Hussein (1991) a number of plates were tested to verify the strength and deformation characteristics of punching shear failure of high strength concrete plates. The results showed that with the increase of the reinforcement ratio, the punching resistance of the plates increased. It was found that the use of cubic root of the concrete compressive strength gives good results than the square root expression used in ACI Codes.

Alexander and Simmonds (1992) they described the test results for the failure of six samples to simulate the isolated slab-column connection, to determine how shear resistance was affected when adding different amounts of fiber to the concrete and changing the concrete cover of the reinforcement bars. The results confirmed that even adding a small amount of fiber to the concrete would increase the performance of the slab-column connection and regardless of the thickness of the concrete cover; the fiber works to improve the ductility and strength of the concrete.

McHarg (1997) examination of the strategic use of fiber reinforced the slab to suggest the best way to improve performance. The variables studied are the punching shear capacity, the negative moment cracking and slab stiffness.

The test results showed improvements that could be made to improve concrete. By providing fibers, cracking load has been increased to about 21 % compared to normal concrete. The plates tested with fibers showed improved crack control and a tendency of higher shearing ability.

Marzouk et.al (1998) Test the slab-column connections under the sets of lateral load and gravity to investigate the effect of using a high-strength concrete slab on the structural behavior of slab-column connections. The strength of the concrete slab increases from 35 to 75 MPa, increasing shear capacity by 7 to 15 % to load the cases from zero and high shear rate for the moment respectively. The use of high-strength slab has a significant impact on the load-deflection characteristics for samples that subject high moment and can be economically justified when good ductility and higher levels of absorbed energy are needed for slab- column connections under high moment

/ shear ratios. The first yield of the samples constructed with a high-strength concrete slab occurs in load, essentially less than those for samples constructed with plain concrete strength. Meanwhile, under high moment the contact displacement and softness rotation increase by 75 % for samples with high strength concrete slabs. On the other hand, it is not recommended to use high strength concrete plates to connect the column slab exposed to gravity loads only because of the small increase in punching capacity to contact compared with the high cost of using high strength concrete.

Menetery (1998) showed experimentally flexural and punching failure tests on flat slabs. This allows the monitoring of the descending branch of the load-displacement curve, and demonstrates that flexural failure is characterized by a smooth decrease of the load carrying capacity, whereas punching failure exhibits a sudden reduction of this capacity. He showed that the punching load was reached for a punching crack inclination of about 30 degrees to the middle plane of the slab. By increasing this inclination, the flexural failure load was closed and the sudden decrease of the load carrying capacity was reduced.

Azevedo (1999) studied the ductility, shear resistance for slab-column connections, and concluded that the addition of high-resistance concrete and fiber greatly improved the ability of shear resistance and reinforced the slab-column connection.

Gomes and Regan (1999) analysis of twelve flat plate panels 3.0 × 3.0 × 0.2 meters with 200 mm square column, to study the shear reinforcement effect on the punching resistance. For this purpose, short lengths of steel I-beam were used. The shear strength is arranged in the surrounding layers around the columns. The most powerful practical measure of experimental analysis is that the failed punching load of a RC flat slab may be at least double with the use of shear reinforcement

Osman et.al (2000) tested high strength lightweight slabs under concentrated loads. Four slabs were constructed of high strength lightweight concrete with the steel ratio ranging from 0.5 to 2.0 %. The two references specimens were constructed with normal strength concrete and lightweight aggregates and had steel reinforcement ratios of 1 and 0.5 %. The results included the ultimate loads, deflections, modes of failure, crack patterns, ductility, concrete strain, and steel strains. The analysis results were compared with other test data on high strength and normal strength normal weight concrete slabs and code predictions for slab strength. Generally, a reduction factor of 0.85 is advised for lightweight aggregates by the ACI code. These reduction factors are conservative when used for high strength concrete. A reduction factor of 0.95 is more acceptable for high strength lightweight concrete, and of 0.85 for normal strength lightweight.

McHarg et.al. (2000) test six samples of two-way slab-column, the probe parameters were placement of FRC in the slab and the focus of slab reinforcement around the column. Use FRC and the beneficial effects of the reinforcement slab are reported near the column.

Sherif and Dilger (2000) presented test setup of two full 5m continuous RC flat slabs. Based on a result of test, the shear strength of slab-column connections were derived in a real slab system with actual border conditions.

Ngo (2001) compared a total of twenty-nine test results from four types of research, with the values of punching strength calculated by using AS3600 (Standard Association of Australia 1994). The tests were applied on square or circular slabs supported by column stubs or loading plates, with the variety of concrete strength, slab reinforcement, and slab depth. It is shown that the provisions in AS3600 are applicable up to 100 MPa; however, the ratios between observed and calculated loads show that AS3600 is less conservative for high strength slab.

Teng et.al (2004) Concentrated on punching strength of slabs with openings and supports on rectangular columns. The openings reduced the punching strength greatly and the best place to open is along the longer side of the column if the opening use is inevitable, discovered that the stresses in the panels was mostly concentrated around the shorter sides of the rectangular columns.

Papanikolaou et.al (2005) carried out testing program including RC slabs with and without shear reinforcement, subjected to a concentrated load in the middle. The calculated punching shear strengths were compared with strengths predicted from two major design codes (ACI 318 and Eurocode 2), as well as from two models from the literature, the plasticity model, and multi-parameter empirical model. It was discovered that predictions by both codes were conservative in the case of slabs without shear reinforcement; Eurocode 2 and ACI 318 predictions are generally similar in this case. Less conservative predictions were found in the case of slabs with shear reinforcement, particularly in the case of Eurocode 2 that overestimated measured strengths of the slabs with stirrups.

Binici and Bayrak (2005) presented results of an experimental study on punching shear strengthening of RC slab-column connections using Carbon Fiber Reinforced Polymers (CFRP). Externally fixed CFRP stirrups considered as shear reinforcement was used as a strengthening technique. It was found that the proposed method resulted in punching shear capacity increases up to 60 % with respect to the specimen without any strengthening. In addition, displacement ductility and post punching resistance of the strengthened specimens increased, resulting in a more ductile failure mode than that of the references specimen.

Chen and Yan Li (2005) the behavior of shear resistance and failure of reinforced concrete in GFRP and steel reinforcing was studied. Reinforced concrete was compared to that of slabs with steel reinforcement, the results showed that the reinforced concrete with GFRP was increased the punching shear capacity of slab-column connections.

Hanai and Holanda (2008) try to compare the similarity between beams and FRC slabs. Panels are designed to fail through punching failures. The test result showed that the ultimate load performance was close to the estimated load values for flexural reinforcement, as more fiber was added to the concrete. The results also confirmed that the panels, cast with high strength concrete and 2.0 percent (160 kg / m3) fiber of the ratio of volume, cover the ductility outcome and the best strength.

Muttoni (2008) presented a mechanical analysis of the phenomenon of punching shear in slabs without transverse reinforcement on the basis of a critical shear crack theory. It leads to the formulation of a new failure criterion for punching shear based on the rotation of the slab. The new approach was shown to give better results than current design codes, with a very low coefficient of variation. Adding for the proposed failure criterion and the load-rotation relationship of the slab, the punching shear strength of a flat slab was shown to depend on the span of the slab, rather than on its thickness as often proposed.

Tian et.al (2008) presented experimental results of large-scale isolated slab-column connections subjected to three types of loading. The specimens failed in punching shear after extensive slab flexural yielding under different loading conditions. The damage caused by simulated seismic loading did not minimize the connection punching capacity under gravity loading. The post-earthquake connection stiffness was significantly reduced. The flexural reinforcement ratio had a significant influence on connection strength and stiffness.

Lee et.al (2009) determined the effect of the type of reinforcement (GFRP versus steel bar) on the punching behavior. In addition, the influence of concentrating the reinforcement in the immediate column region and the effect of using SFRC in the slab were also examined. Concentration the slab reinforcement and the use of SFRC in the slab improved the punching behavior of the slab reinforced with GFRP bars. Concentrating the top mat of flexural reinforcement was results in better effects on punching behavior, post cracking stiffness, and crack control.

Cho (2009) presented a new technique to improve the punching shear capacity in new flat plate structures using the studs with perforated steel plate reinforced at column-slab connections. Tests took place on slabs of 3/4 scale, which were designed to fail in punching shear. The slabs variables were as follows: first, stud rail as control specimens; second, used four stud specimens with perforated steel plates with different lengths; third, used a perforated steel plate with the same length as the stud with steel plate. From the test results, the following conclusions were found:

(a) The maximum strength of slabs have been designed to resist punching shear based on ACI 421 and Eurocode 2-04, and shear reinforcement for slabs has been compared with the results from the structural experimental.
(b) The studs contributed substantially to the increase of ultimate strength.
(c) The studs with steel plates contributed to the increase of ultimate strength.

Higashiyama et.al (2011) present an equation for the behavior of shear resistance of SFRC according to Japan Society of Civil Engineering (JSCE) standard specifications. The proposed design equation accounted for the critical shear perimeter changed by the fiber factor and fiber pullout strength. Furthermore, the design equation is verified by the test data conducted by earlier researchers, and consequently, the punching shear capacity of SFRC slabs can be predicted by the design equation with an applicable accuracy.

Moreillon, et al (2012) presented an experimental program on thin ultra-high polymer concrete slabs with and without conventional steel reinforcement. The goal from tests is to analyze the interaction between the thickness, the reinforcement ratio and fiber volume on structural performance. The tests have highlighted the good contribution of ultra-high polymer concrete combined with steel reinforcement on flexural and shear capacity. They also found that increases in fiber content tends to decrease the strain capacity at ultimate load by locating the plastic strains of the rebars on a single macro-crack.

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CHAPTER 3

EXPERIMENTAL WORK

3.1 Generals

This chapter describes the experimental work, which is conducted in the structural, and materials laboratory at the University of Gaziantep. The experimental program is described as following:

Experimental work consists of ten slabs, which were designed to study the punching shear strength of two-way flat plate slabs, which reinforced with fibers and steel bars. The experimental program can be described as follows: the main parameters are the effect of fiber percentage and different types of fiber. The experimental program comprises of casting and testing of ten slabs, including one control slab of normal concrete that were marked, three groups. Each group contains three slabs of different percentages of fiber, as shown in Table 3.1.

Table 3.1 Test groups.

Group No	Mix code	Fiber type	FiberV_f (%)
A	N	-	0
B	PV6-0.5 PV6-1.0 PV6-1.5	PVA/ 6 mm	0.5 1.0 1.5
C	PV12-0.5 PV12-1.0 PV12-1.5	PVA/ 12 mm	0.5 1.0 1.5
D	PP-0.5 PP-1.0 PP-1.5	PP/ 12 mm	0.5 1.0 1.5

All slabs will be compared with control panels of normal concrete, and the slabs designed to simulate the interior slab-column connection. The test specimens are simply supported along four edges to simulate the line of contra-flexure. A concentrated load are applied to the slabs through the column stub from the top.

3.2 Description of Slab

The specimens are selected as a square model with dimensions of 500 × 500 × 60 mm, which was supported by column steel plate of dimension 55 ×55 mm, this steel plate was used as loading through, where the slabs are supported by the special made support.

The support is 8 points of half steel balls, distributed with 45° degree central angles, with a total loading radius of 400 mm as shown in Figure 3.1 These half balls are used so that the frictions would be as minimum as possible, in this case, the axial forces induced from this friction are prevented.

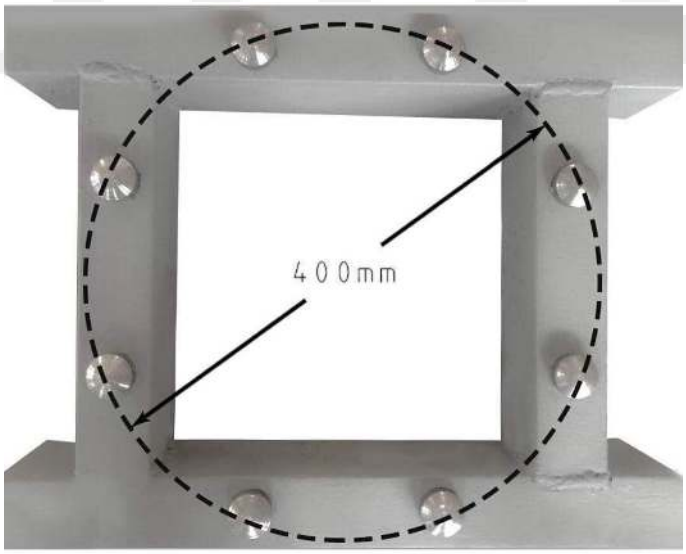


Figure 3.1 Test support model.

The specimens were designed to fail in punching shear ($V_u < P_{flex}$) where V_u is the punching shear nominal strength according to ACI 318, P_{flex} is the flexural capacity which is obtained from yield line analysis. Overall, all slabs are reinforced with one conventional reinforcement layer of 0.9 % ratio with an ultimate and yield strength of 476 MPa and 400 MPa respectively, an eight deformed bars of Ø5.3 mm diameter were used in each direction as shown in Figure 3.2. This reinforcement was placed orthogonally at tension face as a single reinforcement layer with clear cover of 15 mm and equally spaced in each horizontal directions $S_x = S_y = 67$ mm center-to-center. All bars were bended with 90 deg.; all free bends are tied together by additional one bar in each side of compression face.

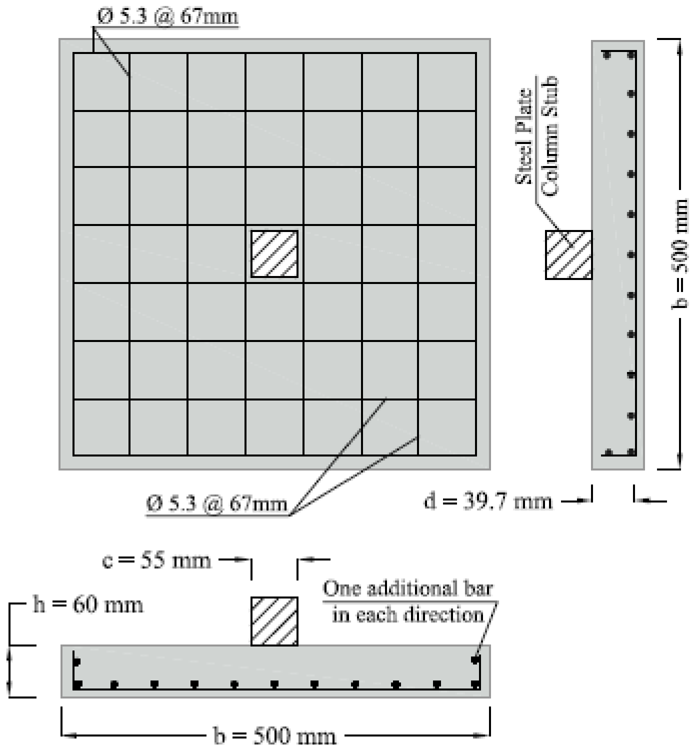


Figure 3.2 Slab geometry and reinforcement bars' details.

In order to construct slabs with uniform dimensions that can sustain the vibrating forces, and with right angle faces, the mold sides shutter is made from angle iron of 5 mm that is fixed perpendicularly to the plywood as shown in Figure 3.3.

Figure 3.3 Casting mold and reinforcement details

3.3 Materials Properties

The flat plate slabs were cast using normal strength concrete, which consists of ordinary Portland cement, water, fine aggregate, coarse aggregate, fibers, and silica fume.

According to earlier researchers and studies, fibers are more active with a mixture with fine aggregate, therefore; the plan was introducing a mixture with 63 % of fine aggregate and 37 % of the total mix percentage. Table 3.2 shows the design mix proportion.

Table 3.2 Concrete mixture amount per cubic meter

Mix code	C kg	G kg	S kg	S.fm kg	HWR kg	W Lt
N	465	680	1170	35	6.6	216
PV6-0.5 PV6-1.0 PV6-1.5						
PV12-0.5 PV12-1.0 PV12-1.5						
PP-0.5 PP-1.0 PP-1.5						

C; Cement, **G**; Gravel, **S**; Sand, **S.fm**; Silica fume, **HWR**; High water reducer, **W**; Water

3.3.1 Cement

Portland cement (PC) is a hydraulic cement that is manufactured as a homogeneous product by grinding together Portland cement clinker and calcium sulfate. The type of cement used in this study was cem II / A-LL 42.5 R. It is obtained from Limak Gaziantep cement factory.

3.3.2 Admixture

Admixtures are chemicals, added to mix of concrete at the mixing stage to modulate some of the properties of the mix. A superplasticizer is one of the classes of admixtures called water reducers that are used to depress the mix water requirement of concrete.

The basic advantages of superplasticizers include high workability of concrete, resulting in easy placement without a reduction in strength and cement content, high strength concrete with normal workability but lower water content, and a concrete mix with normal strength and workability but less cement. A super plasticizer under traditional name Glenium 51 is used, which it complies with ASTM C 494 Types A. The optimum dose is observed to be 0.5% of the weight of cement by done several trial mixes. The reduction in water for this dosage is up to 30%; it meets the requirements for superplasticizer (SP) according to [ASTM-C- 494] Types G and F and BS EN 934 part 2: 2001.

3.3.3 Fine aggregate

A graded river sand brought from a local source. The size of particles are ranging from 0.075 mm to 4.75 mm was used. The sieve analysis of the used fine aggregate as shown in Table 3.3 and Figure 3.4.

Table 3.3 Grading of fine (river sand) aggregate.

Sieve opening (mm)	Retained weight (gm.)	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

3.3.4 Coarse aggregate

A crushed stone with a gap graded of crushed stone is used. The maximum size of the particles was 9.5 mm. As shown in Table 3.4, and Figure 3.4 it is shown that there is a gap between particles of 4.75 mm and 9.5 mm, this means that even the coarse aggregate has higher fine aggregate.

Table 3.4 Grading of coarse (crushed stone) aggregate.

Sieve opening (mm)	Retained weight (gm.)	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

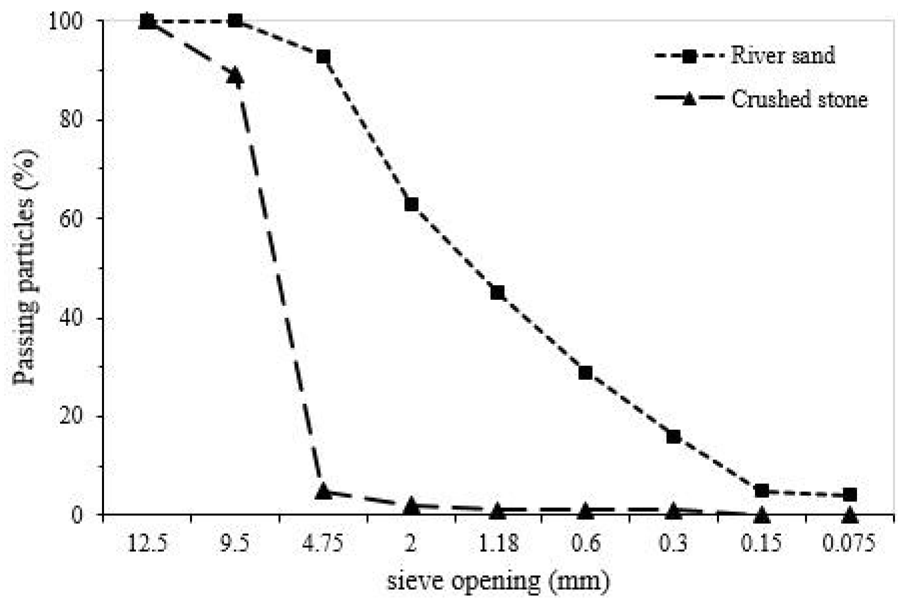


Figure 3.4 Fine aggregate and coarse aggregate sieve analysis.

3.3.5 Polyvinyl alcohol fiber

A product independently researched and developed by Changzhou TianYi Engineering Fiber Co., Ltd is designed for use in cement mortar or concrete to increase the internal quality, reduce maintenance cost and prolong the service life of cement mortar and concrete. PVA fiber can reduce the formation of shrinkage cracking in cement mortar and concrete prior to the curing process and increase their toughness.

PVA fiber is subjected to a process of dissolution, spinning, heat setting, cutting and baling to form a high-strength, high modulus fiber. This high-strength, high-modulus PVA fiber can disperse quickly and easily in the mortar and concrete mix after being added to the base materials. Due to its fine microstructure and large specific, the fiber can form a randomly oriented support system in concrete, which thus can effectively control the formation and development of non-structural cracking such as plastic shrinkage cracking and drying shrinkage cracking, effectively reduce the segregation of aggregate and the formation of settlement cracking. As a result, the concrete's impermeability, impact resistance, toughness and abrasion resistance are greatly improved and thus the architecture's service life is greatly prolonged. High-strength, high modulus PVA fiber has the higher tensile strength and elastic modulus than regular PP fiber and can replace subordinate reinforcement bar in concrete, which makes it superior to PP fiber. PVA fiber sourced from China as shown in Figure 3.5 are used in this study. Table 3.5 shows properties of PVA fibers as provided by the manufacturer.

Table 3.5 Physical properties of PVA fiber.

Fiber type	**Density** kg/m^3	**Length** mm	**Diameter** mm	**Aspect ratio** mm/mm	**Tensile strength** MPa	**Elastic modulus** GPa
PVA-6	1260	6	0.015	400	1600	34
PVA-12	1260	12	0.015	800	1600	34

(a) PVA 6 (b) PVA 12

Figure 3.5 PVA fiber

3.3.6 Polypropylene fiber

The fiber used is according to the standard ASTM-C1116 Type Homopolymer as shown in Figure 3.6, where used to reduce cracking and improves flexural strength. Table 3.6 shows properties of PP fibers.

Table 3.6 Physical properties of PP fiber

Fiber type	**Density** kg/m^3	**Length** mm	**Diameter** mm	**Aspect ratio** mm/mm	**Tensile strength** MPa	**Elastic modulus** GPa
PP-12	910	12	0.03	400	350	1.4

Figure 3.6 PP fiber

3.3.7 Silica Fume

Micro silica (silica fume) is a densities or undensified admixture, which consists primirily very fine amorphous SiO_2 particles and meets ASTM C-1240 standards, micro silica is used in construction, construction chemicals and refractory industries Table 3.7 shows Technical Specifications.

Table 3.7 Technical specifications of silica fume

Amorphous SiO_2	min % 90 (real %93,1)
H_20 (humidity)	max %0,3 (real %0,19)
LOI	(L.O.I max %3,5) (real % 1,81)
Density	0,25-0,35 kg/dm³(U)
Retained 45micron	max %2.5 (real %0,58)
BET	min. 15-28 m^2/gm (real 23,36 m^2/gm)

3.3.8 Water

Tap water is used throughout this work for both mixing and curing of concrete.

3.4 Mixing and Casting

As a first step, the dry materials (sand, gravel, cement and silica fume) is mixed in vertical rotations mixer that has four paddles for blending the materials as shown Figure 3.7. The dried materials are mixed for almost five minutes to get homogeneous mixture before adding water. The water is added slowly to the mixture also in slow rotations for almost five minutes, then superplasticizer is added and rotates the mixer on the maximum speed before adding the fiber which is added slowly soon after adding the fiber the mixture will be ready for casting. The mold is oiled well to prevent the concrete attaching the mold and make it easy to extract the sample.

Figure 3.7 Mixing of materials

When the mix is ready, it is moved to the mold for casting the slab by using a vibrator in this operation, exterior vibration for the slabs. Also, a standard cylinder, 100 mm in diameter and 200 mm long was casted, exterior vibration for the cylinder containing fibers, however: the cylinder containing normal concrete is cast as three layers, each layer flattened with a rod carefully. The vibration process continued until the air bubble escaped from the surface of the specimen. These mentioned cylinders are used to determine the compressive strength f'_c and the tensile strength f_{sp}, casting three cylinders to get an accurate test reading.

After pouring the concrete into the mold, the surface of the concrete is leveled and smoothed using a trowel as shown in Figure 3.8. It can easily be noticed that the concrete mix without fibers is so eased when it comes to finishing using a trowel and a lot more workable than the mix containing fibers.

(a)

(b)

Figure 3.8 Concrete casting (a) Specimen before finishing with cylinders and (b) Specimen after finishing with cylinders

3.5 Slump Test

Slump test is an empirical method that measures the workability of fresh concrete. More specifically, it measures the consistency and variations in uniformity of the concrete in a specific batch. The apparatus used for this test is a hollow frustum of a cone with specifications shown in Figure 3.9.

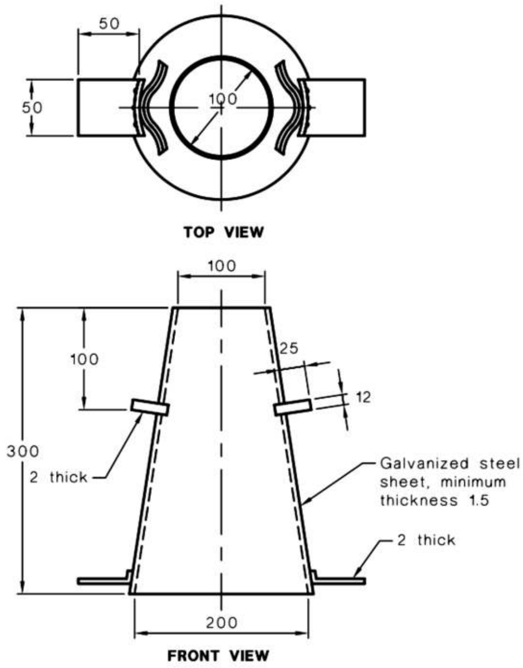


Figure 3.9 Typical mold for slump test (AS 1012.3.1-1998)

The slumped concrete may take one of the three forms; true slump, shear slump and collapse slump as shown in Figure 3.10. If concrete is slumping evenly all rounds, it is called a true slump, which is of use in the tests. If instead of a true slump, one-half of the cone slides down an inclined plane, a shear slump is said to have taken place. In this case, the test should be repeated and if the shear slump persists, this is an indication of lack of cohesion in the mix. It may undergo segregation and bleeding and thus is not desirable. A collapse slump generally means that the mix is too wet or there is a high workability level, for which the slump test is not appropriate. The concrete slump values may vary in the range between zero (no slump-very low workability) to collapse.

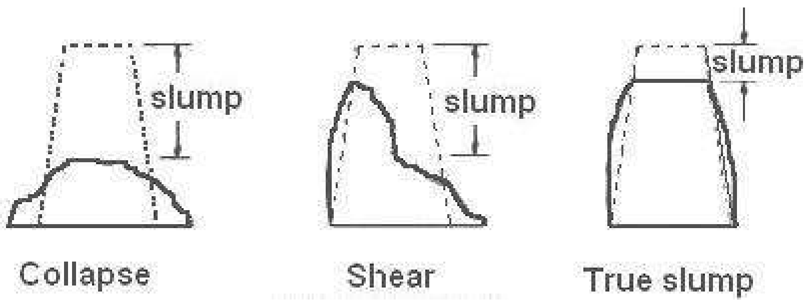


Figure 3.10 Different profiles of concrete slump (Noushini, 2013)

The slump test result of the work is as shown in Table 3.8, which shows that there is a direct relation between the slump result and the increasing percentage of fibers. Also, it shows that there is an inverse relation between the workability and the percentage of fibers as shown Figure 3.11.

Table 3.8 Slump test results.

Group No	Specimen	Fiber V_f %	Slump test result (mm)
A	N	0	87
B	PV6-0.5 PV6-1.0 PV6-1.5	0.5 1.0 1.5	67 65 64
C	PV12-0.5 PV12-1.0 PV12-1.5	0.5 1.0 1.5	60 55 51
D	PP-0.5 PP-1.0 PP-1.5	0.5 1.0 1.5	70 68 65

Figure 3.11 Slump test

3.6 Curing Process

The curing of concrete started after the casting had completed. The external sides of formwork and cylinders were removed after 24 hours is passed then the slabs and cylinder were moved to a water tank with a heater to begin the curing process with an average temperature of 25°C and it remains there for 28 days as shown in Figure 3.12.

Figure 3.12 Curing tank.

3.7 Weighting

After curing is finished, the samples surfaces are wiped with a piece of cloth to make it saturated surface dry and weight it as shown in Figure 3.13.

Figure 3.13 Weighting the specimens

3.8 Concrete mechanical properties

Compression test is conducted for the cylinders and the average of three-cylinder test specimen for each slab was taken. Cylinders tests were carried out on the same day as the corresponding slab test.

3.8.1 Compressive strength

The target compressive strength of normal concrete was 30 MPa, while (ASTM C39, 1997) describes the procedure of calculating the compressive strength of concrete cylinders. After preparing the sample putting it in the center of the machine, a compressive axial load shall be applied until failure occurs, as shown in Figure 3.14.

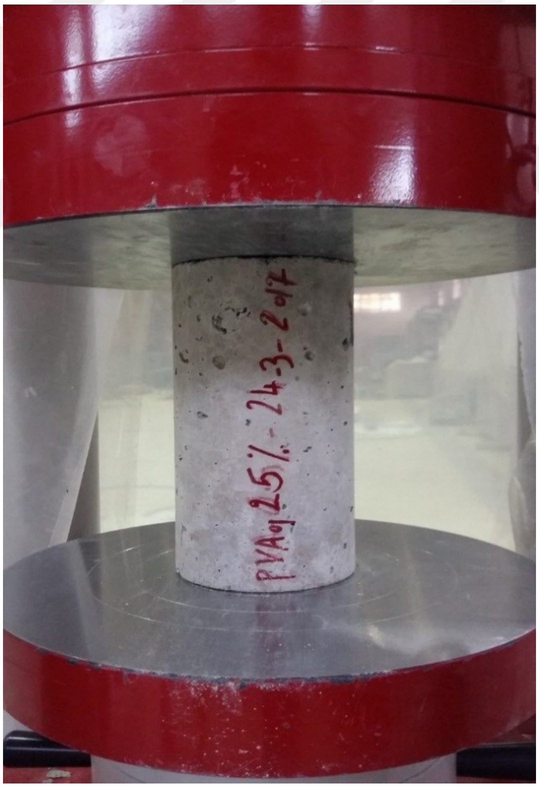


Figure 3.14 Cylinder compressive test.

3.8.2 Tensile strength

(ASTM C496, 2004) setup the foundation for developing this procedure. A diametric compressive load shall be applied along the specimen length until the failure occurs.

The cylinder shall be positioned vertically in the test frame exactly in the center, two segments of plywood must be placed longitudinally on the upper and lower sides of the cylinder. A steel bar is used to strict the cylinder in place. The next step would be setting the frame in the center of the compression machine and stating the test as shown in Figure 3.15.

Figure 3.15 Splitting tensile test.

3.8.3 Modulus of elasticity test

(ASTM C469, 2002) describes the procedure of measuring the modulus of elasticity in compression, the concrete cylinders are submitted to a slow increasing longitudinal compressive stress. Longitudinal strains are specified using a bonded or not bonded sensor, which helps measure the average deformation of two locations of quite the contrary. ASTM C469 does not restrict a standard test samples dimensions. However, casted concrete cylinders are usually the same dimensions as the cylinder used for compression resistance measurements.

Firstly the frame is assembled by adjusting the frame rings while the spacers are kept in position, then Keep the longitudinal screws must be tightened to lock the rings before placing the cylinder on a level surface. After placing the cylinder, the horizontal screws must be tightened on the specimen by an equal distance from every side of the ring. When all the adjustments are finished, the vertical screws must be removed before the test. The next step would be setting the frame in the center of the compression machine and stating the test as shown in Figure 3.16.

Figure 3.16 Modulus of elasticity test.

3.9 Specimen Test Setup

The load applied until the failure, in displacement control rate of 0.4 mm/min. In addition to the jack displacement measurement, one more LVDT is attached to the slab at the center of the bottom side. Two dial gages where installed on the panel, So that the shear deformation is included in the rotation value of the panel.

The frame was centralized on the test machine carefully before testing and also LVTD were adjusted and checked. A steel cubic column of dimensions 55 × 55 mm was placed in the center of the panel centralize the force.

A testing machine (Instron 5590R) with a maximum capacity of 250 kN was used. The details of the testing machine and specimen are shown in Figure 3.17 and Table 3.9.

Table 3.9 Testing machine specifications.

INSTRON	
Model No	5985
System ID / SN	5985L2125
Configuration	E1-F1-G1
Capacity	250 Kn (56250 lb)
Wight	882 kg (1949 lb)
Date of Manufacture	July - 2011
Voltage	220 Volts
Frequency	47 – 63 Hz
Maximum Power	3500 VA
Circuit Breaker	20 AMP
Short Circuit Current	

Figure 3.17 Testing machine.

In all tests, the machine is stopped after reaching the ultimate load and the machines jack was removed to allow more photographs of the final cracks and failure patterns to be taken. When the test is finished, the sample is removed from the test machine and the crack lines were marked with a black marker as shown in Figure 3.18, then the sample is photographed and placed aside and another sample is placed on the test machine.

Figure 3.18 Sample of marking the tested slab.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 General

This chapter aimed to present the test results of the program produced in the previous chapter, the discussed parameters include the effect of inclusion fiber in normal concrete. The main parameters used in improvement judgment are the effect of fiber volume fraction and the effect of the two types of fiber. The effect of the fibers on the ultimate load resistance, the load-deflection, and the failure mode are discussed in this chapter.

4.2 Mechanical Properties

As mentioned in experimental work in order to overcome the errors, an average of three cylinders of 100 × 200 mm are tested for both compressive strength (f'_c) and tensile strength (f_{sp}), of PVA and PP fibers reinforced, concretes considered in this investigation. Table 4.1 summarizes the test results.

Table 4.1 Concrete mechanical properties.

Group No	Fiber type	Mix code	V_f (%)	f'_c (MPa)	$\frac{f'_{c\ fiber}}{f'_{c\ normal}}$	f_{sp} (MPa)	$\frac{f_{sp\ fiber}}{f_{sp\ normal}}$	$\frac{f_{sp}}{\sqrt{f'_c}}$
A	-	N	0	32.12	1.0	6.14	1	1.08
B	PVA/ 6 mm	PV6-0.5	0.5	40.82	1.27	7.49	1.22	1.17
		PV6-1.0	1.0	35.80	1.11	8.45	1.38	1.41
		PV6-1.5	1.5	43.28	1.35	8.67	1.41	1.32
C	PVA/ 12 mm	PV12-0.5	0.5	55.20	1.72	6.41	1.04	0.86
		PV12-1.0	1.0	55.75	1.74	6.16	1.00	0.82
		PV12-1.5	1.5	47.10	1.47	6.35	1.03	0.93
D	PP/ 12mm	PP-0.5	0.5	37.44	1.17	5.39	0.88	0.88
		PP-1.0	1.0	36.16	1.13	6.62	1.08	1.10
		PP-1.5	1.5	40.61	1.26	6.29	1.02	0.99

4.2.1 Compressive strength

The test results are summarized in Table 4.1, and include the comparison between the f'_c of fibrous concrete with that of plain concrete. It is shown that the all-fiber type of fiber is significantly enhanced the f'_c. The enhancement is ranging between 11 and 74%. This depends on the fiber type and percentages.

In group B, the addition of 0.5% of PVA with 6 mm length to the concrete, it improved the concrete compressive about 27% compared to the plain concrete, while adding 1% of fiber, f'_c are increased 11%. Increasing the fiber volume fraction to 1.5% has increased concrete strength to about 35%.

Group C includes slabs that contain 12 mm length PVA fiber. From the Table 4.1, it shows that increasing the length of the fiber, the obtained compressive are in general higher than that obtained by the previous group. Where inclusion 0.5% fiber, f'_c was increased 72% compared to plain concrete, this is means that duplicating the length of the fiber from 6 mm to 12 mm are increased the strength by 166%. Moreover, increasing the fiber percentage to 1 % are increased the f'_c by 74%, i.e. 572% compared to concrete with PVA of 6 mm. However, increasing the fiber to 1.5% shows less improvement than the previous two percentages, where the f'_c increased 47%

compared to plain concrete, i.e. 34% compared to concrete with PVA of 6 mm. This is not surprising because the lengthy fiber plays important role in balling the fibers, and in turns decreases the effect of bonding and bridging the cracks.

The effect of fiber type is investigated in Group D, using PP fiber shows less improvement than the two used PVA for all volume fraction. Where the addition of 0.5, 1.0 and 1.5% of PP, f'_c is increased 17, 13 and 26%, respectively, which are less than those obtained from previous two group.

The fibers assist avoiding a sudden and brittle concrete crushing. As a result, the fiber is generally enhanced f'_c; this is agreed with Johnston (1991). Moreover, this is depended on the percentage, and type fibers, where addition 1% of PVA/ 12 mm length provided the optimum value. Figure 4.1 and 4.2 shows the effect of fiber content on the f'_c.

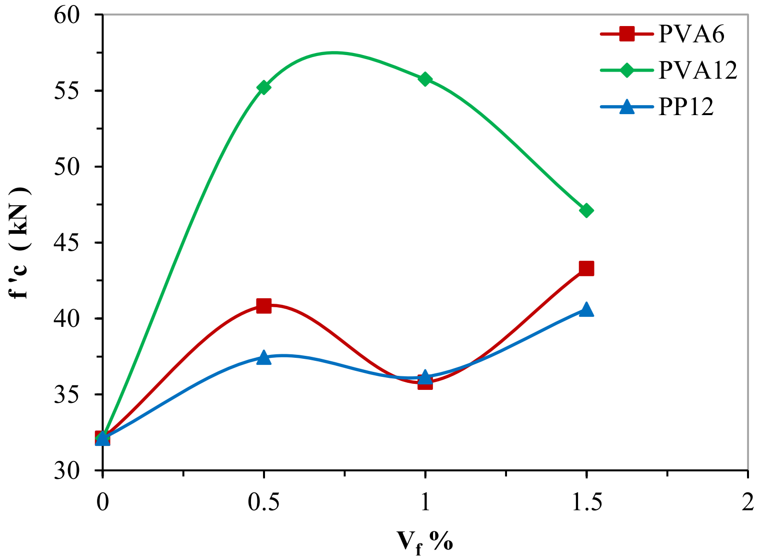


Figure 4.1 Effect of fibers on compressive strength

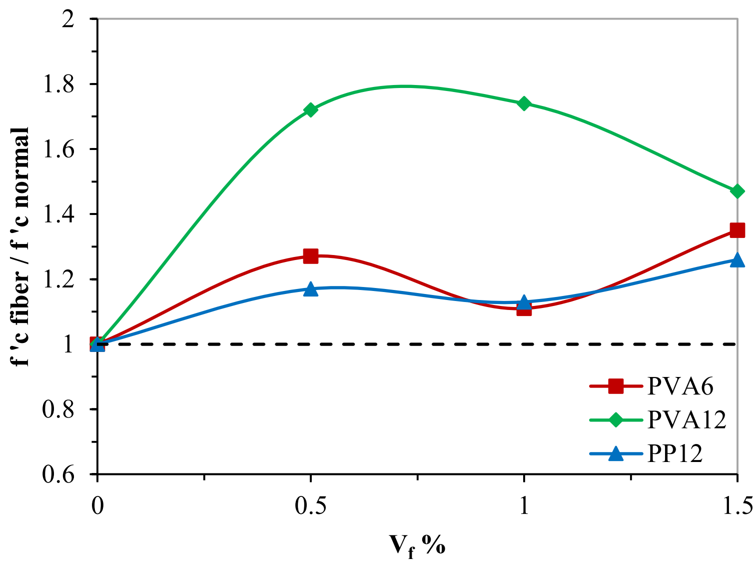


Figure 4.2 Normalized compressive strength of FRCs with respect to control concrete

On the other hand, these fibers give greater coherence to the materials in the mixture, where the work of bonds between the molecules but these are the same grains and the increase in compressive strength depends on the direction of fiber in the mix where the more similar directions the more the material to external stresses.

The values of FRCs compressive strength at 28 days is normalized with respect to the control compressive strength, at the same age. It plotted against fiber volume fraction in Figures 4.2. As also previously stated by Li (1992), the compressive strength may first rise, then drop, with increasing fiber volume fraction. When fibers are present, strength improvement can be an indication of an increase in resistance to microcrack sliding and extension, whereas strength degradation can be a result of an increase in either pore or microcrack density. The pores may be related to insufficient compaction and the additional microcracks may be related to touching fibers, (unbonded) fiber end cracks, poor fiber/matrix bonding, or poor adhesion between filaments within fiber bundles (Li, 1992).

4.2.2 Indirect tensile strength

The results of the indirect tensile strength of the tested specimens (control and FRCs) with 0.5%, 1% and 1.5% fiber volume fractions at the same age of the compressive strength specimens summarized in Table 4.1.

In Group B the addition of PVA6 fiber by 0.5% to the concrete, it improved the concrete tensile strength and increased by 22%, while when the fibers are increased by twice to 1%, the improved tensile strength of the concrete by 38%. Moreover, as fiber increases to 1.5%, we have noticed an increase in concrete tensile strength by 41%; we can conclude from this that by increasing the fiber ratios the tensile strength values increase.

In both Groups (C and D), notice that the addition of fibers to the concrete has not improved tensile strength compared with plain concrete and group B, this agrees with Bentur, (2006) results. The tensile strength behavior of concrete after addition of fiber is shown in Figure 4.3.

It can be concluded from the results shown in Table 4.1 that splitting tensile strength for FRC is almost equal because the fiber enhanced the post-crack characteristics by transferring stress across the crack so results show that fibers are not always enhanced the tensile strength. Figure 4.4 shows the normalized indirect tensile strength of FRCs in 28 days.

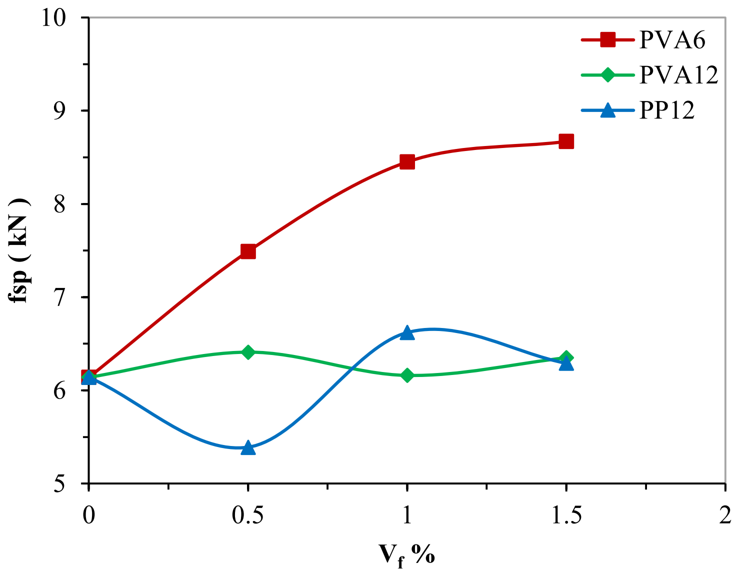


Figure 4.3 Effective FRC splitting tensile strength

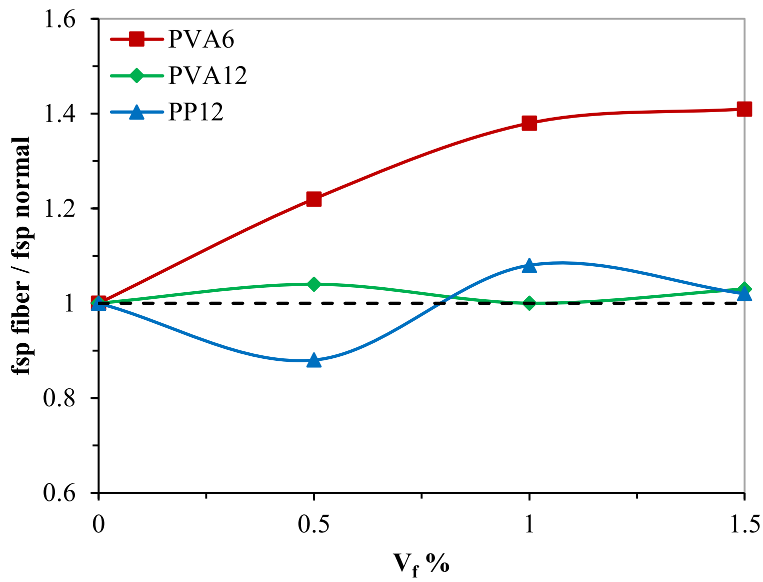


Figure 4.4 The normalized indirect tensile strength

ACI 318 code have been depending on the square root of compressive strength, which presented a good example of punching shear for specimens of reinforcement ratio ρ> 0.5, therefore, $\sqrt{f'_c}$ is used here to estimate the strength of specimens. Furthermore, $\sqrt{f'_c}$ is relating to splitting tensile strength form of $f_{sp} = k\sqrt{f'_c}$, where k is a constant equal to 0.56 according to ACI 318, Figure 4.5 shows the relation between the f_{sp} and the f'_c.

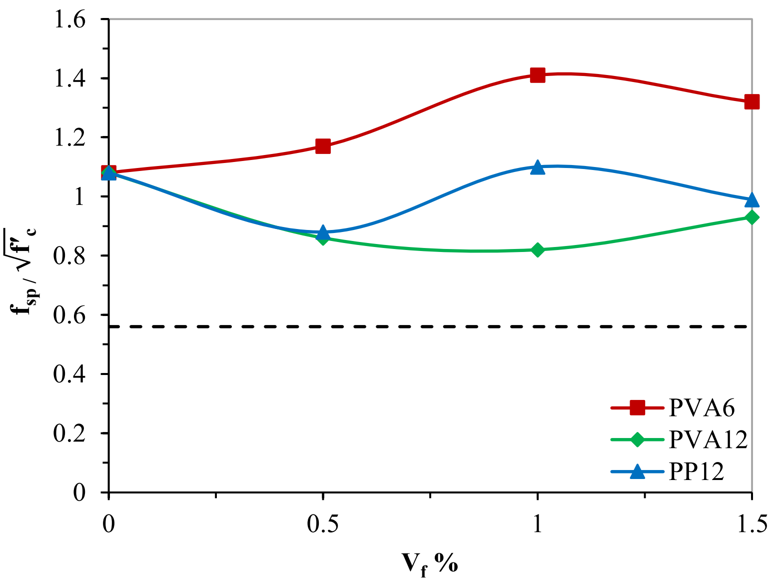


Figure 4.5 Correlation of splitting strength to square root compressive strength in FRC

4.3 Structural Behavior

Although creating a perfect-engineered construction material is great achievement, it should also be applied to structures to reap the benefits from the structural point of view, as well. Accordingly, the structural properties of RC slabs incorporating fibers as intrinsic reinforcement are investigated. The results of tested ten slabs are presented in Table 4.2.

Table 4.2 Numerical values for the parameters of the flexural behavior

Group No	Fiber type	Mix code	V_f (%)	P_u[1] (kN)	δ_{u1}[2] (mm)	δ_{u2}[3] (mm)	$\frac{p_{u\ fiber}}{p_{u\ normal}}$
A	-	N	0	58.87	4.02	3.02	1.00
B	PVA/ 6 mm	PV6-0.5	0.5	81.40	4.67	3.78	1.38
		PV6-1.0	1.0	85.06	5.07	4.19	1.44
		PV6-1.5	1.5	85.30	5.25	4.24	1.45
C	PVA/ 12 mm	PV12-0.5	0.5	75.08	4.95	3.42	1.28
		PV12-1.0	1.0	81.97	4.86	3.57	1.39
		PV12-1.5	1.5	69.95	4.88	3.38	1.19
D	PP/ 12mm	PP-0.5	0.5	72.74	4.48	3.56	1.24
		PP-1.0	1.0	78.88	4.49	3.48	1.34
		PP-1.5	1.5	81.65	4.96	3.98	1.39

[1] Pu: Ultimate load. [2,3] δu: Deflection at ultimate load

4.3.1 Ultimate load resistance

The cracked and ultimate slab strength is listed with its corresponding displacement in Table 4.2. For all group, it shows that adding fibers are significantly enhance the resistant of the slab. It is shown that the all-fiber type of fiber is significantly enhanced the ultimate load. The enhancement is ranging between 19 to 45%; this depends on the fiber type and percentages.

In group B, the addition of 0.5% of PVA with 6 mm length to the concrete, it improved the ultimate strength about 38% compared to the plain concrete, while duplicating the fiber content by 1%, increases the ultimate strength by 6%. Increasing the fiber volume fraction to 1.5% has slightly increased concrete strength to about 1%.

Group C contain slabs that made from PVA of 12 mm length. Noted that increasing the length of the fiber, the obtained comparison are in general less than that obtained by the previous group (Group B). Where inclusion 0.5 % fiber, the ultimate strength was increased 28 % compared to plain concrete, this is means that changed the length of the fiber from 6 mm to 12 mm are decreased the ultimate strength by 26 %. Moreover, increasing the fiber percentage to 1 % are increased the ultimate strength by 39 %, but decreased by 11 % when compared to concrete with PVA of 6 mm. Moreover, increasing the fiber to 1.5 % shows less improvement than the previous two percentages, where the ultimate strength increased 19 % compared to plain concrete but decreased by 57 % when compared to concrete with PVA of 6 mm as shown in the Figure 4.6.

The effect of fiber type was investigated in Group D, it improved the concrete and increased ultimate strength by 24 %, while duplicating the fiber percent by 1 %, enhanced the concrete by 10 %. Moreover, as fiber increases to 1.5 %, the ultimate strength continued to rise and the rate of increase was about 5 %. Figure 4.7 shows the ultimate load resistance for all the FRC compared with the normal concrete slab.

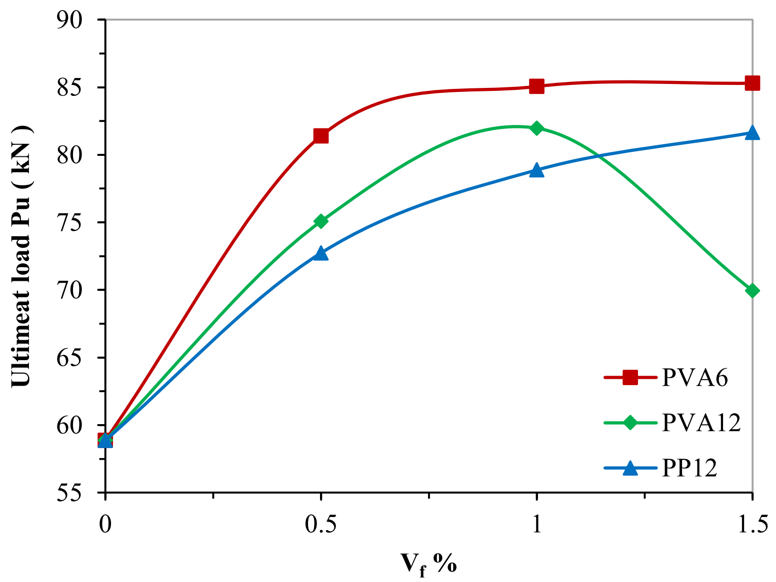


Figure 4.6 The effect of fibers dosages on the ultimate slab strength.

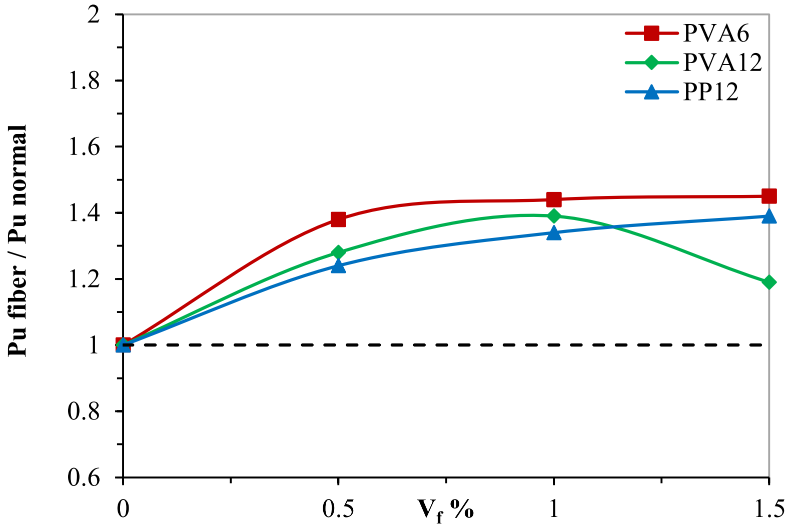


Figure 4.7 The normalized ultimate load resistance

4.3.2 Code provision

The square root expression adopted by the ACI code is derived from Moe's (1961), in which the shear failure was considered to be controlled primarily by the tensile-splitting strength. However, this assumption overestimates the concrete contribution to the shear strength of a slab (Marzouk and Hussein, 1991). Furthermore, ACI 318-02 neglects the influence of flexural reinforcement, size effect on the punching shear strength. In addition, ACI 318-02 not take into consideration the effect of steel reinforcement ratio.

The nominal shear strength for two-way members:-

$$v_n = v_c + v_s \qquad (4.1)$$

Where: v_c is factored nominal shear stress of the slab. v_s Shear reinforcement,

$v_s = 0$, no reinforcement shear.

$$v_n = v_c = v_u$$

For specimens that failed by punching shear, the average failure shear stress can be calculated as-

$$v_u = \frac{\mathrm{V_u}}{\mathrm{A}} \qquad (4.2)$$

where, V_u is the ultimate load (kN), A is the area of failure (mm^2) that is equal to the production of the critical perimeter (b_o) by the average effective depth d that distance from the extreme compression fiber to the centroid of the tension reinforcement (mm),

$$d = \frac{d_1 + d_2}{2}$$

The perimeter of the critical section (b_o) at a specified distance from the face of the column (loading plate) (mm), $b_o = 4(c + d)$, where c is the side dimension of the square column,

To correlate with the design equations used in the ACI code, the shear strength is expressed as a multiplier of $\sqrt{f'_c}$, leading to:-

$$v_u \propto \sqrt{f'_c}$$

$$v_u = K\sqrt{f'_c}$$

$$\frac{V_u}{b_o\, d} = K\sqrt{f'_c}$$

$$V_u = K\sqrt{f'_c}\, b_o\, d$$

ACI 318-14 (American Concrete Institute 318-14, 2014) adopted a minimum nominal punching shear strength of normal concrete weight, the slab minimum strength is the least of the Equations (4.3) sub-numbering. This stress act on a specified perimeter distanced d/2 from the column face, where the code permit to use right angle corners.

ACI nominal shear strength is the smallest value of the three following equations:

$$V_u = 0.33\,\lambda\sqrt{f'_c}\; b_o\, d \qquad (4.3a)$$

$$V_u = 0.17\left(1+\frac{2}{\beta}\right)\lambda\sqrt{f'_c}\; b_o\, d \qquad (4.3b)$$

$$V_u = 0.083\left(2+\frac{\alpha_s\, d}{b_0}\right)\lambda\sqrt{f'_c}\; b_o\, d \qquad (4.3c)$$

Where: f'_c is the concrete compressive strength (MPa). β = Ratio of long to the short side of the column, α_s is column location factor: 40 for interior columns, 30 for edge columns, and 20 for corner columns the terms in this provision refer to critical sections with a continuous slab on four, three, and two sides, respectively. λ is 1 for normal concrete and for lightweight concrete from (0.75 to 0.85) is permitted based on the absolute volume of normal weight fine aggregate as a fraction of the total absolute volume of fine aggregate.

Equation (4.3a) was derived from semi-empirical analysis method based on experimental results and analysis.

Equation (4.3c) considered the size effect, however, Bazant et al., (1987) believe that this equation did not take into consideration the size effect, because it is basis of plastic limit analysis not on fracture mechanics, which is not justified for specimens of short horizontal yielding plateau.

The obtained ultimate load ($P_{u\ test}$) at d/2 from the column stub face are compared to the proposed load by ACI318 (ACI318-14, 2014) see Table 4.3 and Figure 4.8. It is shown that the ACI is significantly conservative, the conservatively are ranging between 104 % to 186 %, this found in slab PV6-1.0 and PV12-0.5 respectively. It is worthy to mention here that the calculated load is excluded the safety factors for the materials and the structure because the loadings are continued up to failure.

Table 4.3 Comparison between tested shear load and load proposed by ACI318.

Group No	Mix Code	V_f (%)	d (mm)	b_o (mm)	p_u (kN)	$P_{u\ code}$ (kN)	$\frac{p_u}{P_{u\ code}}$
A	N	0	39.7	378.8	58.87	28.1	2.09
B	PV6-0.5	0.5	39.7	378.8	81.40	31.7	2.57
	PV6-1.0	1.0	39.7	378.8	85.06	29.7	2.86
	PV6-1.5	1.5	39.7	378.8	85.30	32.6	2.61
C	PV12-0.5	0.5	39.7	378.8	75.08	36.9	2.04
	PV12-1.0	1.0	39.7	378.8	81.97	37	2.21
	PV12-1.5	1.5	39.7	378.8	69.95	34	2.05
D	PP-0.5	0.5	39.7	378.8	72.74	30.4	2.4
	PP-1.0	1.0	39.7	378.8	78.88	29.8	2.64
	PP-1.5	1.5	39.7	378.8	81.65	31.6	2.58

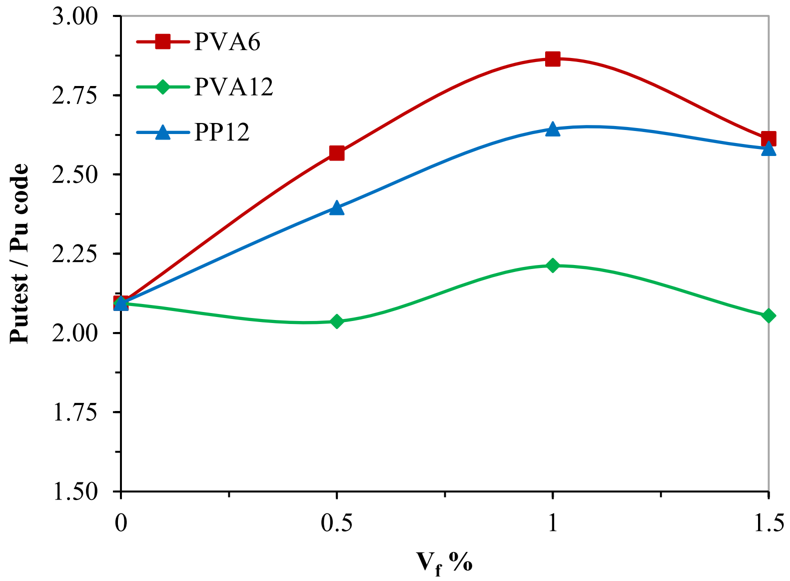


Figure 4.8 Comparison of experimental results with the design codes.

4.3.3 Punching shear capacity

The tested slabs are designed to fail due to punching shear, where the flexural capacity of the slabs P_{flex} are more than punching shear capacity. The punching shear capacity is calculated according to ACI 318 as shown in Table 4.4, while the flexural capacity is calculated basic on yield line analysis that produced by Guandalini et al.,(2009):

$$P_{flex}=\frac{4\,m_R}{r_q\left(\cos\left(\frac{\pi}{8}\right)+\sin\left(\frac{\pi}{8}\right)\right)-c}\times\frac{b^2-(b\times c)-\left(\frac{c^2}{4}\right)}{b-c} \tag{4.4}$$

Where: P_{flex} the ultimate flexural capacity of the slab computed by the yield-line theory without regard to a shear failure. b is the length of the square slab (mm). c the side dimension of the square column. π the angles of eight central balls are 45. r_q The radii of the mentioned supporting system are 200 mm, which is assumed to locate on the line of contraflexure as shown in the Figure 4.9.

Table 4.4 Summary of the test results

Group No	Spce. code	density Kg/m³	P_{cr}[1] kN	δ_{cr1}[2] mm	δ_{cr2}[3] mm	P_{flex} mm	$\frac{P_{cr}}{P_u}$	$\frac{P_u}{P_{flex}}$
A	N	2295.94	14.1	1.0	0.6	51.2	0.24	1.15
B	PV6-0.5	2321.18	17.2	1.0	0.6	51.8	0.21	1.57
	PV6-1.0	2241.84	21.4	1.2	0.7	51.5	0.25	1.65
	PV6-1.5	2240.11	18.8	1.1	0.7	52	0.22	1.64
C	PV12-0.5	2291.04	15.7	1.1	0.2	52.4	0.21	1.43
	PV12-1.0	2277.78	21.1	1.3	0.6	52.4	0.26	1.56
	PV12-1.5	2221.40	17.0	1.2	0.4	52.1	0.24	1.34
D	PP-0.5	2257.73	18.3	1.0	0.5	51.6	0.25	1.41
	PP-1.0	2291.16	22.4	1.0	0.5	51.5	0.28	1.53
	PP-1.5	2268.53	17.8	1.0	0.6	51.8	0.22	1.58

[1] Pcr: Cracking load, [2,3] δcr: Deflection at first crack,

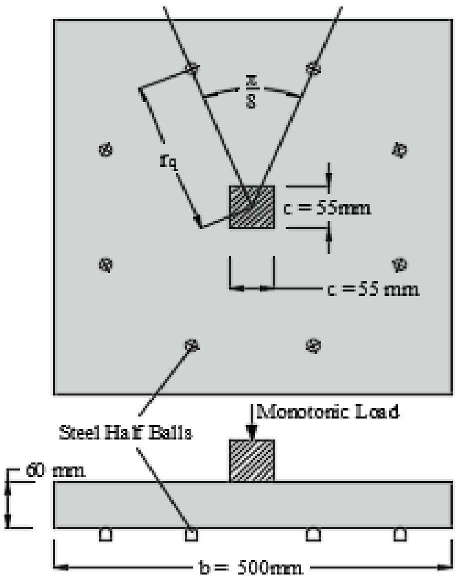


Figure 4.9 Test configuration

The section moment capacity m_R is obtained as follows Guandalini et al., (2009)

$$m_R = f_y \times \rho \times d^2 \times \left(1 - 0.5\, \rho \times \frac{f_y}{f'c}\right) \tag{4.5}$$

Where: d the effective depth of the section. f'_c the concrete compressive strength. f_y bars' yield strength 400 MPa. ρ is 0.9 % the reinforcement ratio taken as a sort of averaging as follows

$$\rho = \frac{\rho_1 d_1^2 + \rho_2 d_2^2}{2\, d^2} \tag{4.6}$$

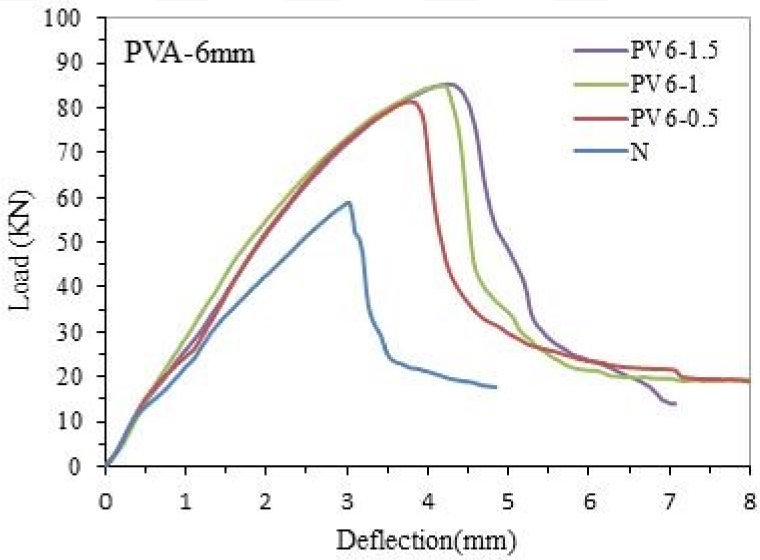
The test results are summarized in Table 4.4 it is shown that inclusion PVA6 are significantly enhanced the ultimate load resistance, increase the resistance load by 38, 44, and 45 % when using 0.5, 1.0, and 1.5 % of PVA6, respectively. The cracking loads (P_{cr}) are ranging between 21 to 25 % of the ultimate load, while inclusion PVA12 the ultimate load resistance, increase by 28, 39, and 19 % when using 0.5, 1.0, and 1.5 % of PV6, respectively. Moreover, the cracking loads (P_{cr}) are ranging between 21 to 26 % of the ultimate load. Addition PP to the concrete shows less improvement than the PVA6 and almost the same of PV12, where the ultimate load resistance increased for the three used percentages (0.5, 1.0, and 1.5 %) by 24, 34, and 39 % respectively, compared to the normal concrete. The cracking loads (P_{cr}) are ranging between 22 to 28 % of the ultimate load, this is same cracking load obtained by most researchers, and it is not surprising because the bridging effect of the fibers starts after the initiation of the crack. However, according to authors' these percentages are less for fibers (PVA, PP) when it is used in Engineering Cementitious Composite materials. This is means that the effects of the fibers are increases with increasing the fineness of the matrix.

The increase of punching shear capacity of FRC slabs is because fibers help to bridge cracks in the whole concrete volume and transfer tensile stress through two opposite faces of cracks until the fibers are totally pulled-out or broken. For this reason, in the stage of initiation and propagation of cracks, the tensile zone of FRC slabs still sustains the load. This increases concrete tensile strength and indirectly leads to increase the punching shear resistance of slabs.

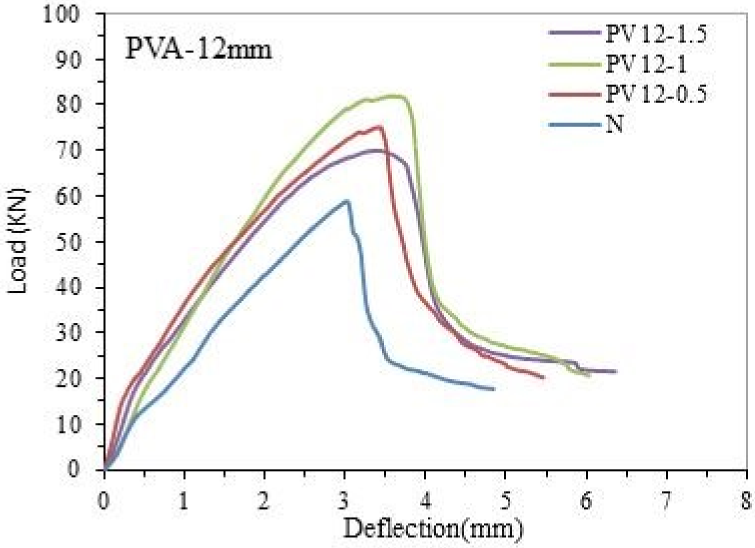
4.3.4 Load –deflection relationship

Load-deflection relationships are important to understand the behavior of slab-column connections because it reflects the general behavior and especially the reinforcement ratio, the loads are applied until the slabs were failed, while the depicted curves are introduced up to 50 % of the peak loads, in order to include the effect of the membrane action. The deflections in the figures are measured from the bottom center of the slab, Figures 4.10 and 4.11 show the effect of the fiber percentages and the type of the fibers on the load-deflection relationship for the PV6, PV12, and PP12 specimens. From the collected data, the load-deflection curves are calculated from the raw data captured load-cells mounted on loading jacks and an LVDT was placed at mid-span to measure the deflection.

(a)



(b)



(c)

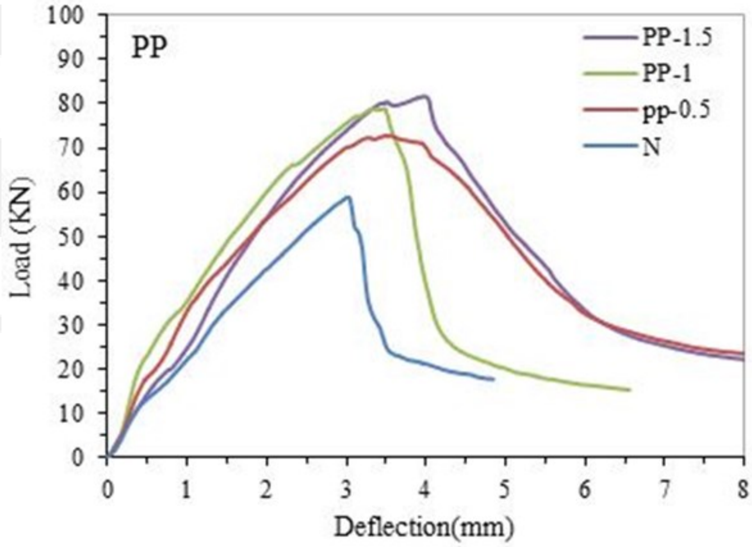


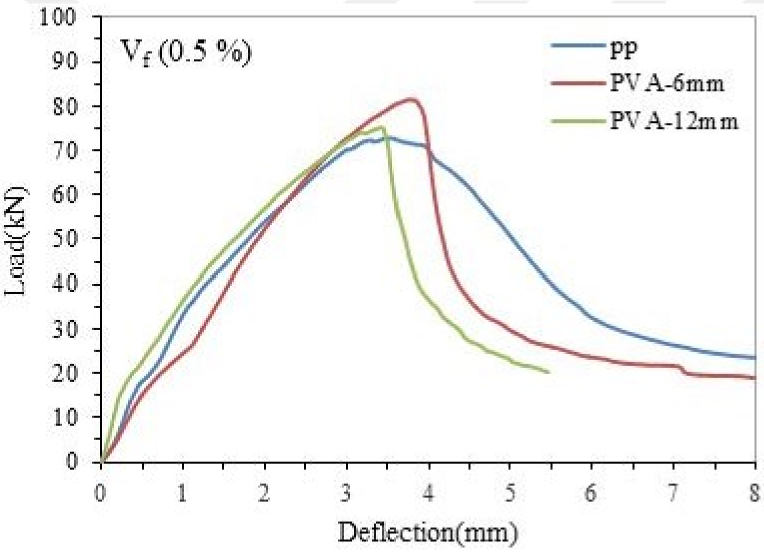
Figure 4.10 Load- deflection (a) PVA6 mm length, (b) PVA12 mm length and (c) PP12 mm length

It is well known that the typical load-deflection relationship (p-δ) of a regular RC slab may essentially compose of three types of behavior: pre-cracking stage, post cracking stage, and post yielding stage. The load-deflection response of each slab is shown in Figure 4.10 and 4.11.

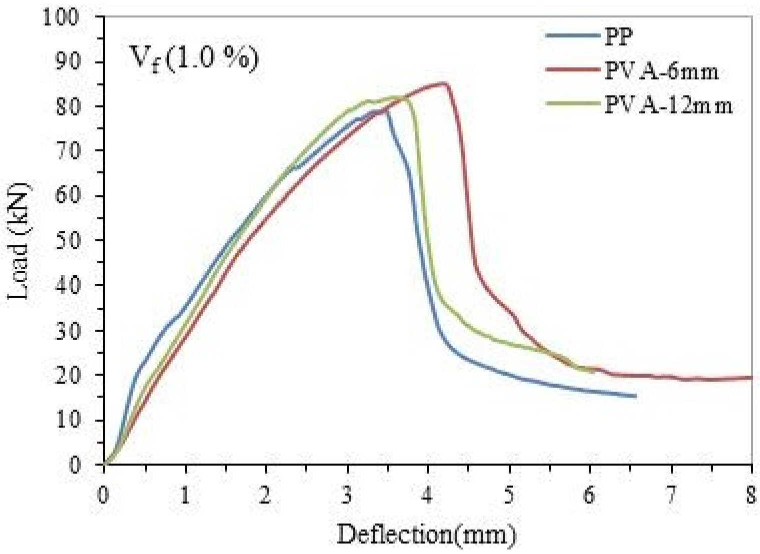
It was noted that once the slab extreme tension fiber reached its tensile strength, there was a significant deviation of the curve from the original slope, implying a relative reduction in the flexural rigidity of the slab beyond the working load level. This is representing the pre-cracking stage, where the deflection increases almost linearly with the loading. This is expected since the strains in the steel and concrete are relatively small and both materials are in the elastic portion of their respective responses.

From Figure 4.10 and 4.11 there were nonlinear extraneous displacements, which is not a surprising thing because it is often associated with such a test. Up to the first initiation crack, the displacement is proportional to the applied load linearly; the first cracks are hardly and carefully located on the curve. After the first crack takes place, the slope of the curve was slightly changed, but still looks to be in linear increasing rate, the increasing rate continues up to yield point. After yielding of the reinforcement, the curves are increasing in a nonlinear manner up to the maximum resistance load, the test is continuing until the slab is collapsed.

(a)



(b)



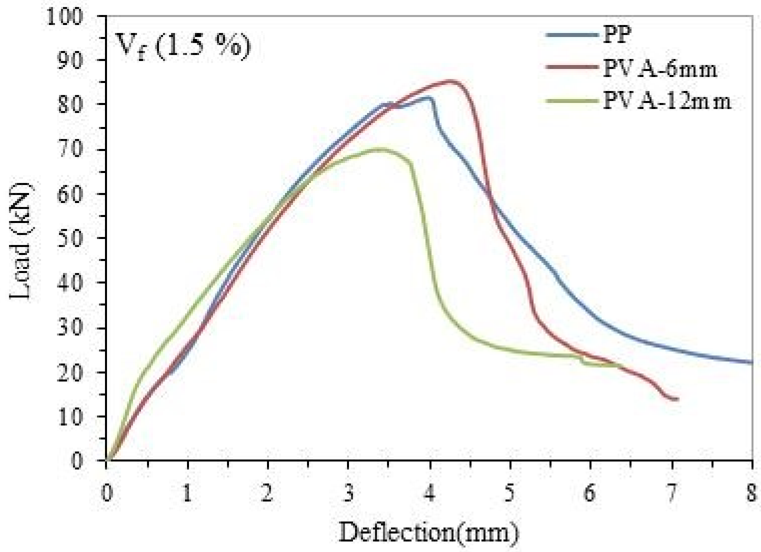
(c) 

Figure 4.11 Compared between the fibers volume fractions (a) Volume fraction = 0.5, (b) Volume fraction = 1.0 % and(c) Volume fraction = 1.5 %

Soon after cracking of the cover concrete, almost no deviation or only a slight deviation from the original slope could be detected. This is the post-cracking stage that indicates that the response of the slab in this region is a function of both the reinforcement ratio ρ and the compressive strength of concrete, which is affected by fibers content. This behavior signifies an increase of the cracking moment capacity and retention of the higher flexural rigidity of the slabs at working load.

As soon as the strain in the tensile steel reached yield level, the slab was considered to have failed structurally. The test specimens continued to deflect rapidly until a secondary compression failure developed, leading to the total crushing of concrete in the maximum moment region, followed by consequent extensive cracking and considerable widening of the stabilized cracks.

The load deflection curves in Figure 4.10 shows a clear difference between the specimens. Reinforcement fibers are reduced the deformation of the slabs with normal concrete slab, this is clearly seen from the high rate of load compared to the deflection ($\Delta P/\Delta\delta$). PVA6 slabs show sudden failure after the peak load of 81, 85 and 85 kN respectively. Moreover, PVA12 in both 1.0 and 1.5 slabs show short plateau beyond the ultimate resistance, whereas plain concrete and 0.5 slabs shows sudden failure after the peak load when the loads are 75, 81 and 69 kN respectively.

In PP fibers, 0.5 and 1.5 slabs show short plateau beyond the ultimate resistance, whereas plain concrete and 1.0 slabs shows sudden failure after the peak load with an increase in load ranging from 72 to 81 kN and with different slopes as shown in the Figure 4.10.

The (p- δ) curves of all the tested slabs of reinforcement ratio from 0.5 % to 1.5 %, with various fiber contents, are shown in Table 4.4. The addition of fibers has a significant effect on the cracking load that induced the first crack, which may be defined as the crack that occurs at the initial change of slope of the (p- δ) curves. However, on the other hand, it is clearly shown that the fiber concrete slabs are stiffer in the initial loading stages (elastic) before the significant change of slopes.

For the ranges bounded by the point of the first crack and ultimate load, specimens made with FRC exhibited less deformation and larger load-carrying capacity from that of conventional concrete, as seen in the Table 4.2 and 4.4. This is due to the ability of FRC in arresting crack growth and crack widening. Figure 4.11 also shows that the effect of fibers in increasing the ultimate strength is less significant than its effect in reducing the vertical deformation. The main reason for such behavior is due to the effect of fiber added to the RC slab, which does not lie in improving the strength but rather in control of cracking and deformation

The addition of fibers leads to a decrease in deformations at all stages of loading, particularly after initial cracking, and enhances the ultimate load carried by the slab-column connection. Fibers not only delay the deformations of diagonal cracking within the slab but also transfer the brittle type punching shear failure to a gradual and ductile shear failure crack patterns

Exception the weak bond between the reinforcement and the matrix, there are three failure types are identified in the testing of slab-column joint (Kuang & Morley, 1993). When there are no forces induced from external membrane, as in isolated slabs such as in the current work configuration, these failures depends on the flexural capacity of the section P_{flex}, where brittle punching shear can be defined if $P_{u\ test}/P_{flex} < 0.95$, while flexural shear failure are defined when the $P_{u\ test}/P_{flex}$ relation is fluctuated in between 0.95 and 1.15, for that relation more than 1.15 the failure is defined as pure flexural, i.e. due to yield line formation. Table 4.5, shows that all the tested slabs are failed in the pure flexural, where $P_{u\ test}$ /P_{flex} were greater than 1.15, this is approved by the crack patterns introduced in Figure 4.12. Although the specimens are failed due to flexure low resistance, two types of cracks can be identified from Figure 4.12, radial cracks, and punching shear cracks, That means that inclusion the fiber not much affected the failure shape and the distance from the column face, this because the effect of high fine aggregate content is more effective than the fibers, where the both normal and shear stress are perfectly transferring from the column to the supports.

Table 4.5 Failure mode for the tested specimens.

Group	Specimen	Failure type[1]	l_{cr}[2] (mm)	Failure Shape
A	N	PF	138	Uncomp.Rectangular
B	PV6-0.5	PF	180	Uncomp. Circle
	PV6-1.0	PF	163	Uncomp. Circle
	PV6-1.5	PF	153	Uncomp.Rectangular
C	PV12-0.5	PF	170	Uncomp. Circle
	PV12-1.0	PF	195	Uncomp.Rectangular
	PV12-1.5	PF	160	Uncomp.Rectangular
D	PP-0.5	PF	146	Uncomp. Circle
	PP-1.0	PF	131	Uncomp.Rectangular
	PP-1.5	PF	155	Uncomp. Circle

(1) PF refers to pure flexural failure.
(2) The distance from the column face to the punching shear crack in term of effective depth d, for the rectangular shape the distance is measured from the shorter side.

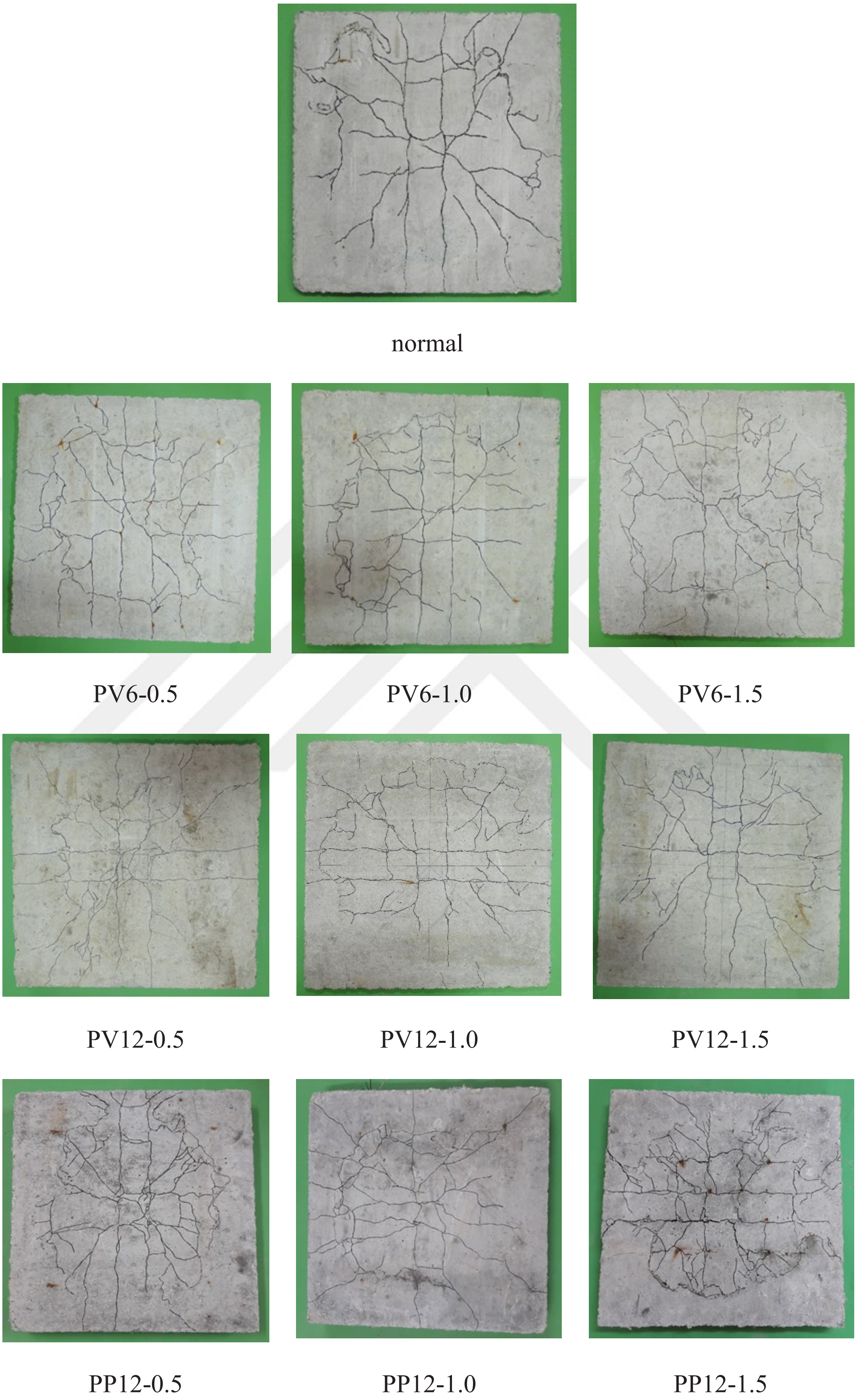


Figure 4.12. Crack Patterns for the Tested Specimens

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This research is a part of a series, aimed to investigate the effect of fibres (PVA and PP) on the behaviour of flat plate-column connection; two types of fiber were used with three percentages of volume fraction. The slab designed to fail in punching, where the flexural capacity of the slabs that calculate basing on yield line theory is more than the punching behaviour calculate from ACI318 provisions, the improvement judgment is based on the ultimate load resistance compared to the normal concrete slab. Important conclusion can be driven from the current work as follow:-

1) Compressive strength is increased significantly by about 74 %, when 1.0 % PVA 12mm fiber is used, whereas that the addition of fibers to the concrete has not improved the tensile strength.
2) Inclusion the fibers in the concrete matrix increased the load resistance gradually as the fiber content increases, the enhancement can reach 45% of slab content 1.5 % when PVA 6mm fiber is used.
3) The obtained ultimate load ($P_{u\ test}$) at d/2 from the column stub face are compared to the proposed load by ACI318 (ACI318-14, 2014). It is shows that the ACI is significantly conservative, the conservatively are ranging between 104 % to 186 %, this found in slab PVA6-1.0 and PVA12-0.5 respectively.
4) The inclusion of PP fiber increases the first crack resistance load up to 59 %, although, the first crack resistance loads are taken place before the participation of the exterior fiber, but the effectiveness of the interior fiber on the microcrack is playing an important role in whole resistance.

5) The addition of fibers leads to a decrease in deformations at all stages of loading, particularly after initial cracking, and enhances the ultimate load carried by the slab-column connection.

6) The load - deflection curves shows a clear difference between the specimens. Reinforcement fibers are reduced the deformation of the slabs with normal concrete slab, this is clearly seen from the high rate of load compared to the deflection ($\Delta P/\Delta \delta$). In PVA6, slabs show sudden failure after the peak load. PVA12 fibers in 1.0 and 1.5 slabs show short plateau beyond the ultimate resistance, whereas plain concrete and 0.5 slabs shows sudden failure after the peak load. PP fibers 0.5 and 1.5 slabs show short plateau beyond the ultimate resistance, whereas plain concrete and 1.0 slabs shows sudden failure after the peak load.

7) The result shows that all the tested slabs are failed in the pure flexural, where $P_{u,\, test}/P_{flex}$ were greater than 1.15.

8) Increasing the fineness of the matrix increase the interaction between the fibers and the matrix.

9) There is no significant effect of the fibers on the shape and size of the failure.

10) The nominal punching shear resistance proposed by ACI318 are underestimated the resistance of the slabs with low slab thickness.

5.2 Recommendations for future works

Based on the findings of this study, it is recommended to further investigate additional parameters that are likely to have some influence on punching shear capacity of flat plats such as:

1) Using more fiber ratios, different type & size of fibers, different slab depths, concrete strength, etc. The use of different reinforcement rebars such as GFRP or basalt fiber-reinforced polymer is also recommended.
2) Study the effect of HSC for the FRC two-way flat slabs with and without FRC shear reinforcement.
3) Testing of edge and corner slab-column connection reinforced with FRC.
4) Another practical benefit gained from FRC is increasing flexural rebar spacing as fiber contribute to flexural strength of certain elements such as slabs. This

fact suggests that FRC is a cost effective solution when considered to reduce flexural rebars, not only because of reduced rebar material but also because of the cost of workmanship and time spent on forming and placing the conventional slab rebars.

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