MAY 2018 M.Sc. in Civil Engineering Ali KADHIM HASSAN ALHUSSAINAWE

UNIVERSITY OF GAZİANTEP

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SIZE EFFECT ON PUNCHING SHEAR BEHAVIOR OF SLAB-COLUMN ASSEMBLY MADE FROM ENGINEERING CEMENTITIOUS COMPOSITE MATERIALS (ECC)

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Ali KADHIM HASSAN ALHUSSAINAWE

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

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Ali Kadhim Hassan ALHUSSAINAWE

ABSTRACT

SIZE EFFECT ON PUNCHING SHEAR BEHAVIOR OF SLAB-COLUMN ASSEMBLY MADE FROM ENGINEERING CEMENTITIOUS COMPOSITE MATERIALS (ECC)

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M.Sc. in Civil Engineering

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Engineering cementitious composite material (ECC) with adding two kind of synthetic fibers (polyvinyl alcohol 6-12mm and polypropylene12mm) are used to search the effect on the punching shear behavior of flat plate column connection. Totally twelve slabs are poured and tested, nine of ECC slabs are dividing for three groups each group have three panels depending on the kind of fiber (PVA 6, PVA 12 and PP12mm) and then compared these ECC panels with three control slabs of normal concrete. The thickness of the slabs in each group is varying (50, 60, and 80 mm). In order to investigate the effect of the size of the panels on the punching shear of flat slabs, with fixing for the rest dimensions (500 × 500 mm). All slabs are reinforced with same reinforcement ratio 0.12. The results of test showed that the slabs made from ECC with fibers give less deformation from the normal concrete. This is due to the ability of the ECC to capture crack growth and crack is widening. The addition of fiber leads to a reduction in deformities at all loading stages and especially after initial first crack, also enhancement the final load carried by the flat slab. Fibers not only defer the deformations of the diagonally cracks within the panels, but also shifting the punching shear failure to gradually and ductile shear failure crack patterns. Also the test shown decreasing in shear stress with increasing the slab thickness. But the nominal shear strength is increased with the slab thickness increasing. The ECC PVA 6 show greatest enhancement for nominal shear strength ranging between 25-43% more than the normal concrete.

Key Words: Column slab connection, PVA and PP fibers reinforced concrete, conventional steel reinforcement, punching shear, size effect

ÖZET

BOYUT ETKİSİ ÇİMENTO ESASLI KOMPOZİTLERDEN YAPILAN KOLON DÜZ DÖŞEME BİRLEŞİMLERİNİN ZIMBALAMA KAYMA DAVRANIŞI

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Mayıs 2018

62 Sayfa

Bu çalışmada iki farklı tip (polivinil alkol 6-12 mm ve polipropilen 12 mm) sentetik elyaf eklenerek üretilen çimento bazlı kompozit malzemeden (ECC) oluşan düz plaka kolon bağlantısının zımbalama kesme davranışı araştırılmıştır. Toplam on iki adet döşeme üretilerek test edilmiştir. Deneyler dört gruptan oluşmaktadır. Bunlar PVA 6, PVA 12 ve PP 12 sentetik elyaf kullanılarak üretilen üç grup ile karşılaştırma amacıyla üretilen normal betondan olan dördüncü gruptur. Her bir gruptaki levhaların kalınlığı 50, 60 ve 80 mm olarak değişirken diğer boyutlar sabit (500 × 500 mm) tutulmuştur. Tüm plakalarda aynı donatı oranı 0.12 kullanılmıştır. Test sonuçları, ECC'den yapılan döşemelerin normal betona göre daha az deformasyon verdiğini göstermiştir. Bu, ECC'nin çatlak büyümesini önleme ve genişlemesini engelleme özelliğinden kaynaklanmaktadır. Elyafın eklenmesi tüm yükleme aşamalarında ve özellikle ilk çatlaktan sonra deformasyonlarda bir azalmaya yol açmaktadır. Ayrıca düz döşeme ile taşınan nihai yükün artması, elyafların, yalnızca diyagonal çatlakların ve deformasyon oluşumunu ertelemekle kalmayarak, aynı zamanda zımbalama etkisinin kırılgan davranıştan sünek davranışa doğru değişmesinden olmaktadır. Ayrıca, döşeme kalınlığı arttıkça kesme gerilmesinde azalma görülmüştür. Ancak döşeme kalınlığı arttıkça nominal kesme kuvveti artmaktadır. PVA 6 sentetik elyaf, normal beton göre % 25-43 daha fazla nominal kayma mukavemeti artışı ile diğer elyaf çeşitlerine göre en büyük artışı göstermektedir.

Anaktar Kelimeler: Kolon kiriş birleşimi, PVA ve PP elyaf takviyeli beton, , zımbalama kesme.

To

The absent we wait for his vision ..

My dear father..

My paradise, my beloved mother ..

My soul .. My wife ..

My children..

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LIST OF SYMBOLS / ABBREVIATIONS

RC	Reinforced Concrete
FRC	Fiber Reinforced Concrete
ECC	Engineering Cementitiues Composite
PVA	Poly Vynil Alkohol
V_f	Fiber volume fraction
SP	Super Plasticizer
HRWRA	High Range Water Reducing Admixture
$f_c{}'$	Compressive strength
d	Slab depth
ρ	Reinforcement ratio
A	Area
d	Effective depth
E_C	Modulus of elasticity
f_y	Yield stress
PC	Portland Cement
m_R	Moment capacity
L_f/d_f	Aspect ratio of fiber
ϱ	Tension reinforcement ratio
b_o	Critical shear perimeter

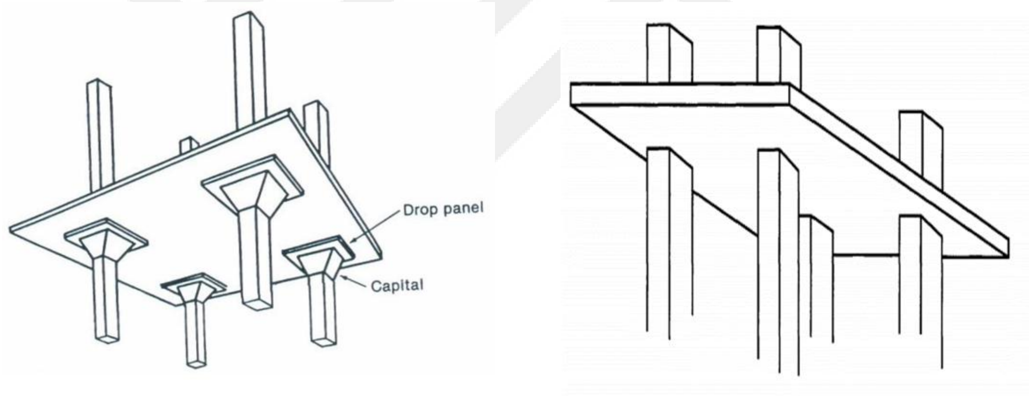
l_f	Length of fiber
f_{ct}, f_{sp}	Tensile strength for concrete
PP	Polypropelene
ACI	Amreiecan Concrete Institute
P_u	Ultimate load
L	Length of cylinder
Δ	Displacement
δu	Deflection at ultimate
δy	Deflection at yielding
δcr	Deflection at first crack
EC3	European Code 3
p_{cr}	Load cracks
P_{flex}	Flexural capacity
CSA	Canadain Standard Association
LVDT	Linear Variable Displacement Transducers
FR	Fiber Reinforcement
Sf	Silica fume
PE	Polyethelene
v_c	Factored nominal shear stress
v_n	Nominal shear strength
c	The side dimension for the square column

CHAPTER ONE

INTRODUCTION

1.1 General

The flat slab is vastly used in multi-story facilities like parking, the flat slab is a Reinforced Concrete (RC) panel supported directly on columns as shown in Figure 1.1. The slab may be in the column area with a fixed thickness or may be thick as if it were a drop-down plate. The drop panels are effective in reducing shear stress as the column is vulnerable to punch through the board, and it provides an increased resistance of moment where the negative moments are greater.



(a) Slab with drop panels (b) flat slab plate

Figure 1.1 Types of slab-column connection.

The flat slabs have an advantage, simplified in wooden work and decrease the high of the story it is more economical. The widows extended up to the underside of the panels and have no beam to prevent the services of the building like the lighting system and air conditioner etc…

One of the important issue in the flat slab design it is the big bending moment and shear force that which created at the area between the slab and the columns support area. We focusing in this study on the punching shear behavior of that type of slabs and the parameter, which may effect on this type of failure.

Punching Shear failure is a local phenomenon that usually happened in a brittle way, in a loading support area or column of the support area. This tragic failure accrue because there are no visually external signals before the failure occurs. Punching shear catastrophe have occurred several times in recent decades. On June 30, 1995, a five-story shop collapsed in South Korea because of this type of failure. In this disaster, 500 people were killed and about 1,000 injured (see Figure 1.2).

Figure 1.2 Post-collapse photograph of the Sampoong Department Store (Gardner et. al. 2002)

The model of the flat slab punching shear failure is described by punching of columns through a section of the Peripheral slab. Figure 1.3 explains the example of a punching shear failure. This type of failure is one of the most important considerations when finding the thickness of the slab-column connection. Therefore, the safety of this type of slabs very important and the precise foretelling of the punching shear strength is the main concern for the designer.

To avoid this problem is by adding shear reinforcement such as shear studs as shown in Figure 1.4. Shear stud could be used when the slab structure insecure to the below statues:

1. A big amount of unbalanced moment happened by pattern or lateral load conditions to transfer it by the slab-column connection.
2. The slab carries heavy gravity loads.
3. The big distance span.

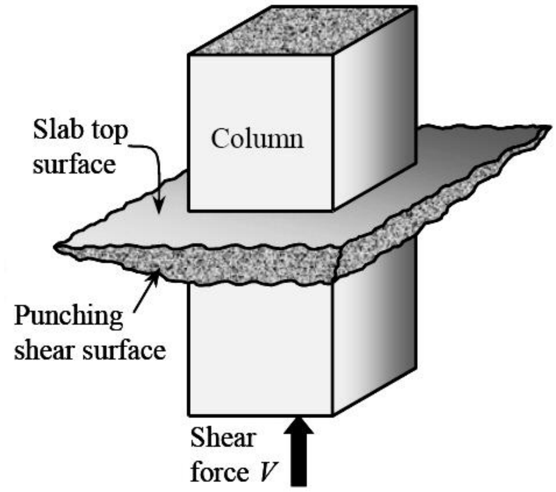


Figure 1.3 Punching shear failure of a slab-column connection (Stein 2006)

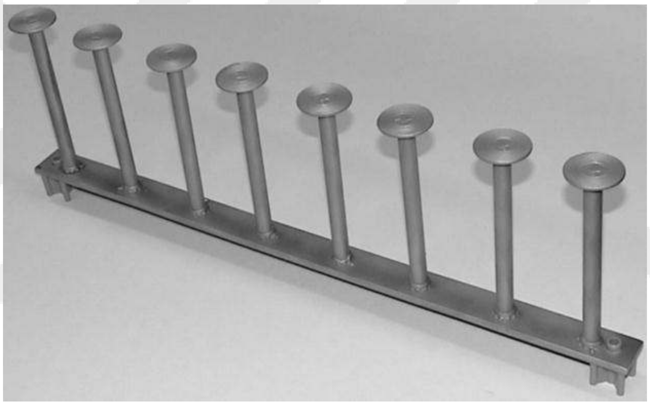


Figure 1.4 Shear studs.

1.2 Fiber Reinforce Concrete FRC

Fiber reinforced concrete (FRC), is a kind of concrete that have diverse fibrous materials that increase its structural strength and cohesion. Given that concrete is a quite brittle material with very good compressive strength but a relatively small tensile force; it makes it likely to crack under many conditions. By adding fiber, you will not only increase the intensity and smoothness of the construction, the crack state will improve radically. The main idea of the use of RC by fibers is to provide a complete concrete block with fiber, thus creating a new building material with its own characteristics. In the event of failure, concrete or RC structures will be reduced only a few centimeters before they are completely broken, thus preventing the risk to the lives of any person (Tepfers, 2010).

1.3 Size Effect

There has been little research on the size effect of the punching shear failure of two ways slabs. Most of the investigations on size effect of the shear strength are for beams or one-way slabs. (Birkle & Dilger 2008) the size effect of slab on punching shear strength the tested nine slabs- columns assembly to find the size effect of panels on shear strength in 3 groups have slab thickness (160, 230 and 300mm) they mentioned that the slab thickness 230 mm without shear reinforcement may not had high safety factor if designed accordance to ACI 318-05. About the thicker panels with shear reinforcement, the shear stress resistance provided by concrete was reduced too. Panels with shear reinforcement result is considerable rise in shear capacity and ductility comparing with panels without shear reinforcement. They recommended the considerable decrease of the shear resistance with slab thickness increasing.

Sohiya (1989) made a many of experimental on large scales beams in which the influence of member depth and aggregate size on shear strength was inspected. Lightly RC beams, changing in depth from 100 to 3000 mm. Contain no transverse reinforcement are tested under a uniformly distributed load. The shear stress at failure decreased as the size of member increased and the aggregate size decreased.

1.4 Research Objective

The objective of this research program is to investigate the ''size effect" in punching shear behavior. An platform is planned to seek the reduction in punching shear stress at failure as the thickness of the slab increases to prevent the sudden failure and brittleness, Twelve Engineering Cementitious Composite (ECC) slab column specimens were designed to fail at punching shear by using three type of synthetic fiber Polyvinyl Alcohol (PVA) PVA 6 mm, PVA 12 mm and Polypropylene (PP) PP 12 mm, and these fiber adding to mixture of engineering cementitious composite material ECC to find out the decrease in shear stress by using this fiber also another parameter was slab thickness ranging between (50, 60 and 80 mm) respectively and then we compare the ECC slab with normal concrete slab to figure out the behavior of the punching shear and it will reduce the shear stress when the slab thickness are increased.

1.5 Problem Statement

Flat slab-on-column construction is subjected to high occasional stresses concentrated at the slab-column connections, which can lead to a non-ductile, sudden and brittle punching failure. Although wide researches had been conducted on enhancing the ductility behavior of flat plates, such as using transverse shear reinforcement (bent bars and shear studs), however improving the shear behavior of concrete materials had also shown a good option. Fibrous Cementitious materials are one of the most important options. Due to the bridging effects provided by the fibers, less brittle shear failures were achieved and, in some cases, the mode of failure was transformed from shear to a ductile flexural mode. Based on the premises, an engineering cementitious composite ECC are experimentally planned to investigate. The classical mix proportion is suggested to use with different aspect ratio and two fibers type (poly-vinyl-alcohol and Polypropylene). Moreover, the suggested flat plate will reinforce with conventional reinforcement bars, in order to investigate the interaction of the steel reinforcement and the fibers.

1.6 Objective and Scopes

This research aimed to investigate the behavior of flat plate made from ECC, and testing under monotonically loading. The main investigation process is summarized as follows:

1. ECC mechanical properties include compressive strength, splitting tensile strength, modulus of elasticity.
2. Experimentally investigation the strength of slabs, deflection history of the tested slabs.
3. Comparison of the shear behavior and the flexural behavior of the slab, in which the slabs are designing to fail in punching.
4. Investigation of the size effect of the slabs, through using three different thicknesses.
5. Reinforcement –fiber interaction through using different types of fibers.

1.7 Structures of Thesis

The current research is presented in five chapters as below:

Chapter 1 where the punching shear problem was defined and the thesis milestone are introduced.

Chapter 2 included the literature review on basic knowledge of size effect on punching shear of flat slab concrete structures made from ECC in addition that, a brief review on the previous researches related to the present study is given.

Chapter 3 shown the experimental work details as well as the used construction materials.

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

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

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Punching shear failures of concrete flat plate structures are unwanted modes of failure since they give little caution and have disastrous consequences. Therefore, it has been important that the engineers try to understand the behavior of slab- column connections. However, although widely research has been done on the punching shear strength of slabs, till now there is still no generally applicable, logical theory. The procedures of the present building code design are depended on the experimental studies and interests have been raised about the punching shear strength of slabs for all situations. There is a big contradiction between design codes of different countries. Many of these codes do not similar value for some main and proved factors affect the shear capacity of concrete members.

The unexpected and brittle nature of this phenomenon carry out in the progressive breakdown of a number of buildings. Sampoong Department Store collapsed in South Korea in 1994 (see Figure 2.1). The building was a 5-story flat plate.

Figure 2.1 Sampoong department store collapse (Gardner et. al. 2002).

The judicial investigations lead that the failure initiated due to distress in the 5th floor slab-column connections after the change of the restaurant, area to a swimming pool (Gardner et. al. 2002). In a similar manner, punching shear was occurred at Piper`s row car parking (built in 1965) Wolver hampton UK 1997 as shown in Figure 2.2

Figure 2.2 Punching shear failure in car park (Wood, 1997).

Many flat slab structures collapsed in past earthquakes. Punching failures are 44 waffle-slab buildings in the 1985 Mexico City earthquake (Rosenblueth and Meli 1986). Baybridge Office Plaza in the 1989 Loma Prieta earthquake (Mitchell et. al. 1990) (see Figure 2.3).

a) Bullocks Department Store- Northridge

b) Waffle Slab- Mexico City

Figure 2.3 Flat slab failures due to earthquakes (Mitchell et. al.1990)

Much confusion is expressed from these factors with regards to the size effect of the members on the punching shear capacity of slab elements.

The interest of this research is to study the "size effect” in normal-strength concrete slabs that which made from engineering cementitious composite materials ECC in order to best understand the mechanisms implicated.

This chapter will give the historical if the previous research focuses on the size effect on the punching shear of flat slab resisting and the factors effect on this behavior.

2.2 Historical Background of Fibers

Historically, the man used the fibrous materials as reinforcement for brittle materials like mud bricks also with masonary about 3500 years before. As founded in some historicity near Baghdad (Hannant, 2000). Fibrous materials such as the use of straw or horse hair reinforcement in a lot of structure at that time (Sanyal, 2009). There are about nineteen kinds of fiber used as reinforcement, as shown in Table 2.1. According to ACI 544 there are four FRC based on fiber material type. H.Alfsen from France at 1918 find a way to develop the properties of the concrete add long steel fibers, long wooden fiber, and other type of fibers. Also he was one of the first researchers which stated that the roughness of the steel fiber surface can affect the concrete mixture, also He insisted on the importance of adding steel fibers to the concrete mix. Thirty years later Porter mentioned the possibility of applying short wires on concrete to improve concrete, Researchers are still developing existing fiber applications and looking for new uses to improve the properties of building materials (Katzer, 2006).

Table 2.1 Type of fibers.

Type of fiber	
Steel	Carbon
E glass	Nylon
AR glass	Polyester
Acrylic (PAN)	Polyethylene
Aramid	Polypropylene

2.3 Fiber Reinforced Concrete

FRC is not new idea. From biblical period fibers were used in cement construction materials as stubble and horse hair (Brandt 2008).

ACI code and other codes generally show the solutions that which generally impact with the services of the facilities like mechanical and electrical works, like drop panels which wants major slab form works customization (Jarallah 2016).

Fiber reinforcement decrease the stress condensation at the tips of flexural and shear cracks and the controls their spread, also the inclusion of fibers not only changed the figure of the punching failure surface on the tension side but also gradually the surface of the failure is pushed away from the face of the column (Swamy & Ali 1982). When adding 1.0% fiber volume, and at service load the deflections are decreased about 30% and tension steel strain compressive of concrete strain and the rotation about 40-50% (Swamy & Ali 1982).

Improved control was also reported in cracks and a 21% increase in crack load due to the addition of steel fibers was documented (McHarg 2000).

2.4 The Definitions of Micro and Macro Fiber

Fibers currently in use or under consideration, may be divided into two categories: micro and macro. Micro fibers are very fine fibers with diameters of the same order as those of the particles of cement (<40pm) and lengths less than 10mm. Macro fibers, on the other hand, are large fibers 0.1 to 1 mm in diameter and 25-60 mm in length. In traditional FRC, macro-fibers (e.g. macro-steel fibers) are generally active in improving the post-cracking resistance of concrete. At the comparative low fiber volume fractions (<1%), due to comparative large fiber-fiber spacing, the action of fibers is show after the appearance of a macro-crack. This act is totally dependent on the fiber opposition to pull-out from the concrete matrix which resist further widening and increase of cracks.

So the participation of macro fibers is generally apparent in the post-cracking response. Important amelioration in the post-cracking behavior of concrete can be carry out, which showed by an increase in post-cracking ductility as shown in Figure 2.4.

However, amelioration in other properties such as first cracking strength, tensile strain at the peak load, and peak load are insignificant.

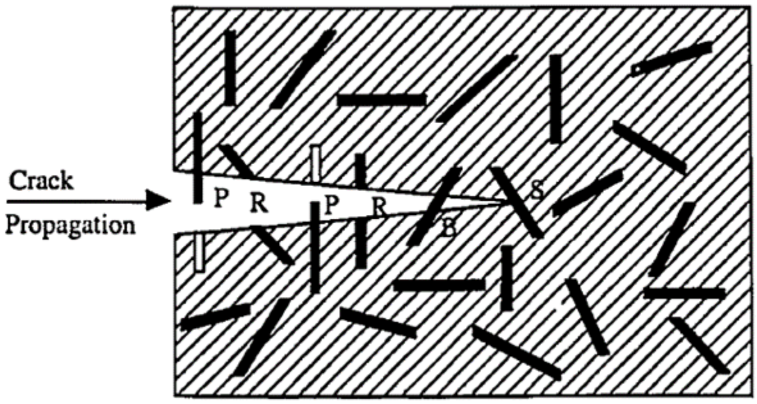


Figure 2.4 A schematic representation of the crack passing in the composite matrix. (P- Fiber pull out from matrix; R- fiber rupture; B- fiber bridging the matrix cracks; S-fiber suppression the matrix cracks.)

They assumed the single microfiber and the cement matrix have same reaction in the macro fiber also. In the case of the microfibers, micro fibers prevent distributed micro cracks instead of one separate macro crack. The acting of micro fibers as preventive of micro cracks allowing stable multiple cracking to occur in the matrix. Many cracking is not hurtful to the cementitious material as is the forming of separate, visual cracks.

Micro cracks will eventually localize in certain regions forming a macro crack pattern which in general depends on the total displacement history (Sheng 1995).

2.5 Polyvinyl Alcohol Fiber

PVA of adopted poly (viny1 acetate) that are readily disintegration by treating alcoholic solution with an aqueous alkali or acid (Feldman 1989). Bringing about the structure appeared in Figure 2.5 PVA containing hydroxyl gatherings (OH) that can shape a hydrogen bond between the molecules resulting in a significant change in the correlation strength between the matrix and the fiber PVA (Toutanji et.al. 2010).

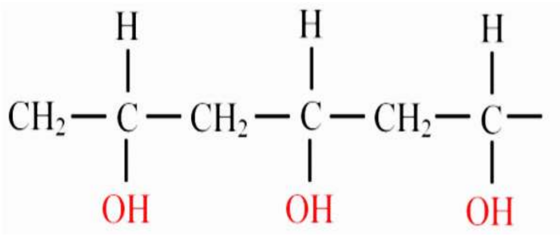


Figure 2.5 PVA structure.

PVA is a white powder with specific gravity ranging from 1.2–1.3 (1200-1300 kg/m^3) (Toutanji, et, al. 2010). This powder is then formed and put into PVA fibers, which are produced commercially. Table 2.2 shows the most common types of PVA fiber commercially available in the market. 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), the tensile strength and elastic (Young's) modulus 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 increase in fiber length and diameter. PVA fibers are also available in both resin bundled (oil coated) and virgin (non-coated) type.

Table 2.2 Common types PVA fiber available in the market.

Length	Diameter	Tensile strength	Modules of elasticity	Manufacture
mm	mm	MPa	GPa	
6	0.024	1600	39	Nycon Corp.USA
6	0.027	1600	39	Kuraray Co.LTD-Japan
8	0.038	1600	40	Nycon Corp.USA
8	0.038	1400	30	Nycon Corp.USA
8	0.04	1600	40	Kuraray Co.LTD-Japan
8	0.04	1300	30	Kuraray Co.LTD-Japan
13	0.1	1200	25	Nycon Corp.USA
18	0.2	1000	29	Kuraray Co.LTD-Japan
19	0.2	1000	29	Nycon Corp.USA
30	0.66	900	23	Kuraray Co.LTD-Japan
30	0.66	800	23	Nycon Corp.USA

PVA fiber has a rough surface. This property mechanical interlocking capability greatly improves the adhesion-related ability of these fibers in the matrix (Feleko et.al. 2009) generally, the surface structure of a fiber is very active on its performance. The smooth surfaces and highly hydrophobic are often significantly reduced by composite performance (Li & Stang 1997). To illustrate the surface roughness differences between fibers, Scan Electron Microscope (SEM) images are captured at the same magnification of PVA fibers versus Polypropylene (PP) fiber, which has a very smooth surface structure, shown in Figure 2.6.

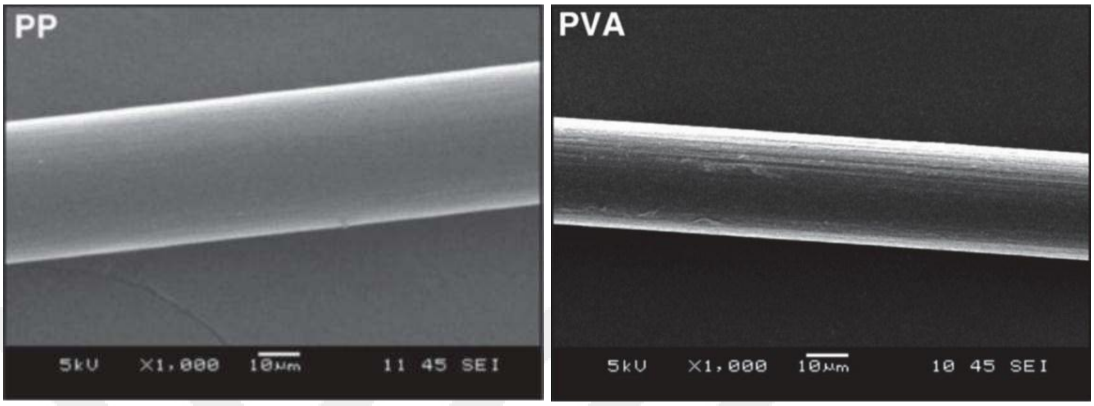


Figure 2.6 Scanning electron microscope (SEM) images of Polypropylene (PP) and PVA fibers (Li & Stang 1997).

2.6 Polypropylene Fiber (PP)

Polypropylene (PP) fibers were proposed as an admixture to concrete for the construction of Explosion-proof buildings for the U.S. Corps of Engineering, This included the integration of many natural and man-made tones in cement and mortar. The publication gave an incentive for the first experiments on fiberglass made of polypropylene in concrete by Shell International Chemical Co.Ltd (Goldfein 1965).

PP is a polymer derived from a pure monomeric C3H6 hydrocarbons such as paraffin wax. Is not fiber polymer concrete reinforcement for the concrete experience of the vehicle until 1965. Large scale use of PP fibers in concrete did not happen until the late 1970 (Balaguru, 1992). Table 2.3 shows some properties of PP fibers.

Table 2.3 Some properties of PP fibers.

PP fibers			
Impurity	Zero	**Young`s modulus**	3.45 GPa
Appearance	Natural white	**Tensile strength**	350 MPa
Cross section	Round	**Elongation**	25%
Standard	ASTM-C1116	**Specific density**	0.90 kg/m^3
Fiber length	6, 12 and 19 mm		

2.8 Punching Shear of Two Way Slab.

Given away for calculate the punching shear strength of the slabs. The relationship between the punching shear and the flexural resistance of the slabs also given. To find the punching strength depend fundamentally on the flexural reinforcement strength (f_y) and the compressive strength of concrete (f_c').the punching shear at distance d from the face of the column, can be define as:

$V_u = (149.3 + 0.164\, \varrho f_y)\, [1 - (0.5 \varrho f_y) / f_c']\, b_o.d$ ……………………..........(2.1)

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 (Yitizhaki 1966). Realization 40 simply support slabs with the space between the load and support small enough for the shape of failure surface to be describe by the samples geometry. The results obtained are used to derive an easy experimental expression for punch strength in terms of cone punching (Regan 1984). Twenty eight slabs were tested to find the effect of the lying of flexural rebar, thickness of slab, f_c' of slabs, ration of tension reinforcement, and the size of the loaded zone on punching of the slabs. It was concluded that the concentricity of rebar towards the padded area did not have any significant impact in terms of punching resistance, the punching resistance of panels can be significantly improved when border conditions are not those with simple support (Regan 1986). Dedicated researchers and code provisions on the ability of punching shear and its association with concrete strength, the results of the empirical study relating the punching shear to concrete strength and the steel ratio. The shear capacity is proportional to the cube root of f_c' and the steel ratio and that ACI-CSA code provisions should be reviewed (Gardner 1990).

Seventeen RC panels were analyzed to verify the deformation characteristics and strength of punching shear failure analysis of high strength concrete panels. The test panels had various thickness and steel ratio ranging between 0.49 and 2.33%. Empirical results show that with increasing the amount of reinforcement, the punching strength of the panels increased too. It is founded that the using the cubic root of the f_c' to figure the punching resistance of concrete of panels in general gave good results that the square root expression used in ACI Code 29. (Marzouk and Hussein 1991).

Present the results of empirical investigation of punching shear force of RC panels with changing span- depth ratios.

Ten panels neutral analysis; five with flexural reinforcement and five with both flexural and shear reinforcement. It has been maintained, the thickness of panels constant while the diameter of support is changed to reflect different span-depth ratios. Was found on the punching shear capacity significantly with low ratio of the depth of depth to less than 6. The maximum test greater capacity five times the expected capacity of the ACI 1983 building code. The high-capacity resulting from the smaller span-depth ratio, in the forces of compression pilot caused by work restraining when stents, an excellent marina has been provided with the reinforcement of the shear (Lovrovich and McLean 1990).

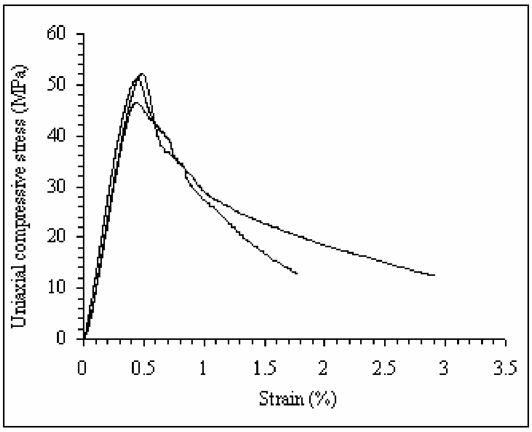
2.9 Engineering Cementitious Composite

ECC adopted by the original developers (Li 1993) to emphasize the basis of the precise mechanics behind the design of these materials. The physical components, ECC uses similar components as FRC. Have water, cement, sand, fiber and some chemicals additions. Do not use coarse aggregates as they tend to negatively affect their unique ductile behavior of the composite.

The typical formulation uses w/c ratio and the sand/cement ratio is 0.5 or less. Unlike some high-performance FRC, ECC does not use large amounts of fiber. In general, 2% or less of the volume of non-contact fiber is sufficient, although the compound is designed for structural applications. Due to the relatively small amount of fiber, and their individual nature, the ECC mixing process is similar to that used in ordinary concrete mixing. Also by intentionally limiting the amount of fiber, a number of feasibility studies have concluded the economic feasibility of ECC in specific structural applications. Different types of fiber can be used in the ECC, but the detail structure must comply with certain rules imposed by micro-mechanical considerations (Kanda & Li, 1998).

From semi-static loading tests, ECC reinforcement systems have significantly improved the out of plain resistance to construction walls. In specific, the ultimate load capacity and max.deflection of the masonry wall increased from 6.5 to22 times and from 4.2 to 15.9 times. The steel mesh within ECC strengthening layer increase the ultimate load capacity of the samples by 17-74%. The ability of ECC to strain hardening and develop multiple micro-cracks was also shown in the masonry implementation (Maalej et.al.2005).

A hybrid –fiber ECC using the appropriate volume ratio of high and low modulus fibers have been developed to better meet the functional requirements of impact and blast resistant structures. This type of hybrid fibers ECC have 0.5% steel and 1.5% PolyEthylene (PE) fiber, it’s shown an optimal balance between ultimate strength and strain capacity. The uniaxial compressive and tensile stress- strain curves of the ECC materials are shown in Figures 2.7 and 2.8 (Zhang et al. (2004).



Figures 2.7 Typical hybrid-fiber ECC uniaxial compressive stress-strain curves.

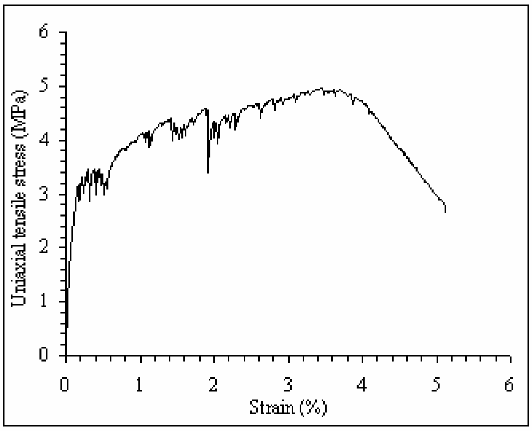


Figure 2.8 Typical hybrid-fiber ECC

Studied the high velocity impact resistance of this hybrid-fiber ECC experimentally, which indicates its high capacity to absorb energy and its ability to resist multiple effects with small fragmentation, Remove the portion and size of the small hole on the shock surface. The above study concluded that ECC is a good material for impact and design resistant to structures to resist explosions (Maalej et al. 2005).

f_c' of the ECC changed from 30-70 MPa, Depending on the matrix configuration. Compressive strain capacity is about twice of the FRC's (0.4-0.65%) (Li 1998).

ECC's ability to reduce stress the redistribution of damage in the joints to the inside of the shear slabs is responsible to improve structural strength and ductility observed in ECC slabs. The prevention of local fracture in the joint was also shown in the shear stress test common using a steel bolt (Kanda et.al, 1998).

ECC It also represents a family of materials with different functions in addition to Common properties of high tensile softness and multiple fine cracking. Unification of self ECC (eg, ECC M45 and its variants) is designed extensively on site building applications. Table 2.3 givesECC Mix Design Proportions by Weight for ECC-M45 (Kong et al., 2003; Lepech and Li, 2007).

Table 2.3 ECC mix design proportions by weight for ECC-M45.

Mix designation	Cement	Fly ash	Sand	Water	HRWR*	Fiber percent
M45	1.0	1.2	0.8	0.56	0.012	0.02

*High Range Water Reducer

The reference mix modifications were used in various construction projects. Full range ECC production carried out in Japan (Kunieda and Rokugo, 2006).

2.10 Size Effect

There has been little research on the size effect of the punching shear failure of two ways slabs. Most of the investigations on size effect of the shear strength are for beams or one way slabs. (Kani 1966 & 1967) was among the first to investigate the effect of member size on concrete shear strength. He tested four series of beams without web reinforcement with varying member depths, longitudinal steel percentages, and shear span-to-depth ratios, a/d. He concluded that member depth and steel percentage had a great effect on shear strength and there is a transition point at a/d = 2.5 at which beams are shear critical.

(Bazant & Kim 1984) suggested the shear force equation is based on the theory of fracture mechanics. This equation represents the phenomenon of size effect and the longitudinal ratio was calibrated using 296 previous tests. They contain that the thicker samples depth, the factor of safety in ACI code nearly out. although a part from Kani's test no experimental indicate was helpful yet to clarify that fact as all the test performed till that time were relative to small samples.

2.11 Size Effect on punching shear

The results of several research tests showed that the punching shear strength of the slab increased when the slab thickness are decreased. Reagan (1984) tested six samples, showing the test results that the force shear punching conformed to the standard British standard $\sqrt[4]{1/d}$.

Then nominal shear stress at the failure is not fixed, as mentioned at the design formula, its decrease when the size of thickness increase. The effect of the observed volume in punching shear strength is described as an almost improved design formula which uses the effect size law for fragile failure due to distributed cracking (Bazant & Cao 1987).

Size effect presence in punching shear failure of the samples have one-side reinforcement layer (Bazant & Cao 1987). Find the effect of the slabs thickness on the punching shear strength of flat panels clearly demonstrate the significant impact of size on shear stress resistance, Especially for tests without shear reinforcement. New tests where panels thickness varies between 160 and 300 mm and tests by others with panels up to 500 mm indicate that panels no more than 260 mm thick may not have a high safety factor if designed in accordance with ACI 318 05, For thick panels with shear reinforcement, the shear stress resistance provided by the concrete is also decreased but in a small amount (Birkle and Dilger, 2008). Tile thickness is a very important factor governing the final shape of the perforation cone (Al-Quraishi 2014).

Geometrically similar slabs with varying thickness have been tested by (Kinnunen, et.al, 1978 & 1983; Tolf 1988; and Regan 1981). The results suggest a continuous reduction of relative shear strength with increasing depth. Both the British BS 8110-85 and CEB-FIP Model Code 90 include the size effect in calculating the shear strength.

The American ACI 318-95 and Canadian CSA A23.3-94 do not, and therefore are expected to be unconservative for thick slabs. To assess this statement, test results of slabs with d > 120 mm are compared with the code predictions.

CHAPTER THREE

EXPERIMENTAL WORK

3.1 General

This chapter explains the experimental works that which were conducted in the Structures Laboratory in the Department of Civil Engineering at Gaziantep University, The experimental works describe as following:

The main parameter is the effect of the thickness of the slab (h), by using three type of fibers polyvinyl alcohol and polypropylene.

Twelve slab specimens with similar geometry and steel reinforcement were Constructed and tested. Which were designed to study the punching shear strength of two-way flat plate slabs, which reinforced with fibers and steel bars made from Engineering Cementitious Composite materials (ECC).

The experimental program contain casting and testing for three control panels made from normal concrete with different thicknesses (50, 60 and 80mm) respectively as there marked and three group of panels with different thicknesses as above, each group included four panels depending of the fiber type, one of these panels without steel bars and the other were reinforced with same volume fraction of fibers 2% for each casting panels and steel bars distributed in two orthogonal layers as shown in Table 3.1.

All slabs were 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 is applied to the slabs through the column stub from the top.

Table 3.1 Test groups.

Group	Mix code	Fiber type	Slab thickness (mm)
A	N5	-	50
	N6		60
	N8		80
B	V6-5R0	PVA 6 mm	50
	V6-5		50
	V6-6		60
	V6-8		80
C	V12-5R0	PVA 12 mm	50
	V12-5		50
	V12-6		60
	V12-8		80
D	PP-5R0	PP 12 mm	50
	PP-5		50
	PP-6		60
	PP-8		80

3.2 Specimens Geometry

The specimens are selected as a square model with dimensions of 500×500 mm, and varied thicknesses (50, 60 and 80 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.

The specimens were designed to fail in punching shear (Vu < Pflex) where Vu is the punching shear nominal strength according to ACI318, P_{flex} is the flexural capacity which is obtained from yield line analysis, therefore all tested slabs were reinforced by one layer of convenient flexural reinforcement by ϕ5.3 mm deformed bars, with 400 MPa yield strength. The ends of reinforcement bars are bent by 90º deg. one additional bar in each direction of the free ends is added. The concrete cover was 15 mm in all directions. The reinforcement ratio (ρ = 1.2%) was constant for all slabs, that means there are different bars spacing, Figure 3.2 shows the slabs reinforcement details.

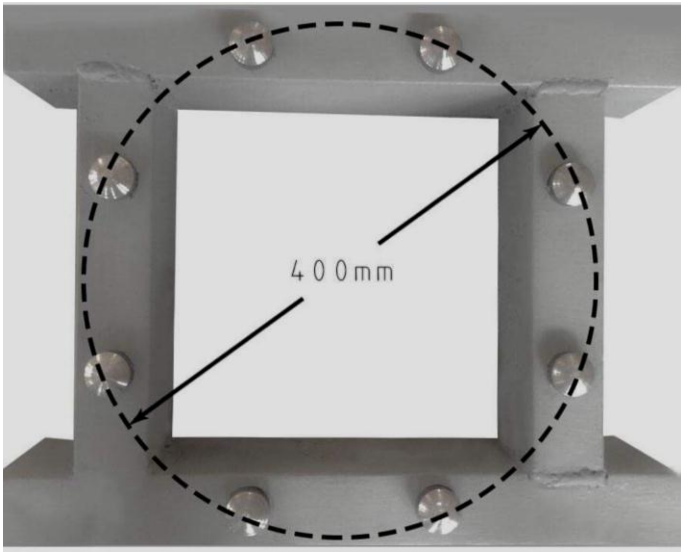


Figure 3.1 Test support model.

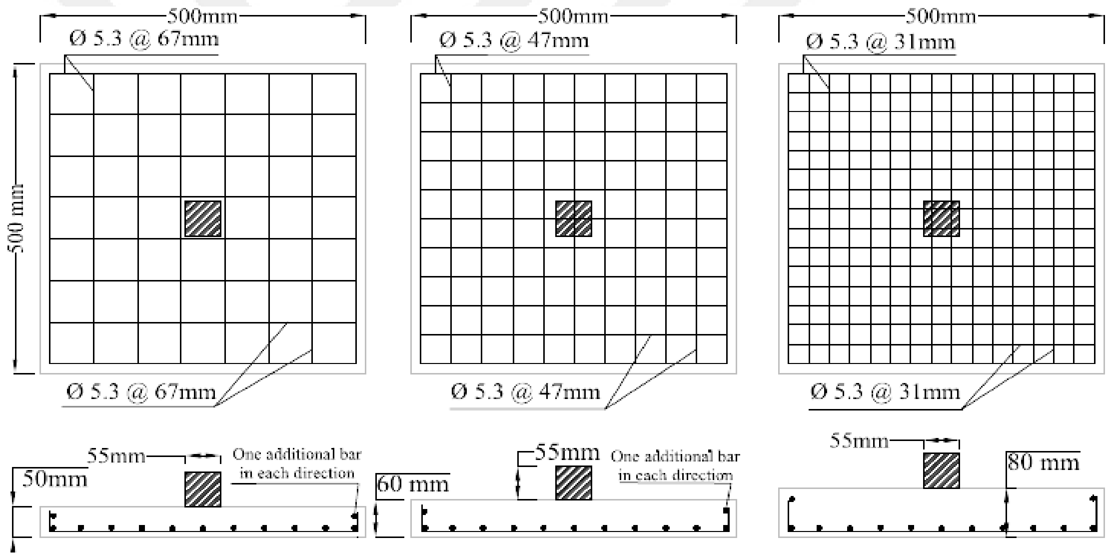


Figure 3.2 Slab geometry and reinforcement bars' details.

In order to construct slabs with uniform dimensions that can sustain the vibrating forces, and with right angle faces, the mold side's shutter is made from angle iron of (50, 60 and 80 mm) that is fixed perpendicularly to the plywood as shown in Figure 3.3.

Figure 3.3 Casting mold and reinforcement details.

3.3 Material Properties

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

According to earlier researchers and studies, fibers are more active with a mixture with fine aggregate, therefore; the plan was introducing a mixture with 63.24% of fine aggregate and 36.75% of the total mix percentage.

Also, for ECC the mix consist, cement, water, silica sand, fly ash, super plasticizer, and volume fraction of fibers 2%. Table 3.2 shows the design mix proportion.

Table 2. Mix of concrete for one cubic

Mix type	**Fiber percent**	**Water** lt	**Cement** kg	**Flyash** kg	**SF** kg	**Sand** kg	**CS** kg	**SS** kg	**SP** kg
Normal	0	216	465	-	35	1170	680	-	6.6
ECC	2	352	551.4	662	-	-	-	441.12	7.33

SF: Silica Fume; CS: Crashing Stone; SS: Silica Sand; SP: Super Plasticizer

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 cement used for normal concrete and ECC. 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 Percent** %
12.50	0.0	100
9.50	0.0	100
4.75	104.7	93
2.00	554.0	63
1.18	816.5	45
0.60	1048.7	29
0.30	1255.4	16
0.15	1407.4	5
0.075	1431.0	4

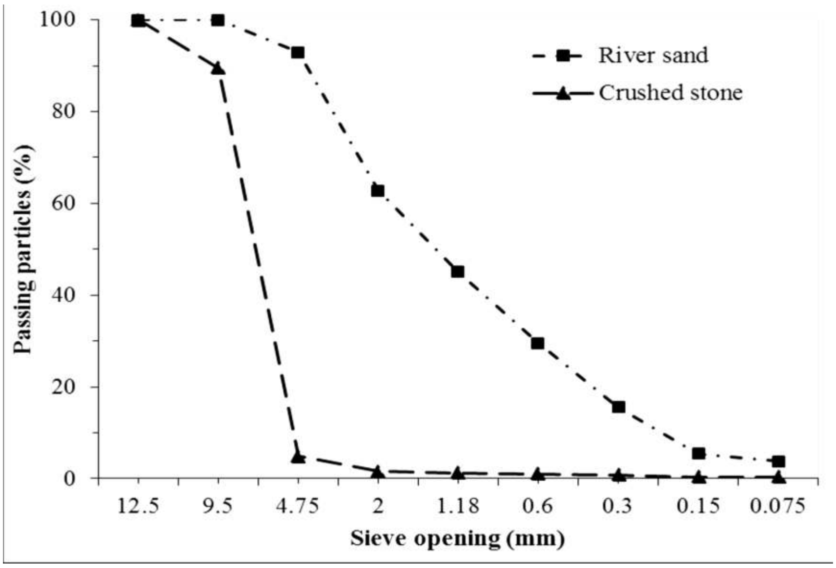


Figure 3.4 Fine aggregate and coarse aggregate sieve analysis.

3.3.4 Course 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 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 course (crushed stone) aggregate.

Sieve opening (mm)	**Retained weight** (gm)	**Passing percent**
12.50	0.0	100
9.50	186.6	89
4.75	1690.8	5
2.00	1749.7	2
1.18	1754.9	1
0.60	1758.5	1
0.30	1763.8	1
0.15	1770.0	0
0.075	1770.0	0

3.3.5 Polyvinyl alcohol fiber

Two type of PVA fiber have been used 6-12mm, PVA fibers can reduce the formation of shrinkage crack in cement and concrete before processing and increase its durability. The source of the type is from China as shown in Figure 3.5 and the volume fraction has been use is 2% for both length. Table 3.5 shown the physical properties of PVA.

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 mm	1260	6	0.015	400	1600	34
PVA-12 mm	1260	12	0.015	800	1600	34

(a) PVA 6 mm

(b) PVA 12 mm

Figure 3.5 PVA fiber.

3.3.6 Polypropylene

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

Table 3.6 Physical properties of PP fiber.

Fiber type	**Density** kg/m3	**Length** mm	**Diameter** mm	**Aspect ratio** mm/mm	**Tensile strength** MPa	**Elastic modulus** GPa
PP-12 mm	910	12	0.03	400	350	1.4

Figure 3.6 Polypropylene (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	max 3,5% (real 1,81%)
Density	0,25-0,35 kg/dm^3
Retained 45micron	max 2.5% (real 0,58%)
BET	min. 15-28 m^2/gm (real 23,36 m^2/gm)

3.3.8 Silica sand

Silica sand is the type of sand with a high proportion of silica in the form of quartz. They are manufactured from both sedimentary deposits gently and with weak cement sandstone crushed. It was also found in the river basin and rocky area. Also workability of concrete decreases because by silica sand. The silica sand has a maximum grain size of 250 µm and a mean size of 110 µm. In order to maintain sufficient stiffness and volume stability, incorporate fine silica sand to binder ratio (S / B) of 0.36.

3.3.9 Fly ash

It is a solid material extracted from the exhaust gas of a boiler burned mixed with pulverized coal, which is a by-product of coal combustion. Adding FA to the mixture increases the strength and durability of the concrete over the long term by prolonging the moisturizing process.

FA improves its rheological properties and process ability it's sphere-shaped particles and concrete by fineness. This leads to a general densification of the cement matrix, which contributes to increased strength, condensed permeability, and increased long-term durability.

3.3.10 Water

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

3.4 Mixing and Casting for Specimens.

We using two type of mixer in this experimental work depending on the matrix of concrete, Normal concrete as control and ECC concrete, as following.

3.4.1 Mixing normal concrete

At the beginning, the dry materials (sand, gravel, cement and silica fume) were mixed in vertical rotations mixer that has four wings for blending the matrix as shown Figure 3.7. The materials are mixed for almost five minutes to get homogeneous mixture before adding water. The water is added slowly to the drum mixer, also in slow rotations for almost five minutes, then superplasticizer is added and rotates the mixer on the maximum speed the mixture will be ready for casting.

Figure 3.7 mixing for normal concrete.

3.4.2 Mixing for ECC

The dry binder materials (cement + fly ash and silica sand) are mixed for three minutes in slow speed, after that the specified water is added with increasing the mixer for high speed for 30 minutes, in this stage the Super plasticizer is added for 2 minutes and then the PVA fibers are interspersed by hand during the mixing Figure 3.8 show the mixing of ECC.

Figure 3.8 ECC mixing.

After mixing is complete the matrix is molded and externally consolidated for ECC, internally vibrated for normal concrete slabs, in order to overcome the errors, three standard cylinders were cast for each standard test, where the compressive and tensile strength are evaluated in this work. The slabs and the standard cylinders were kept for 24 hours in laboratory condition, and then cast specimens are de-mold and cured for 28 days in the water tank.

The mold is oiled well to prevent the concrete attaching the mold and make it easy to extract the sample. When the mix is ready, it is moved to the form for casting the slab by using a vibrator device in this process, exterior vibration for the ECC slabs. And internally for normal slabs Also, a standard cylinder, 100 mm in diameter and 200 mm long was casted, exterior vibration for the cylinder containing fibers ECC, 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_{ct}, casting three cylinders to get an accurate test reading. After pouring the concrete into the form, the surface of the concrete is leveled and smoothed using a trowel as shown in Figure 3.9. 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 3.9 Concrete casting (a) Specimen before finishing with cylinders and (b) Specimen after finishing with cylinders.

3.5 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 3.10

Figure 3.10 Curing process.

3.6 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 3.11.

Figure 3.11 Weighting for sample.

3.7 Mechanical Properties for Samples

A convenient time schedule for testing of hardened specimens preserved in demand to ensure convenient testing on the due date. In order to evaluate the material characteristics of concrete samples, compressive strength, indirect tensile strength, modulus of elasticity, for this reason, the cylinders tests were carried out on the same day as the corresponding slab test.

3.7.1 Compressive strength

Perform compression tests to see the compressive strength when adding fibers to concrete. After the required curing period of the specimen, for each mix three cylindrical specimens of (100 mm x 200 mm) were tested, following (ASTM C39, 1997) describes procedural requirements. The compressive axial load is applied to the cylinder using hydraulic pressure from machine after preparing the sample and putting it in the center of the machine until failure occurred. The device of this test process is BESMAK as shown in Figure 3.12.

Figure 3.12 Compressive test process.

3.7.2 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 horizontally 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 3.13.

Figure 3.13 Tensile test process.

3.7.3 Modules 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 3.14

Figure 3.14 Modules of elasticity test.

3.8 Samples 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 LVTDs 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 Table 3.8. and Figure 3.15.

Table 3.8 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 3.15 Test 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 3.16, then the sample is photographed and placed aside and another sample is placed on the test machine.

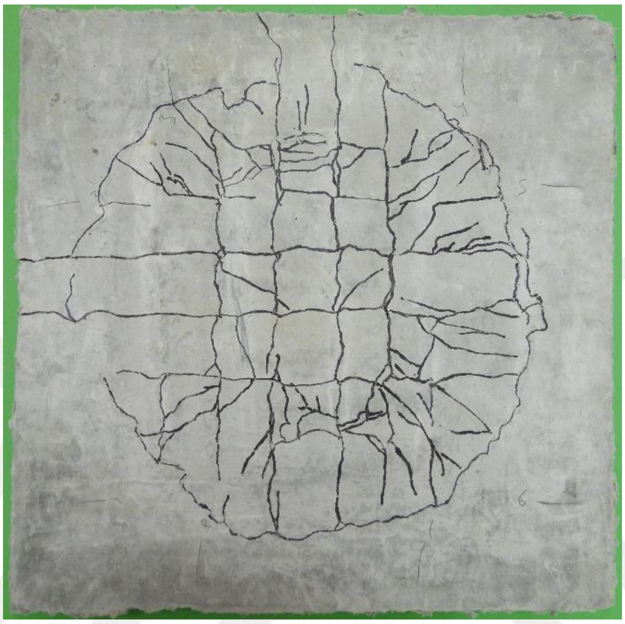


Figure 3.16 Sample after test process completed and marked the cracks.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 General

The main target of this chapter is to inspect the material properties and structural behavior of flat plate slabs under punching shear stress. In this chapter, we discussed the results of the experimental work .The results were briefed and discussed in many headings, which is load deformation behavior, material properties, size effect on ultimate load resistance of slabs, type of fiber effect, the load- deflection, tensile strength, and the cracks pattern were at the failure mode.

The experimental work is arranged to four Groups (A, B, C and D) the Group A it's the control panels have three slabs from normal concrete without fiber the thicknesses were (50, 60 and 80mm), the other Groups have four panels made from ECC and have fiber in the matrix will compare with the control panels.

4.2 Result of Control Test Specimen

Two control tests were used to evaluate the compressive strength of concrete and splitting tensile test. The compressive strength (f_c') was assessed using standard 100 mm diameter cylinders ASTM C39 (ASTM C39, 1997). On the other hand, split tensile strength (f_{sp}) was performed on similar cylinders based on ASTM C496 (ASTM C496, 2004) to assess tensile strength, Table 4.1 shown the detail of mechanical properties of the groups.

4.2.1 Compressive strength

According to the compressive strength test (f_c') in age of 28 days, the results that which shown in Table 4.1, We get average of the 3 cylinders tested for all the ECC - fibrous concrete and then compare it with the control plain concrete cylinders average, then we found that the fibers not at all time useful to enhance the compressive strength.

Table 4.1 Test results of the experimental works.

Groups	Mix code	Fiber type	f'_c MPa	$\frac{f'_{c\ \mathrm{fiber}}}{f'_{c\ \mathrm{normal}}}$	f_{sp} MPa	$\frac{f_{sp\ \mathrm{fiber}}}{f_{sp\ \mathrm{normal}}}$
A	N5	-	43.20	1	3.85	1
	N6					
	N8					
B	V6-5	PVA 6 mm	44.46	1.03	6.91	1.79
	V6-6					
	V6-8					
C	V12-5	PVA 12 mm	38.66	0.89	7.02	1.83
	V12-6					
	V12-8					
D	PP-5	PP 12 mm	29.73	0.69	6.50	1.69
	PP-6					
	PP-8					

By see the result in Group B ECC– PVA 6 mm, we found the compressive strength 3% more than the control concrete. But according to the test result of Group C ECC–PVA 12 mm the compressive strength is 11% less than the control concrete. Finally the result of the Group D ECC–PP 12 mm shown that the compressive strength is 31% less than the control concrete. As shown in Figure 4.1

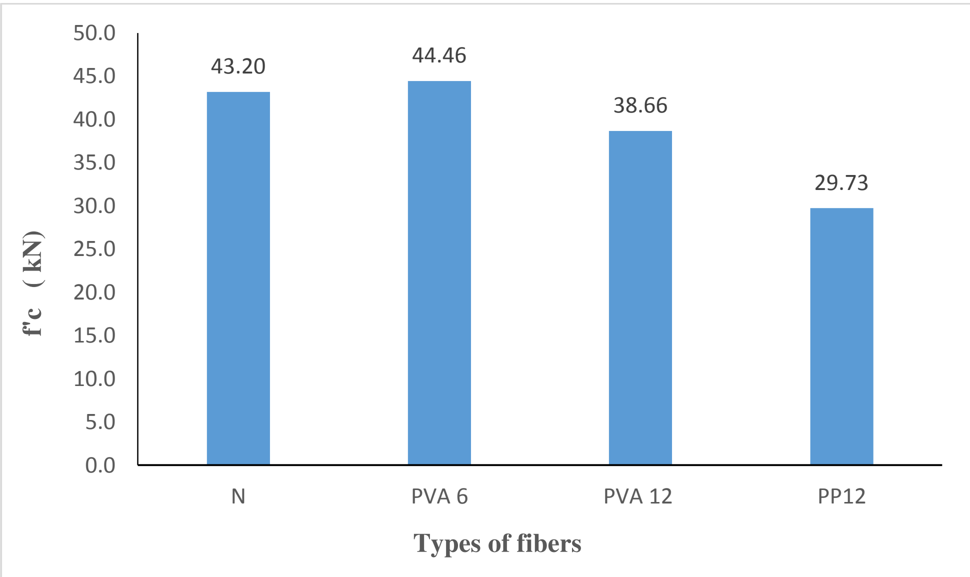


Figure 4.1 The compressive strength for the test result

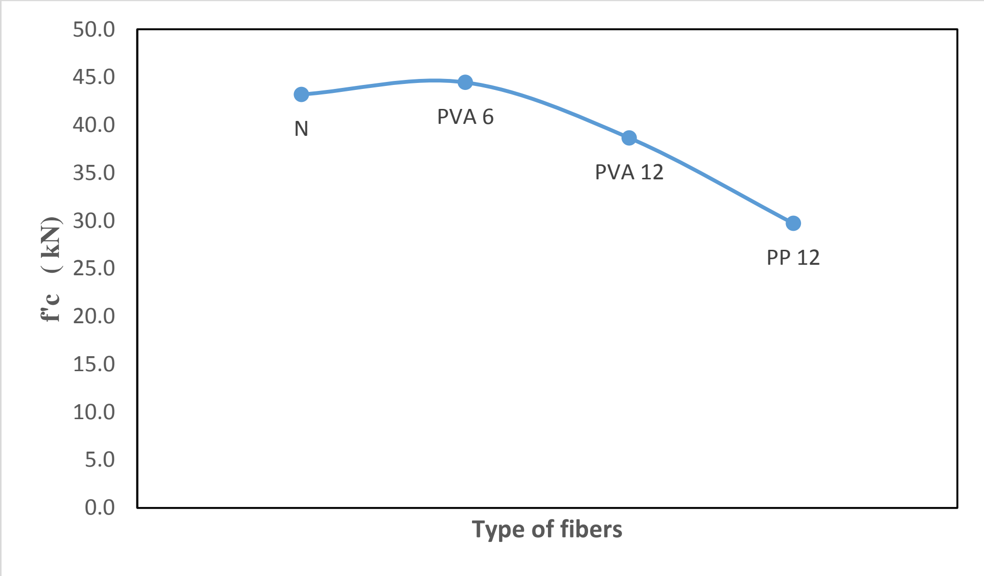


Figure 4.2 The compressive strength relation for the type fibers.

4.2.2 Splitting tensile strength

The test results in table 4.1 that which showing the tensile strength f_{sp} according to the ASTM C496 (ASTM C496, 2004). We get average of the 3 cylinders tested for all the ECC - fibrous concrete and then compare it with the control plain concrete cylinders average, We found that the fibers very useful to enhance the tensile strength f_{sp}. The following is the explaining for the groups details.

By see the result in Group B ECC –PVA 6 mm, we found f_{sp} is 79% more than the control plain concrete. But according to the test result of Group C ECC –PVA 12 mm f_{sp} is 83% more than the control plain concrete. Finally the result of the Group D ECC –PP 12 mm shown that f_{sp} is 69% more than the control plain concrete. As shown in Figure 4.3 and 4.4 respectively. According to previous results the PVA 12 mm is the best type of fiber to get the better enhancement of f_{sp} compared with the rest type of fibers.

4.3 Structural Behavior

To get more knowing about the structural behavior of the ECC slabs and find the parameters that which effect on the this behavior, we arranged the slabs in three groups and compare it with control made from normal concrete the test result in the Table 4.2 explain that.

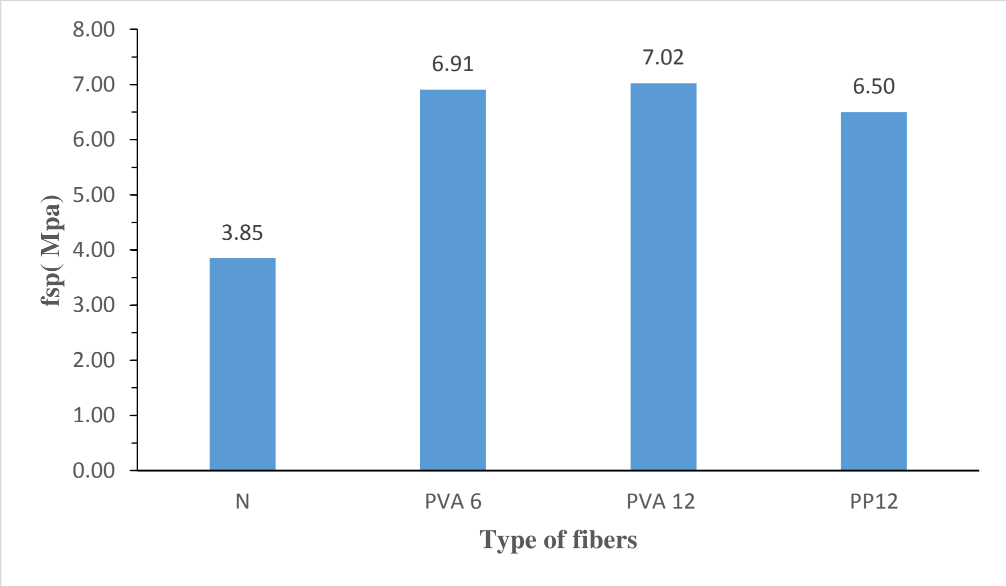


Figure 4.3 Splitting tensile strength result for different type of fibers.

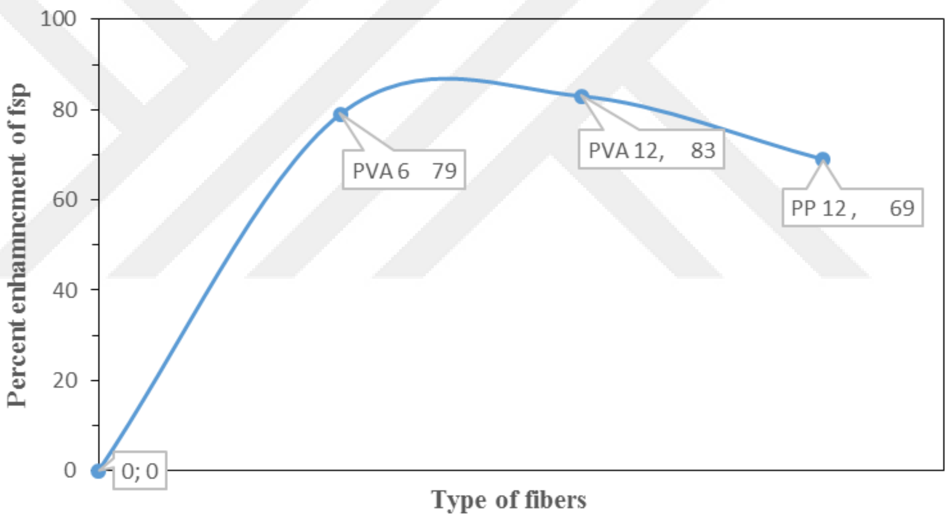


Figure 4.4 Percent enhancement of f_{sp} by using different type of fibers.

4.3.1 Effect of type fibers on ultimate load

According to the test results showing in Table 4.2. We made a comparing between the ECC-fibers slabs and normal concrete slabs in the same thickness and prepare it as three groups (50, 60 and 80mm), we found that the enhancement of ultimate load was ranging between 12 to 43%, and also we found some of slabs are have decrease in ultimate load and this ranging between 8 to 24%. This is mean not all type of fiber made enhancement in ultimate load, we can get more explaining about the groups at the following details.

By see the result in Group A ECC –50 mm, we found the PVA 6 mm is increase the P_u 43% more than the control plain concrete, the PVA 12mm is 19% more than the control slab, but when we use the PP 12 mm the decrease is 16% less than the control concrete.

By see the result in Group B ECC – 60 mm, we found the PVA 6 mm is increase the P_u 23% more than the control plain concrete, but the PVA 12mm is decrease the P_u 8% less than the control slab, and the PP 12 mm the decrease is 21% less than the control concrete slab.

By see the result in Group C ECC – 80 mm, we found the PVA 6 mm is increase the P_u 25% more than the control plain concrete, the PVA 12mm is 12% more than the control but when we use the PP 12 mm the decrease is 24% less than the control concrete .

As shown in Figures 4.5 - 4.9, respectively. The previous results of P_u for all thickness showing that the PVA 6 mm giving the best enhancement is ranging between 43 to 23% from the rest type of fibers.

Table 4.2 Test results of ECC slabs and structural behavior.

Groups	**Slab Thickness mm**	**Fiber type**	P_u [1] (kN)	δ_{u1} [2] (mm)	δ_{u2} [3] (mm)	$\frac{p_{u\ fiber}}{p_{u\ normal}}$
A	50	N	51.31	5.52	4.70	1.00
		PVA 6 mm	73.42	5.09	4.51	1.43
		PVA 12 mm	61.02	6.15	5.27	1.19
		PP 12 mm	43.30	4.12	3.03	0.84
B	60	N	74.89	3.84	3.02	1.00
		PVA 6 mm	92.42	4.96	4.24	1.23
		PVA 12 mm	69.27	3.96	2.98	0.92
		PP 12 mm	59.23	5.13	3.95	0.79
C	80	N	120.72	2.89	1.81	1.00
		PVA 6 mm	150.52	4.35	3.01	1.25
		PVA 12 mm	135.53	3.81	2.42	1.12
		PP 12 mm	91.64	3.39	1.96	0.76

[1] P_u**:** Ultimate load. [2, 3] δ_u**:** Deflection at ultimate load

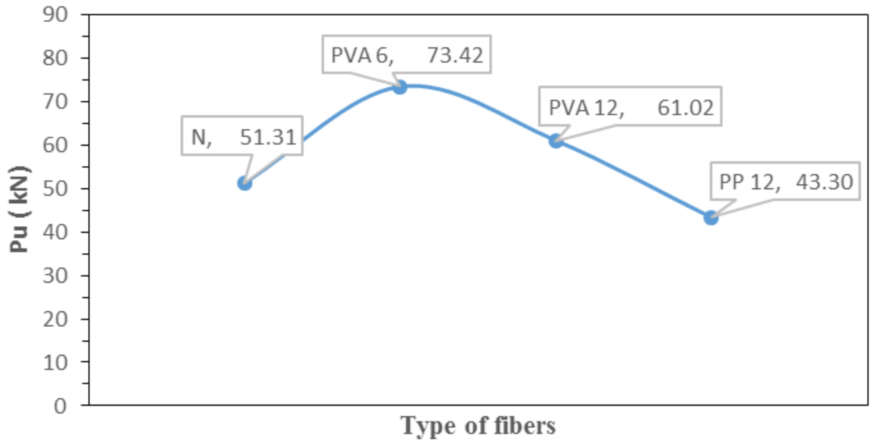


Figure 4.5 Group A slab thickness 50 mm.

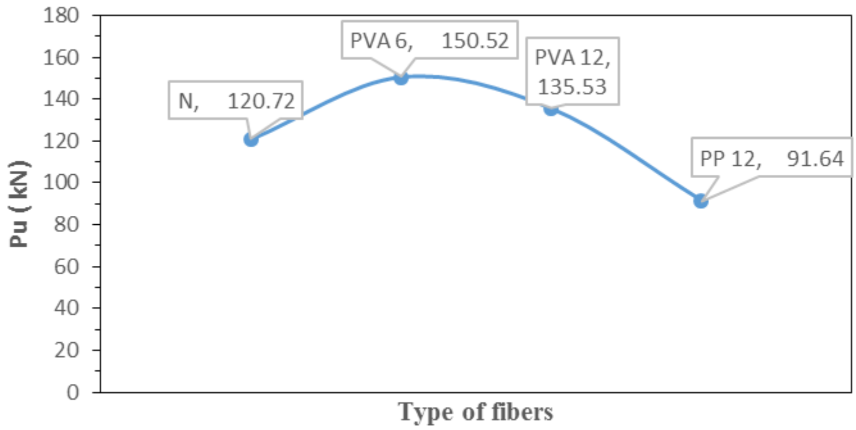


Figure 4.6 Group B slab thickness 60 mm.

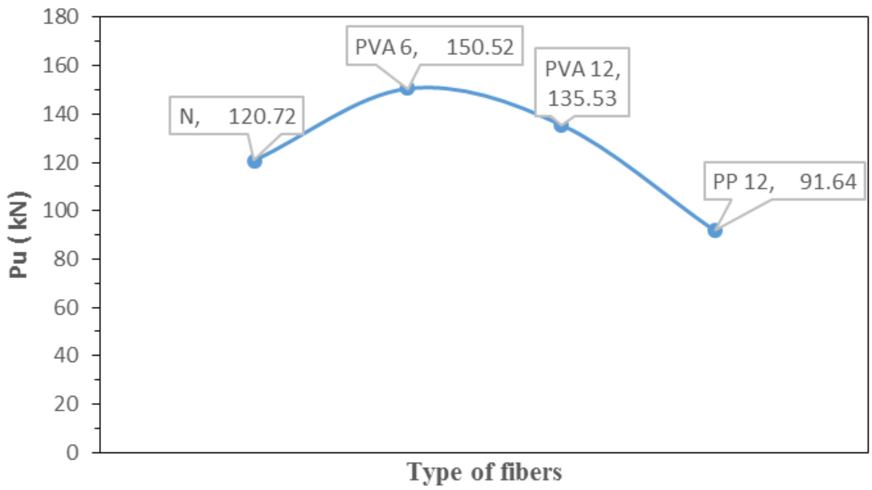


Figure 4.7 Group C slab thickness 80 mm.

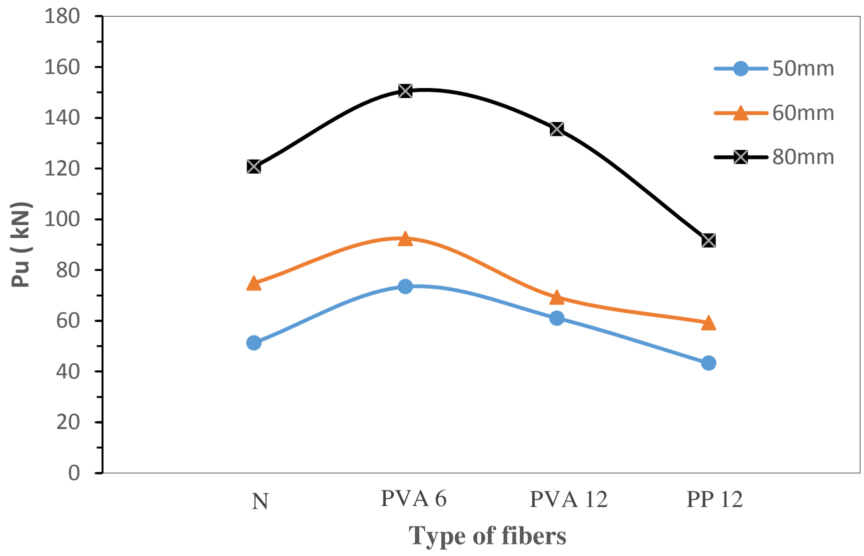


Figure 4.5 Effect of the type of fibers on the ultimate load P_u.

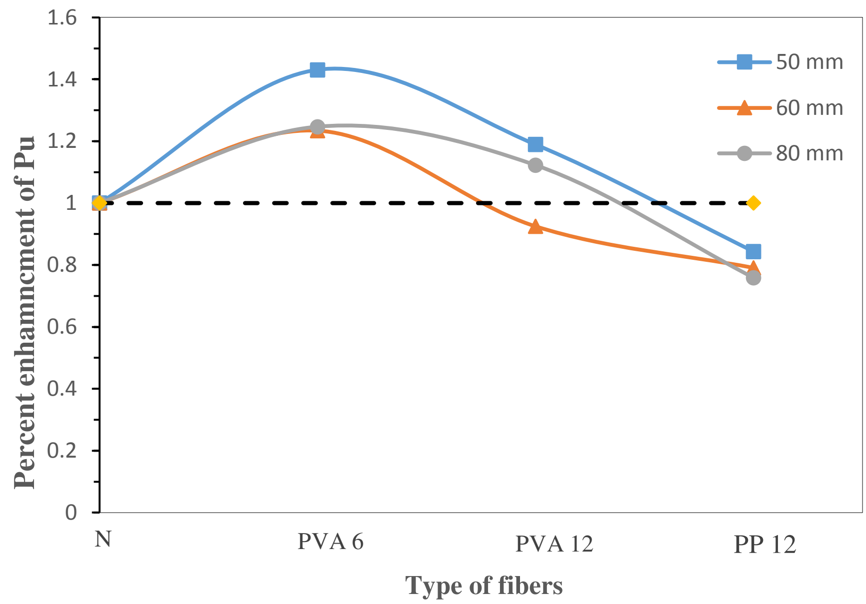


Figure 4.6 Percent enhancement of P_u by using different type of fibers.

4.3.2 Size effect of slab on ultimate load.

Depending on the test results of the slabs showing at Table 4.3 we found there is an effect for the size of the slab thickness on P_u and this is depending on the type of fibres and thickness of slab panel, we classify the slabs in to four groups according to type of fiber, and make comparing between the fibers and normal slabs in same thickness so we got the below results showing in Figures 4.7 and 4.8 respectively.

Table 4.3 Size effect of slab on ultimate load P_u.

Groups	Fiber type	Slabs thickness mm	P_u (kN)	$\frac{P_{u\,\text{fiber}}}{P_{u\,\text{normal}}}$
A	Normal concrete	50 60 80	51.31 74.89 120.72	1 1 1
B	PVA 6mm	50 60 80	73.42 92.42 150.52	1.43 1.23 1.25
C	PVA 12mm	50 60 80	61.02 69.27 135.53	1.19 0.92 1.12
D	PP 12mm	50 60 80	43.30 59.23 91.64	0.84 0.79 0.76

**V_f 2% for all type of fibers.

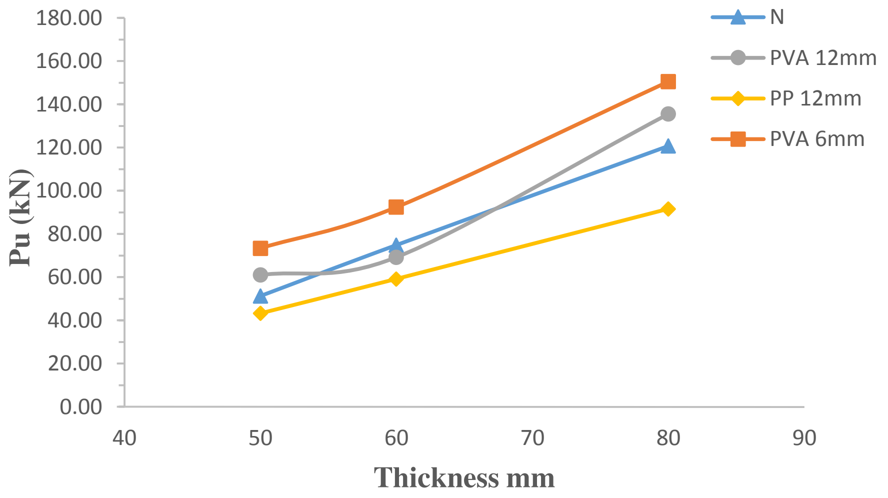


Figure 4.7 Size of the slabs thickness effect on P_u.

Group A; Normal concrete thickness (50, 60 and 80mm) its control slabs and we will compare the other groups made from ECC- fibers with it.

Group B ECC –PVA 6 mm, there is increasing in P_u from 23 to 43% more than the control plain concrete, at the slab thickness 50mm we get increasing 43%, the slab thickness 60 mm get increasing 23% and at the slab thickness 80 mm we get increasing 25%.

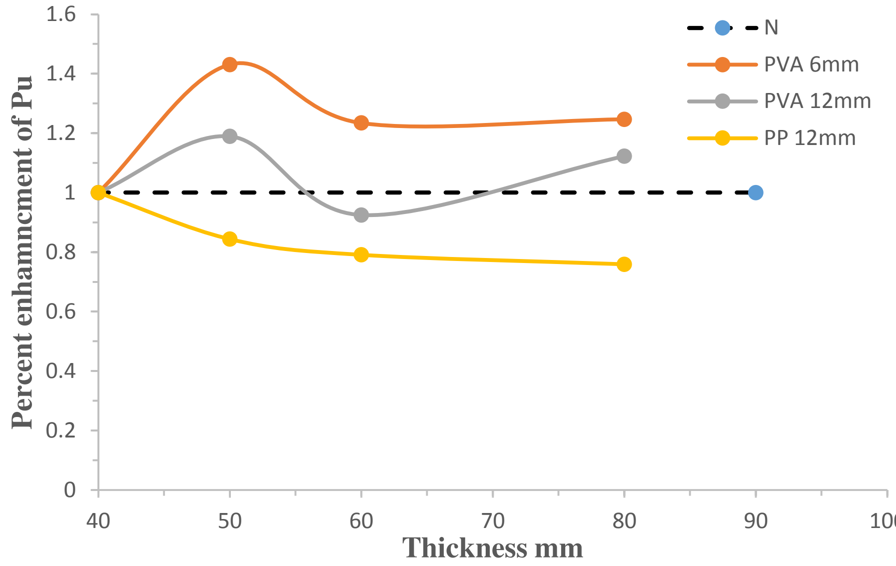


Figure 4.8 Size effect of slab on the percent enhancement of P_u

Group C ECC –PVA 12 mm, there is increasing at the P_u from 12% to 19% more than the control plain concrete in two of slabs thickness, but we get decreasing in the rest slab about 8%, at the slab thickness 50mm we get increasing 19%, the slab thickness 60 mm, get decreasing 8% and at the slab thickness 80 mm, we get increasing about 12%. This is means that changed the length of the fiber from 6 mm to 12 mm are decreased the P_u by 24% at thickness 50mm, 31% at thickness 60mm and 31% at thickness 80 mm.

Group D ECC –PP 12 mm, there is decreasing at the P_u from 16 to 24% less than the control plain concrete, at the slab thickness 50mm we get decreasing 16%, the slab thickness 60 mm get decreasing 21% and at the slab thickness 80 mm, we get decreasing about 24%.

From the above brief, we get indicate that the ECC- PVA 6 mm give the best result and enhancement on P_u especially at the thickness slab 50 mm it is about 43% and this very important to reduce the slab thickness and weight in same time. And the PP 12mm were decreasing the P_u at all the slabs thickness less than the P_u of the control plain concrete.

4.3.3 Load -deflection relationship

Load -deflection relationships are leading for realization the behavior of slab column connection because they explain main behavior of the slab member, especially the reinforcement ratio, the load applied till the failure of the sample. The data are collected from the test device have two LVDT's one is at the load cell jack and the second one is at the bottom of the slab sample.

The deflection in the figures are calculate form the bottom side of the slab center, figures 4.9 and 4.10 shows the type of fiber effect and the size of the slab thickness on the load-deflection relationship for the ECC slabs made from PVA6, PVA12 and PP12.

It is known that the typical model of the deviation of the load (p-δ) panel regular RC may consist mainly of three types of behavior: pre-cracking stage, post cracking stage, and post yielding stage.

It was observed that once the tensile tension fibers reached the tensile strength, there was a significant deviation in the curve from the original slope, indicating a relative reduction in the flexural stiffness of the plank beyond the load level.

This is explain the pre – cracking level, the deflection increase often linearly with the loading. This is expected because the strains are relatively small in the steel and concrete, both in the elastic part of the responses. The Figure 4.9 and 4.10 there were cases of non-linear alien displacement, which is not surprising because it is often associated with this test. Till the first crack was initiated, the deflection is proportional to the applied load linearly, the first cracks were difficulty noticed on the curve. After the first crack occurred, the slope of the curve was changed slightly, but it still seems to be at a linearly increasing rate, the increase still continue till the yield point. After that yielding of steel the curves are increasing non-linear manner to the maximum load impedance, the test continues until the sample is breakdown at once after cracking the cover of concrete, generally no deviation or just a slight deviation from the original slope can be found.

This is post-cracking, which indicate that the sample response in this region is a function of both the proportion of reinforcement ρ and f_c' of the concrete, this stage effected by type of fiber and the size of the slab thickness. This behavior indicates an increased ability of cracking moments and retention of higher rigidity of sorting when using load. When the strain in tensile of steel is reached to the yield level, the sample deem failed in structurally.

(a)

(b)

(c)

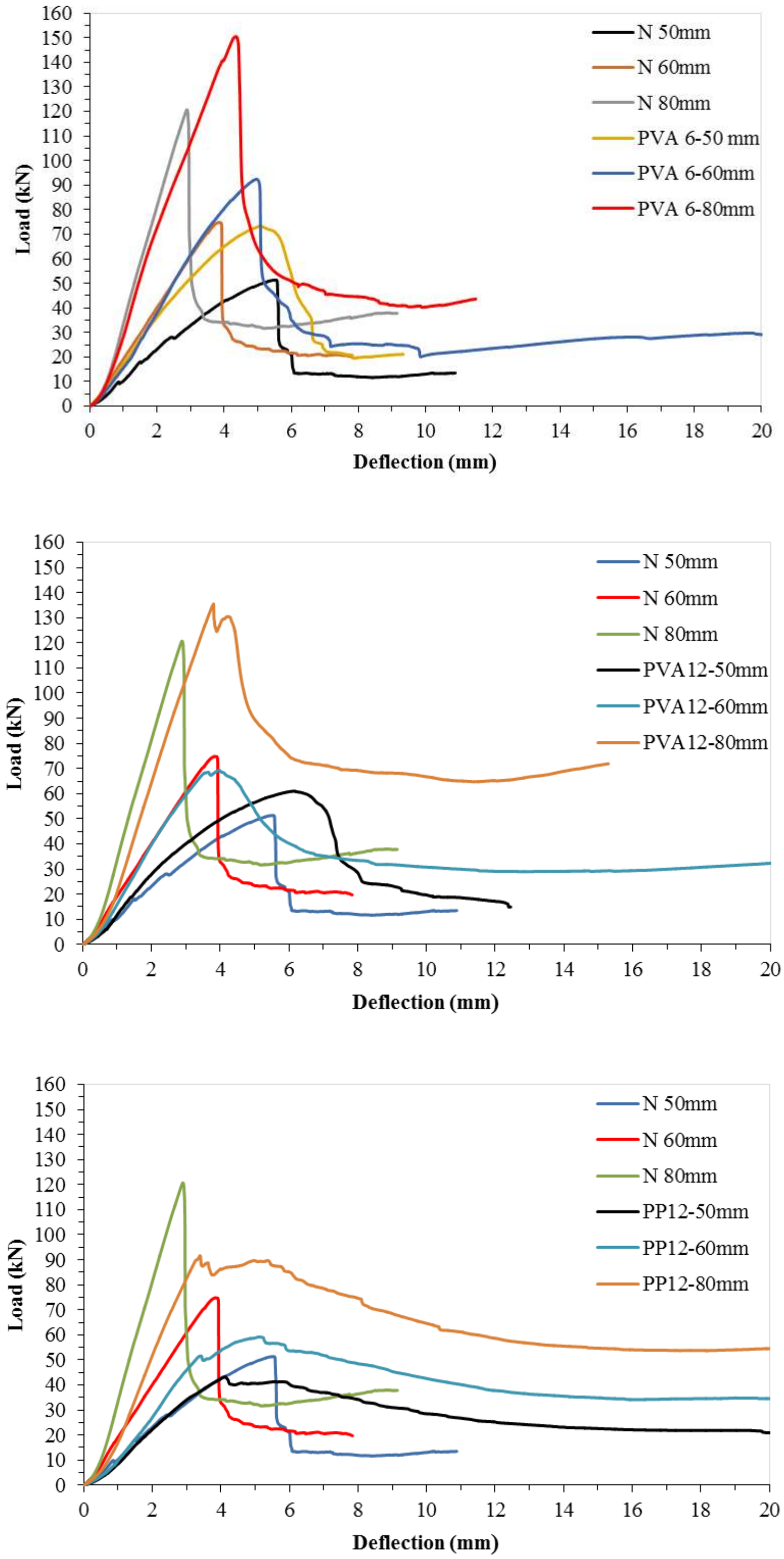


Figure 4.9 Load- deflection (a) PVA6 mm, (b) PVA12 mm and (c) PP12 mm in slab thickness (50, 60 and 80mm)

Continued to test samples deviation quickly even developed a secondary compression failure, which led to a complete cracking of concrete in extreme moments, followed by cracking a large-scale and breadth of a large stable cracks.

The curves in Figure 4.9 shows that the variation is clear between samples. Adding fiber to the ECC panels are decrease the deformation of the ECC panels comparing with normal panels and same thickness, this is clearly seen from the high rate of the load to deflection (ΔP/Δδ).

Figure 4.10 show size effect of slab thickness on the load – deflection relationship between the ECC slabs have fibers with the normal concrete panels in same thickness. when we show the Figure 4.9 (a) ECC-PVA6 slab thickness 50mm have short plateau after the peak load 73 kN, but the slab thickness 60 and 80 mm show sudden failure after the peak load (92 and 150) kN, whereas the plain concrete (N) that have thickness (50, 60 and 80mm) show sudden failure after the peak load (51, 74 and 120) kN respectively. The P_u for the ECC-PVA 6 slabs is more than the P_u of the normal concrete it's ranging between 23-43% and the behavior of the ECC-PVA 6 after the peak load were more slightly than the normal slabs till the failure point because of the ECC –PVA 6 fiber give more ductal than the normal concrete that which have sudden failure.

Figure 4.9 (b) ECC –PVA12 at slab thickness 50 mm, it's has short plateau after the peak load 73.4 kN, and the other slabs thickness 60 mm has short plateau after the peak load 69 kN but the P_u less than the normal concrete in same slab thickness 50 mm it's 74.8 kN, the slab thickness 80mm has sudden failure after the peak load till 50% and then continue slightly.

The normal concrete slabs 50, 60 and 80 mm all have sudden failure after the peak load, the behavior of the ECC-PVA 12 after the peak load give more slightly and ductal than the normal in same thickness.

Figure 4.9 (C) ECC-PP12, show the short plateau for all slabs thickness (50, 60 and 80mm) after the ultimate load (43.3, 59.6 and 91.6) kN respectively there were less than the P_u of the normal concrete slabs in same thickness (51.3, 74.89 and 120.7) kN and then slightly move with ductal behavior till the failure of the slabs but the normal slabs have sudden failure after the peak load.

(a)

(b)

(c)

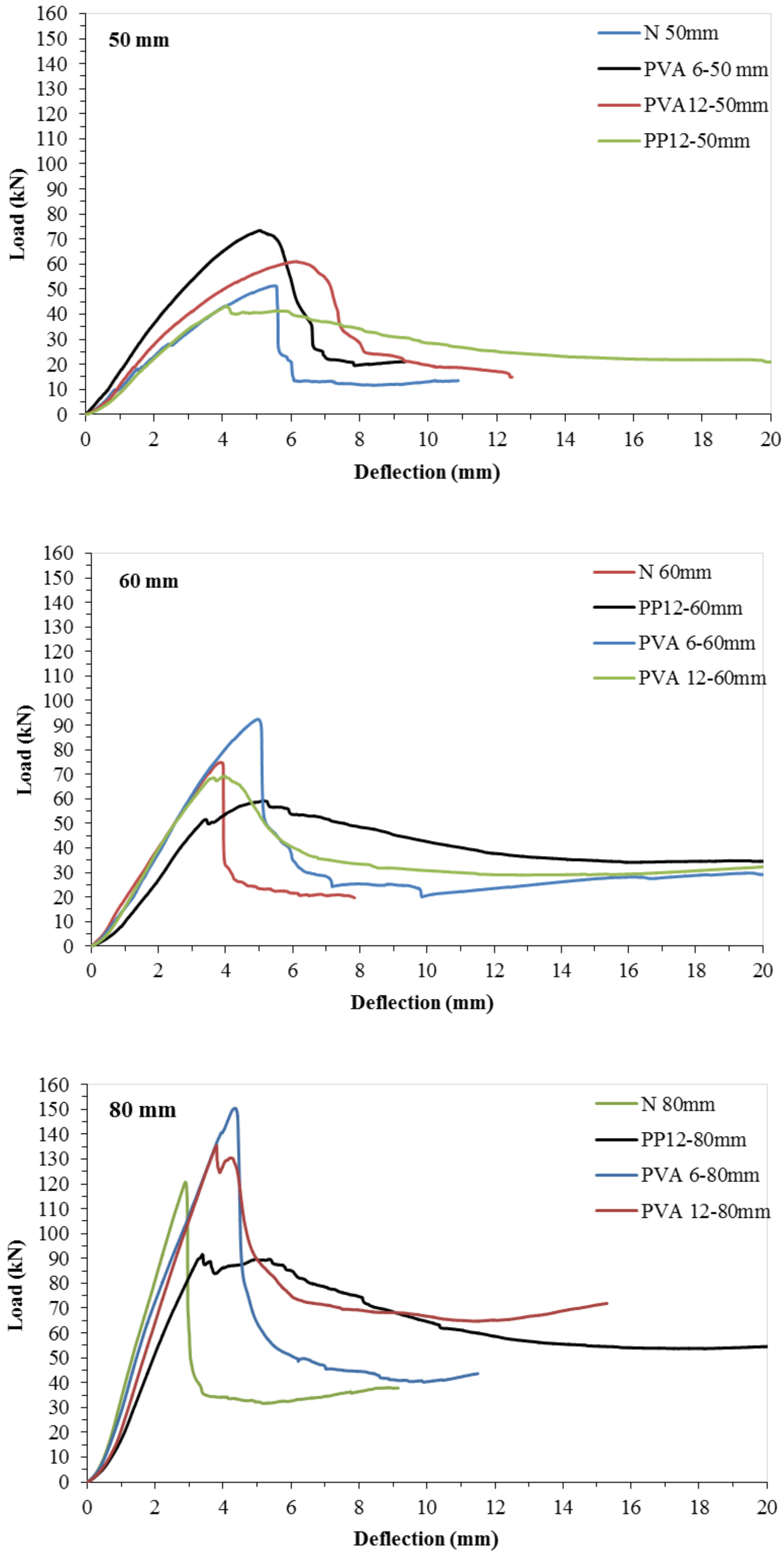


Figure 4.10 Slab thickness effect and type of fibers on the load-deflection relationship (a) slab thickness 50mm, (b) slab thickness 60mm and (c) slab thickness 80mm.

The Figure 4.10 (a) show the behavior of the ECC slabs in same thickness 50 mm but different in type of fibers and compare these with normal concrete slab. This show that the PVA 6 have the greater P_u than the other ECC slabs and also the normal concrete it's has short plateau after the peak load. The PP 12 have short plateau and more slightly before the failure mode.

The Figure 4.10(b) show the behavior of the ECC slabs in slab thickness 60 mm, PVA 6 have the greater P_u than the other slabs but it has sudden failure after the ultimate load. The PP 12 has the smaller P_u than the other ECC slab in same thickness also it's has short plateau and slightly move till the failure so the ductal so clear in this type of fiber.

The Figure 4.10(c) show the behavior of the ECC slabs in thickness 80 mm reinforced in type of fibers, the PVA 6 it's have been the greater P_u than the other ECC slabs also the normal concrete but also has sudden failure after the peak load, the PP 12 have short plateau and the smaller P_u than the rest slabs, the slightly of the curve appears till the failure load.

From the above we get that the ECC-PVA 6 have greater P_u that the other at all slab thickness 50, 60 and 80 mm.

The PP12 have smaller P_u the rest type of fiber but it has short plateau and slightly move of the curve till the failure point.

The (p- δ) curves as shown in Figures 4.9 and 4.10 for the ECC slabs with fibers 2% but in various in thickness 50, 60 and 80 mm, shown the Adding fibers have a worthy effect on the load of cracks, which causes the first crack, that which seen as a crack that occurs at the first change of slope curves (P- δ). In other hand the ECC fibers slabs are tough at the first loading stage (elastic) before the worthy change of the slop.

The curve stage from the initial crack to the ultimate load point, the slabs made from ECC with fibers shown the less deformation from the normal concrete. This is due to the ability of the ECC teams to capture crack growth and crack is widening. Figures 4.9 and 4.10 it also shows that the effect of fiber in increasing P_u is less important than its effect in decrease vertical deformation. The main reason for such behavior to the effect of fiber added to the ECC slabs, which is not to improve strength, but instead of controlling the cracking and deformation.

The addition of fiber leads to a reduction in deformities at all loading stages and especially after initial first crack, also enhancement the final load carried by the flat slab. Fibers not only defer the deformations of the diagonally cracks within the panels, but also shifting the punching shear failure to gradually and ductile shear failure crack patterns.

4.3.4 Size effect of ECC panels on punching shear

(ACI 318 M-14 2014) Nominal shear strength for two-way members without shear reinforcement shall be calculated by.

$$v_n = v_c + v_s \tag{4.1}$$

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-

$$v_u = \frac{V_u}{A} \tag{4.2}$$

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_0) at a specified distance from the face of the column (loading plate) (mm), $b_0 = 4(c + d)$, 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:-

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

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

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

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

The code 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:

$$V_u = 0.33\,\lambda\sqrt{f'_c}\ b_0\ d \tag{4.3a}$$

$$V_u = 0.17\left(1+\frac{2}{\beta}\right)\lambda\sqrt{f'_c}\ b_0\ d \tag{4.3b}$$

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

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, **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.

When applied the equation (4.3-c) it's considered the size effect on nominal shear strength. We get the result can show up in Table 4.4 explain the effect of thickness on the shear resistance and the Figure 4.11 and 4.12 show the relation between the shear stress and nominal shear strength with the slab size thickness respectively.

Table 4.4 is shown that the slabs strength increase with increasing the slab thickness for all groups, however, the reduction in shear stress with the increasing of the slab thickness see Figure 4.11, and the Group A showing the result of normal concrete slab the shear ranging between (12.7, 10.43 and 7.75) for slab thickness (50, 60 and 80 mm) respectively.

Table 4.4 Shear stress and nominal shear strenght accroding ACI 318-14

Group	Fiber type	Thick.	d	f'_c	b_o	P_u, test	Vc ACI	Vu	Vfiber / Vnormal
		mm	(mm)	Mpa	mm^2	(kN)	MPa	MPa	
A	Normal concrete	50	29.7	43.20	140.8	51.31	3.93	12.27	1.00
		60	39.7	43.20	180.8	74.89	4.09	10.43	1.00
		80	59.7	43.20	260.8	120.72	4.25	7.75	1.00
B	PVA 6mm	50	29.7	44.46	140.8	73.42	4.25	17.56	1.43
		60	39.7	44.46	180.8	92.42	4.39	12.88	1.23
		80	59.7	44.46	260.8	150.52	4.60	9.67	1.25
C	PVA 12mm	50	29.7	38.66	140.8	61.02	3.73	14.59	1.19
		60	39.7	38.66	180.8	69.27	3.87	11.00	1.05
		80	59.7	38.66	260.8	135.53	4.03	8.70	1.12
D	PP 12mm	50	29.7	29.73	140.8	43.30	3.29	10.35	0.84
		60	39.7	29.73	180.8	59.23	3.42	8.25	0.79
		80	59.7	29.73	260.8	91.64	3.55	5.89	0.76

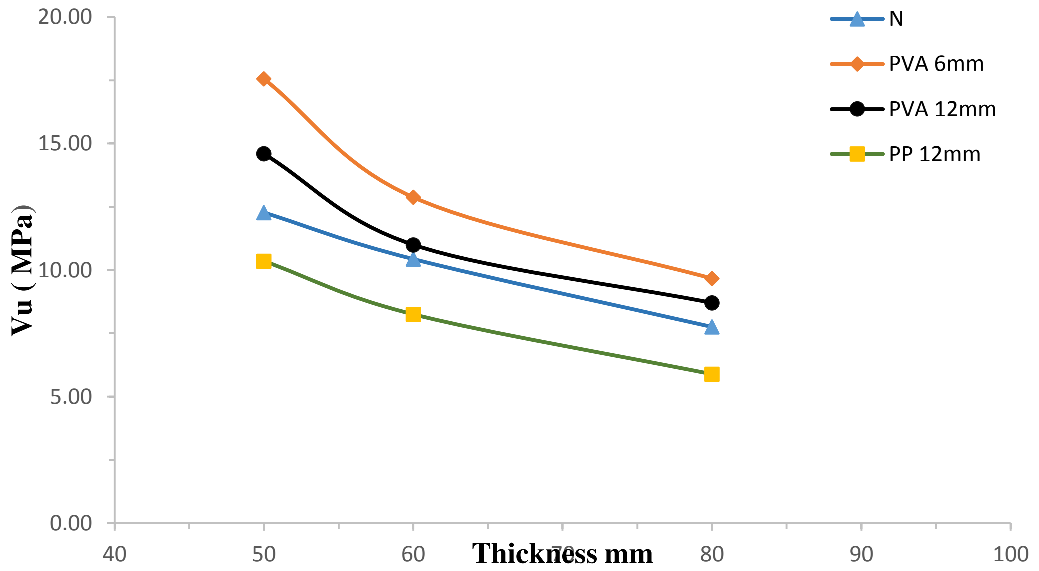


Figure 4.11 Size effect of slab on shear stress

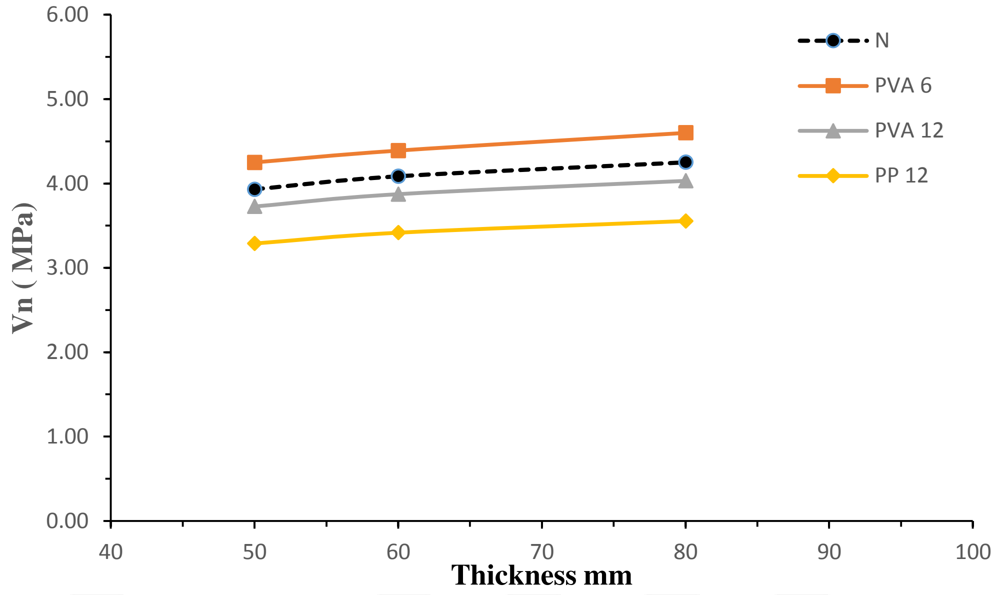


Figure 4.12 Size effect of slab on nominal shear strength

The Group B showing the shear stress for ECC -PVA 6 the result (17.56, 12.88 and 9.67) for slab thickness (50, 60 and 80 mm) respectively. For Group C the shear stress for ECC-PVA 12 the shear stress are (14.59, 11.0 and 8.7) for slab thickness (50, 60 and 80 mm), the group D for ECC –PP 12 showing the shear stress (10.35, 8.28 and 5.89) for the (50, 60 and 80 mm) respectively, all the above results showing the stress decrease when the size of slab thickness were increased.

Figure 4.12 shown the slabs nominal shear strength according to (ACI 318-2014) equation we found that the shear strength increase with the size of slab thickness increasing, Group A, normal concrete; the nominal shear strength ranging between (3.93, 4.09 and 4.25) for slab thickness (50, 60 and 80 mm) respectively, Group B ECC-PVA 6 strength results (4.25, 4.39 and 4.6) for the slab thickness (50, 60 and 80 mm), Group C ECC-PVA 12 shear strength result (3.73, 3.87 and 4.03) for slab thickness (50, 60 and 80 mm). For Group D ECC-PP 12 the shear strength are (3.29, 3.42 and 3.55) for slab thickness (50, 60 and 80 mm). That is lead to reduction in shear stress with increasing the slab thickness. But the nominal shear strength is increased with the slab thickness increasing. However, the ECC-PVA 6 show greatest enhancement for nominal shear strength ranging between 25-43% more than the normal concrete. But the ECC- PP12 smallest type of fiber in strength it’s reduce the strength about 16 to 24%.

4.4 Crack Pattern

The slabs designed to fail due to punching shear, the design applied to normal reinforced concrete in order to compare the effect of using high tensile and ductility materials. All slabs show the punching cone in deferent load levels.

Figure 4.13 shows the cracks patterns, where the failure of the ECC slabs are ranging between uncompleted circle and completed circle. Table 4 shows the type of failures. Moreover, it is recognized that the thicker slab shows more cracks than that thinner; this is because of the brittle behavior of the thicker slab in addition of the congestion of the reinforcement bars.

Table 4.5 Cracks and failure type

Group	Fiber type	Thickness	d	P_u, test	Failure type	failure shape
		mm	mm	kN		
A	Normal concrete	50	29.7	51.31	P+F	uncompleted Circle
		60	39.7	74.89	P+F	uncompleted Circle
		80	59.7	120.72	P+F	uncompleted Circle
B	PVA 6mm	50	29.7	73.42	P+F	uncompleted Circle
		60	39.7	92.42	P	completed circle
		80	59.7	150.52	P	completed circle
C	PVA 12mm	50	29.7	61.02	P+F	uncompleted Circle
		60	39.7	69.27	P	completed circle
		80	59.7	135.53	P+F	uncompleted Circle
D	PP 12mm	50	29.7	43.30	P+F	uncompleted rectangular
		60	39.7	59.23	P+F	uncompleted rectangular
		80	59.7	91.64	P+F	uncompleted Circle

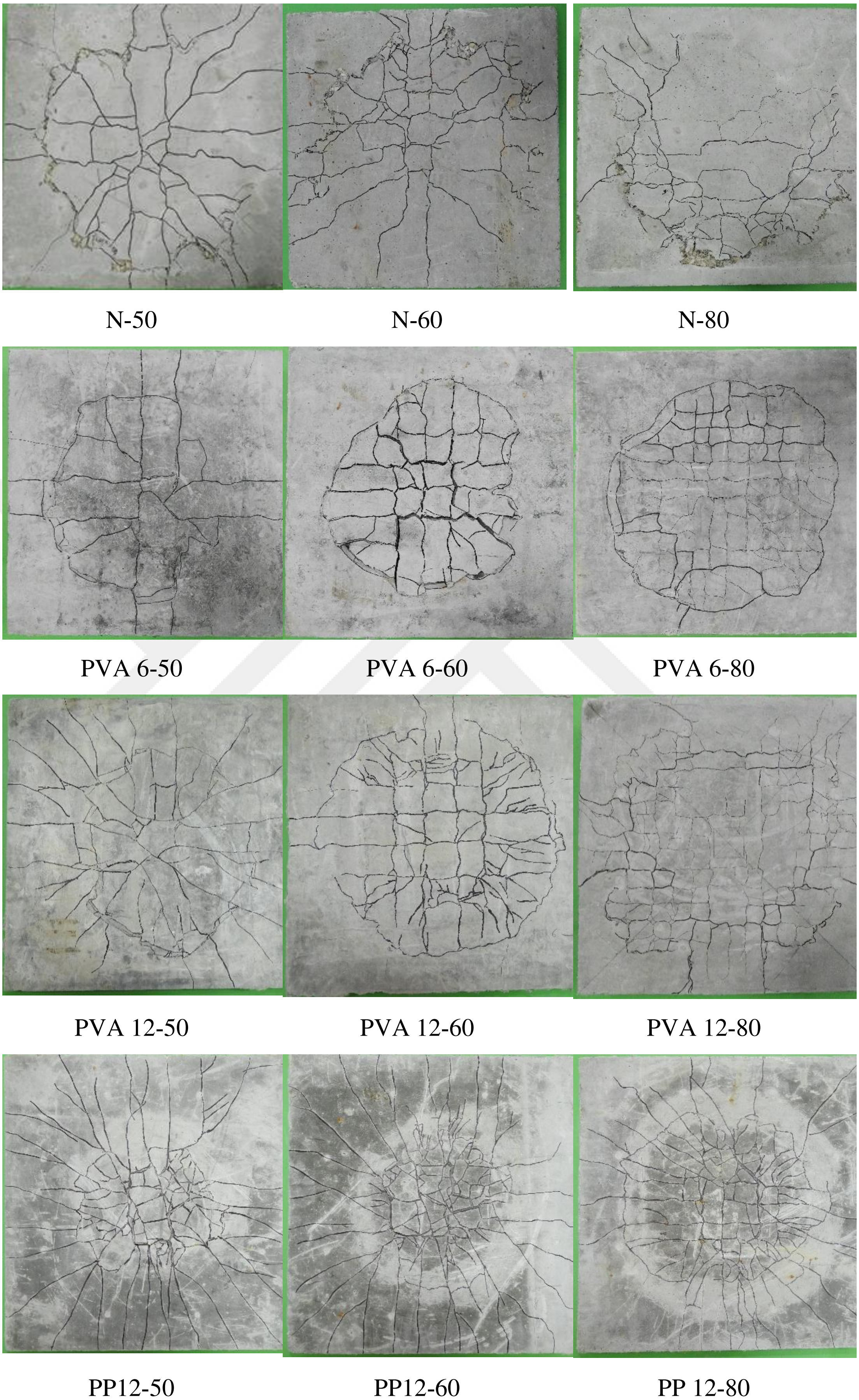


Figure 4.13 Crack pattern

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This chapter is presented the size effect of slab thickness on punching shear in flat slab made from ECC with ranging between (50, 60 and 80 mm) also by using three type of fiber PVA6, PVA12 and PP12 with same V_f 2%, the slab design to fail into punching shear, however, the ECC panels are compare with the normal concrete slab in same thickness to improve the behavior of the ECC panels, the conclusion it's from the present work maintained as below:

1- The fibers not at all time useful to enhance the compressive strength enhancement ECC-PVA6mm 3% but the PVA 12 and PP12 are 11% and 31% less than the normal concrete.

2- The fibers very useful to enhance the tensile strength (f_{sp}), the enhancement for ECC PVA 6, PVA 12 and PP12 ranging between (79, 83 and 69%) respectively. We recommended the PVA 12 mm is the best type of fiber to get the better enhancement of (f_{sp}) compared with the rest type of fibers.

3- This is mean not all type of fiber made enhancement in ultimate load. The previous results of P_u for all thickness showing that the PVA 6 mm giving the best enhancement is ranging between 43 to 23% from the rest type of fibers.

4- The ECC- PVA6 slab thickness 50 mm give enhancement for P_u about 43%, this is very important to reduce the slab thickness and weight in same time. The PP 12mm were decreasing the P_u at all the slabs thickness less than the P_u of the control plain concrete.

5- From the load-deflection relationship the ECC-PVA 6 have greater P_u that the other at all slab thickness 50, 60 and 80 mm, The PP12 have smaller P_u the rest type of fiber but it has short plateau and slightly move of the curve till the failure point.

6- The Adding fibers have a worthy effect on the load of cracks, which causes the first crack, that which seen as a crack that occurs at the first change of slope curves (P- δ). In other hand the ECC fibers slabs are tough at the first loading stage (elastic) before the worthy change of the slop.
7- Adding fibers reduces deformation at all loading stages, especially after the initial crack, as well as improving the final load of a flat plate.,
8- Fibers not only delay deformation of the internal cracks in the panels but also transform the shear failure into ductile crack patterns.
9- That is lead to reduction in shear stress with increasing the slab thickness. But the nominal shear strength is increased with the slab thickness increasing.
That is lead to reduction in shear stress with increasing the slab thickness. But the nominal shear strength is increased with the slab thickness increasing. However, the ECC PVA 6 show greatest enhancement for nominal shear strength ranging between 25-43% more than the normal concrete. But the ECC PP12 smallest type of fiber in strength it's reduce the strength about 16 to 24%.

5.2 Recommendation for Future Work Studies

Depending on the limits of the research parameters in the current study based on the previous conclusions, we suggest the below titles for future study:

1- Use another fiber volume fraction, different kind of fiber another different slab thicknesses, different reinforcement ratio.
2- Study the flexural shear behavior of ECC fibrous slab with same thickness.
3- Trail to find the structural behavior for ECC fibrous flat slab column connections in the edge and corner of the slab.
4- Study for the fire exposed properties for ECC fibers panels and the effect on the mechanical properties and structural behavior at high temperatures (500 °C to 750 °C) also the effects of ECC fibers on the residual strength.

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