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M.Sc. in Civil Engineering

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UNIVERSITY OF GAZIANTEP

GRADUATE SCHOOL OF

NATURAL & APPLIED SCIENCES

INVESTIGATION OF DUCTILITY BEHAVIOR OF POLYPROPYLENE FIBER REINFORCED CONCRETE BEAMS

M. Sc. THESIS

IN

CIVIL ENGINEERING

BY

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M.Sc. Thesis

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University of Gaziantep

Supervisor

Assoc. Prof. Dr. Nildem TAYŞİ

by

Ahmed Naeem ABDALAH

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Ahmed Naeem ABDALAH

ABSTRACT

INVESTIGATION OF DUCTILITY BEHAVIOR OF POLYPROPYLENE FIBER REINFORCED CONCRETE BEAMS

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Fibers are widely used in structural concrete members in recent years, because of its ability in improving many parameters of concrete. Present research is attempted to employ a balance among the three factors (cost, quality, and construction time). This study aims to investigate the methods of improving ductility behavior of polypropylene (PP) fiber reinforced concrete beams. This will be done through constructing a conventional high strength concrete that have ability to gain its strength quickly after the casting, by increasing the fine aggregate and fine additive materials which complementing by decreasing the coarse particles. In order to improve the mechanical properties of both fresh concrete in term of slump and fiber dispersion efficiency, furthermore in hardened concrete in term of displacement, and robust multiple cracking behavior under tensile action tests are done. Several concrete beams reinforced with different percentages of PP fiber (0.5, 1.0, 1.5 %) are constructed with different number of conventional longitudinal steel reinforcement and compared with control beams. The clear dimensions of the beams used in this investigation are 150 X 150 X 850 mm. In general, the addition of PP fiber improved the mechanical properties of concrete. As well as the more ductile behavior is found in beams with PP fibers compared with normal concrete beam, so increase of the volume fraction is giving better ductility. Where the ductility of beam 1.5 PP-2R has improved by 53 %.

Key Words: Polypropylene, fiber-reinforced beams, ductility

ÖZET

POLİPROPİLEN ELYAF TAKVİYELİ BETONARME KİRİŞLERİN SÜNEKLİK DAVRANIŞLARININ İNCELENMESİ

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Ocak 2018
62 sayfa

Son yıllarda lifler, birçok beton parametresini iyileştirme özelliği olduğu için yapısal beton elemanlarında yaygın olarak kullanılmaktadır. Mevcut araştırmada, maliyet, kalite ve inşaat süresi gibi üç faktör arasında bir denge kurulmaya çalışılmıştır. Bu çalışma, polipropilen (PP) fiber takviyeli betonarme kirişlerin süneklik davranışlarını geliştirme yöntemlerini araştırmayı amaçlamaktadır. Bu, ince agrega ve ince katkı malzemelerini arttırarak ve kaba parçacıkları azaltarak dökme işleminden hemen sonra mukavemetini alabilen, geleneksel yüksek mukavemetli beton üretilerek gerçekleştirilecektir. Hem taze betonun çökme süresi ve elyaf dağılımı verimliliği hem de katılaşmış betonda deplasman ve çekme testlerinde çoğul çatlakların araştırılması açısından mekanik özelliklerinin iyileştirilmesi için testler yapılmıştır. Farklı yüzdeli (0,5, 1,0,% 1,5) PP elyaf ile takviye edilmiş birçok beton kiriş çeşitli sayılardaki geleneksel donatı ile inşa edilmiş ve kontrol kirişleri ile karşılaştırılmıştır. Bu araştırmada kullanılan kirişlerin net boyutları 150 X 150 X 850 mm'dir. Genel olarak, PP elyaf ilavesi betonun mekanik özelliklerini iyileştirmektedir. Normal beton kirişine kıyasla PP lifli kirişlerde daha fazla süneklik davranışının yanı sıra hacim fraksiyonunun artışı daha iyi süneklik kazandırmaktadır. 1.5 PP-2R kirişinin sünekliği % 53 oranında iyileşmiştir.

Anahtar kelimeler: Polipropilen, elyaflı betonarme kirişler, süneklik.

To

The greatness of a father,

The generosity of a mother,

And to

The togetherness of a family

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LIST OF SYMBOLS/ABREVIATIONS

RC	Reinforced Concrete
FRC	Fiber Reinforced Concrete
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British Standards Code
A	Area
h	Height
d	Effective depth
S.fm	Silica fume
EC	Modulus of elasticity for concrete
f'c	compressive strength of concrete
fst	Splitting tensile strength for concrete
fy	Yield stress of steel
δ	Deflection
δu	Deflection at ultimate
δy	Deflection at yielding
δcr	Deflection at first crack
Py	Yield load
Pu	Ultimate load
ρ	Reinforcement ratio
μ	Ductlitiy
V_f	Volume fruction

GFRC	Glass Fiber Reinforced Concrete
HSC	High Strength Concrete
NSC	Normal Strength Concrete
PP	Polypropylene
FR	Fiber Reinforcement
NFRC	Natural Fiber Reinforced Concrete
SNFRC	Synthetic Fiber Reinforced Concrete
PPFRC	Polypropylene Fiber Reinforced Concrete
SFRC	Steel Fiber Reinforced Concrete
LWC	Light Weight Concrete
LVDT	Linear Variable Displacement Transducers
ASTM	American Society For Testing And Materials

CHAPTER 1

INTRODUCTION

1.1 Background

The application of the idea of adding material to another to improve the property or set of properties, one of these articles has been added straw and horse hair to mud to improve the characteristics of the blocks.

Since the beginning of the twentieth century, it has become clear that reinforced concrete is one of the main building materials. Today, concrete structures of various types, such as buildings, bridges, dams, power plants and others, represent the largest part of the infrastructure of modern cities. Therefore, improving the performance of the concrete constantly requires a more efficient building, taking into consideration the economic cost. This is considered as a future competitive necessity for concrete.

On the other hand, there are many concrete technologies available, including Fiber Reinforced Concrete (FRC), which is defined as a concrete mix consisting of cement, aggregates, water and separate concrete fibers, as well as the addition of chemical and / or metal materials and quantities and measurements calculated into the concrete mix for certain uses، PP fibers are commonly used in applications of FRC, as well as steel fiber, natural and glass fiber. They can be utilized as an alternate for reinforcement. The tensile strength and flexural strength increases when fiber is added to concrete mix as well as increases durability performance. FRC is also a substance used in seismic applications (Mehta, 2006).

(Krenchel, 1974) pointed out early that “If, as in the case of the fibre-reinforced mortar, it one day proves possible to achieve an apparent elongation at rupture for ordinary concrete that is ten or more times the value normally achieved, it will be found that, for example, many of the structures for which pre-stressed concrete is now used can be produced more simply and economically in ordinary, reinforced concrete with a certain percentage of fibres added as secondary reinforcement for crack distribution. Moreover, the risks of corrosion of the principal reinforcement will be so reduced that it should be possible to use considerably less concrete cover than is normal to-day. Particularly in the case of reinforced concrete water tanks, sea-bed structures and similar, this should be of great economic importance."

There are types of concrete structures such walls and foundations that can be used for fiber as a substitution for normal reinforcement completely. In other types of concrete structures like as beams and suspended panels, fibers can be used together with the main reinforcement or pre-stressed reinforcement. Through the above cases, economic advantage can be obtained to improve the work environment in the workplace. Structurally, the main reason for adding fibers to concrete is to improve fracture properties and structural behavior through the ability of fibers to bridge cracks. See Figure 1.1 and this mechanism influences both the ultimate limit states and serviceability. The effects on the service load behavior are controlled crack propagation, which primarily reduces the crack width and crack spacing, so increased flexural stiffness. The effects were apparent on final load resistance, first crack, shearing, punching failure and ductility when reaching the maximum load stage (Löfgren, 2005).

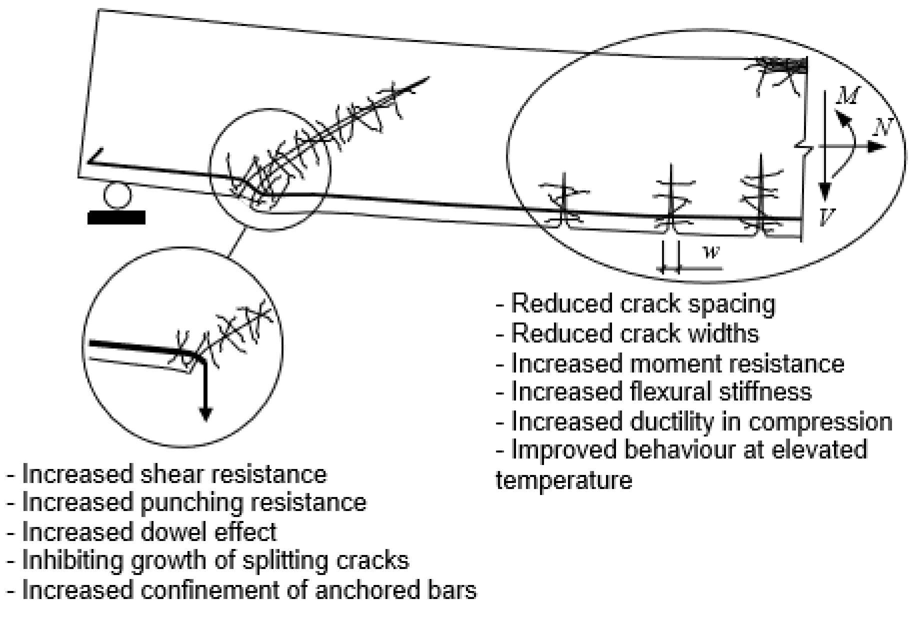

Figure 1.1 Effect of fiber on the structural behavior (Löfgren, 2005)

The fibrous concrete is expressed as a two-tier material in which the concrete represents the phase of the bonding material that binds the fibers, which in turn represents the embedded part of the bonding material، the size of the sample fiber is one of the most influential variables on the properties of fibrous concrete and there are many other characteristics such as the surface area of the fiber, the distance between the fiber and the proportion of length of fiber to diameter.

The tensile strength and ductility of concrete is low. This weakness of concrete reveals the idea of fortification with various fiber materials incorporated into it. Various fiber materials have been developed for this purpose. One of these materials developed is PP fiber material.

This is one of the types of artificial fibers that human intervention in the composition of the petrochemical industries and textile industries.

1.2 Polypropylene Fiber Reinforcement Concrete

In recent years, PP fibers have become more popular in concrete applications because the random distribution of fibers in concrete structures increases the strength of cohesion between concrete particles and prevents them from separating from each other. The addition of PP increases the tensile strength in the concrete as well as attempts to reduce the formation of small openings that lead to the formation of concrete cracks and thus get low pressure at the end of cracks formed by the transfer of tensile strength in PP fiber, which means trying to reduce crack growth and helping the concrete sample to increase its ability to withstand the added loads when the concrete cracks are visible.

The addition of fiber is designed to enhance the desired behavior of the member, but must ensure the safety of the members through the design of the method reinforced by regular reinforcing steel. Even if the addition of PP fiber leads to an additional cost, but there may be a justification for increasing the cost result of getting increased ductility, reduced shrinkage, reduced cracking and improved durability.

1.3 Objectives and Scopes

The effect of PP fiber on the ductility of the concrete beam is experimented. In order to achieve this objective, PPFRC (Polypropylene Fiber Reinforced Concrete) are exposed to four-point flexural test that are studied through a comparison between the ductility behavior of PPFRC beam reinforced with several percentages of steel bars the tension zone also investigation of the effect of PP volume fraction on the first crack, ultimate load, ductility and the post cracking and cracks pattern at failure stage Figure 1.2 shows the study program diagram.

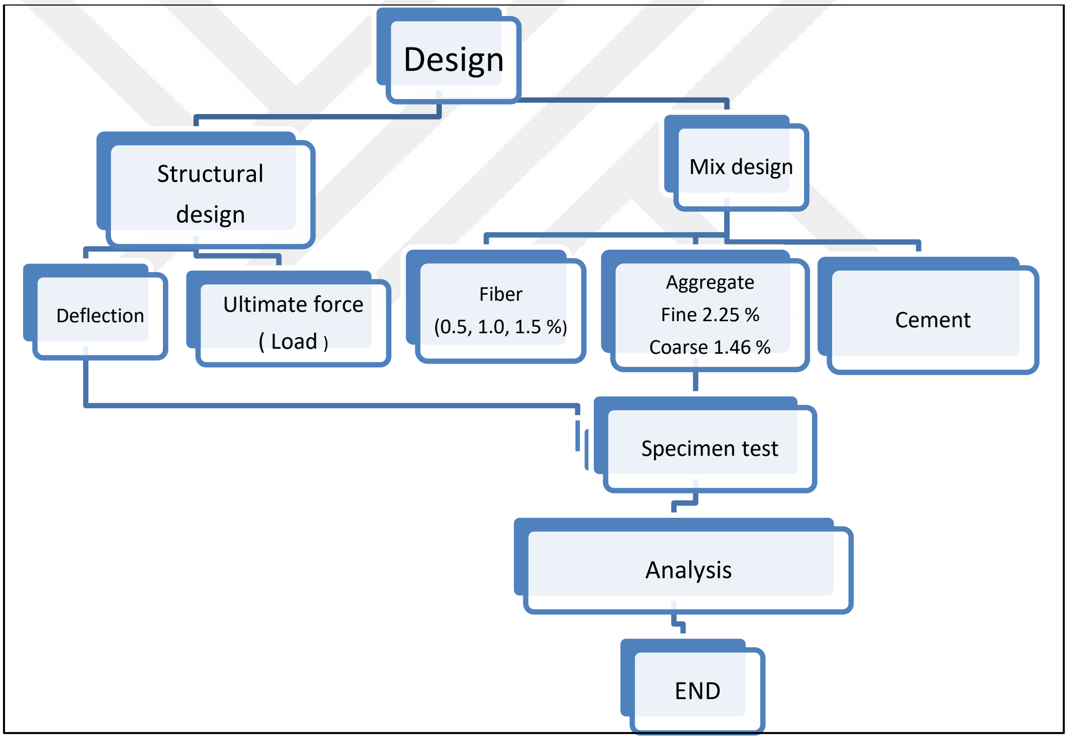

Figure 1.2 Progress flowchart of study program

1.4 Organization of the Thesis

This thesis consists of five chapters. Chapter one is introduction to the behavior of concrete beams and the impact of PP fibers on the behavior of concrete as in view of compression loads.

When the second chapter presents a general overview of PP fiber and its effect on ductility, as well as the effect of changing the percentage of steel reinforcement on the ductility also, in other words compared to previous works in terms of mechanical properties, the V_f % of fiber added and others.

Chapter three reviewes the mix design and the properties of the materials used in the mixture, as well as the mechanical properties of the mixture.

The fourth chapter presents the results obtained from the test and the method of calculations used. Finally Chapter five is the conclusion and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 General

Concrete beams are a popular structural element of modern buildings at the same time the many factors and the wide variety of materials that impact the behavior of beams is also diverse therefore; an intensive study of characteristics and the factor that influence it and how to get better it are always behave such as adding PP fiber to the mix and the behavior on ductility to the structure.

The cement was used in the early time, as well PP fiber was blended with cement based matrix whether these fibers are in the form of threads or in the form of a network and in different lengths and diameters. When ordinary concrete is mixed with PP fiber we get a concrete mixture is called PP Fiber Reinforced Concrete (PPFRC). The addition of the fiber to the concrete is the latest in quality in the field of engineering industry where there are new horizons in modern construction projects.

FRC is a concrete mixture added with a kind of fiber, the concrete is fragile material is affected by the strength of pressure, but its ability to withstand the resistance of shear and tensile weakness so it will crack and fail as a result of compression, so we found that the addition of fiber will improve the properties of concrete and will increase its ability to resist failure at a certain point, as shown in Figure 2.1.

The purpose of using FR is to create a whole new building material with a new property better than the properties of concrete alone, which could save a lot of lives when building collapse because FRC structures post tension will fall a few millimeters or centimeters before completely fall down (Tepfers, 2010).

The types of fiber used in concrete reinforcement are many and varied as shown in Table 2.1 These fibers is divided into four groups according to the type of fiber material According to ACI 544 :

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

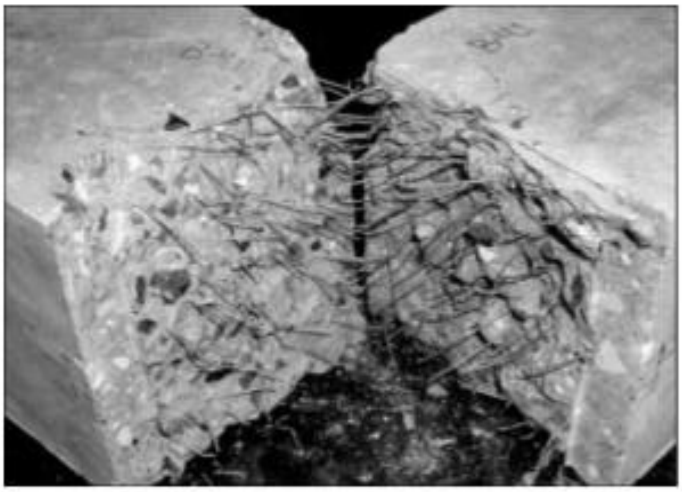

Figure 2.1 Steel fiber reinforcement (Löfgren, 2005)

PP fiber is one of the most common fibers used in concrete reinforcement. It is considered the second most used fiber after the steel fiber by twenty percent, while the steel fiber is used in fifty percent as well as the class path used five percent, glass fiber is also used five percent, The remaining twenty five percent is distributed between the other kinds of fibers (Banthia, 2008). In our current study, we have achieved only PP fibers.

Table 2.1 Types of fibers

SN	Polypropylene, Polyethylene, Nylon, Polyester, Aramid
SF	Hooked-end, Twisted, Straight, Slit sheet
GF	AR glass, E glass
NF	Wood cellulose, Bamboo

2.2 Historical Background

The idea of strengthening the concrete in the past was in the form of fiber randomly distributed in concrete such as horsehair, straw and other plant fiber where these materials strengthen the strength of fragile materials [ACI 544.1R (1996)].

According to (Hannant, 2000) the use of the fiber back to the minimum of 3500 years, where the construction of a hill in city Aqar Quf near Baghdad, where it reached its height 57 meters، in the past period asbestos fibers have been used to reinforce cement products for about 100 years, and used cellulose fiber for more than 50 years, and metal, glass, and PP fiber were used 30 years ago for the same purposes.

2.3 Polypropylene Fibers

PP is a polymer derived from the monomeric C3H6 and is a pure hydrocarbon like paraffin wax. Polymeric fibers were not tried as concrete and cement composite reinforcement until 1965. Large scale use of PP fibers in concrete did not happen until the late 1970 (Balaguru, 1992). Table 2.2 shows some properties of PP fibers.

Table 2.2 Some properties of PP fibers

PP fibers.	
Impurity	Zero
Appearance	Natural white
Cross section	Round
Standard	ASTM-C1116
Fiber length	6-12&19 mm
Young`s modulus	3.45×10^3 Mpa
Tensile strength	350 Mpa
Elongation	25 %
Specific density	0.90 kg/m^3

According to the researchers (Bentur, 2006) there were several ways to reinforcement concrete with PP fiber, fiber can be used as thin sheets and is adopted as a basic reinforcement where the fiber content should be higher than 5 % and as it exceeds the critical stage specified according to the specified ratio of fiber, As a high-performance fibrous concrete, this type of reinforcement does not depend on the simple mixing methods of mixing fibers and bonding materials. Instead of placing these layers by hand, special techniques are used to complete the process.

The second type of reinforcement is the secondary reinforcement, which is made of PP fiber with a containment of up to 1 % of the size. It is added to reduce plastic shrinkage cracks and has no effect on hardened concrete cracks and is also used for fire protection. When fires occur, fiber melts and fine channels allow the fume generated during the fire, which also protects the cover reinforcement from damage.

2.4 Polypropylene Fiber Reinforced Concrete

PPFRC is a combined material made of concrete mixed with PP fibers that are accommodating the cement-matrix. The matrix, also occasionally of fly ash, silica fume or any other materials are added to the concrete mixture.

PP fibers and concrete are bonding together homogeneously. After using and casting in a building or any other structure, it behaves differently during the increasing of loads, when concrete start to crack, PP fiber will still carry out the load, the raw material is 100 % PP. Varieties produced in 6, 12, 19 and 38 mm length have less filamentous structure. It can be used as a replacement for mesh reinforcement for site concretes, walkways, garages and parking lots.

The volume fraction of fiber used in PP fiber reinforced concrete is currently very low and in most cases limited to not more than 0.1 percent (1.6 lb/yd^3) of concrete. The concrete contains coarse aggregates and used primarily the PP fibers to control cracking in the early stages of setting of concrete. Researchers have used up to 2 percent fiber volume fraction with conventional mixing (Balaguru, 1992). PP fibers have a low elastic modulus and a high ductility compared to concrete. This implies that the inclusion of the fibers may reduce cracking strength of the composite and result in very large strains before multiple cracking is complete. The composite with fibers of low aspect ratios is expected to be characterized by curve OABD or OAEF in Figure 2.2 (Soroushian, 1992).

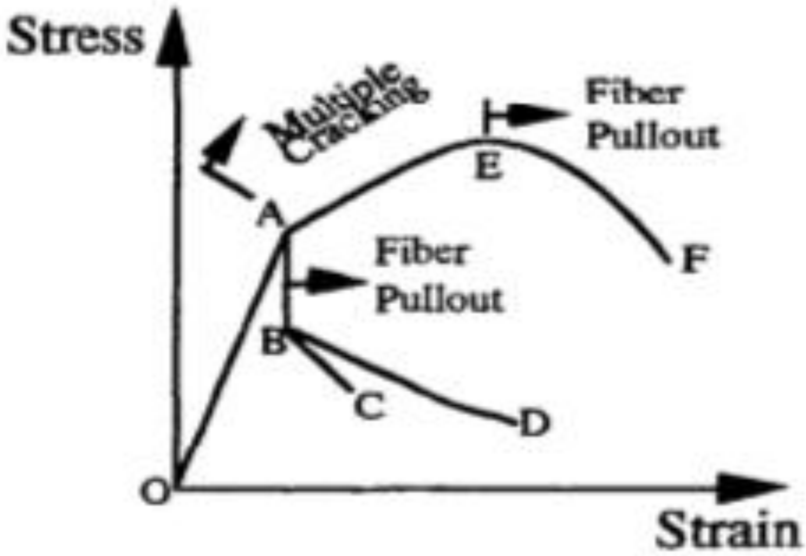

Figure 2.2 Stress-strain relationship composite (Soroushian, 1992)

2.5 Mechanical Properties

The mechanical properties imply the reactions of PPFRC, deflect either in plastic or elastic, In the design and quality control of concrete there are many factors that are based on the classification of concrete, such as the strength of pressure, which is a fundamental characteristic compared to other properties This test is relatively easy, in addition there are a lot of properties that affect reinforced concrete with fiber tensile strength, ductility, flexural strength, shear resistance, crack pattern and punching shear. The mentioned mechanical properties appear to be affected by parameter of V_f (%), the length of fiber was used, shear span ratio, concrete strength,and also thickness (h).

2.5.1 Compressive strength

According to (Ahmed, 2006) an experiment was conducted to measure the impact of the fiber on the resistance of concrete compression. The producted 36 concrete cylinders were divided into four groups. The fiber was added in different quantities to three groups while the fourth was without fiber as a control cylinder. It was concluded that the addition of PP in quantities ranging from 0.18 to 0.40 % increase compressive strength by about 5 %, but when adding amounts ranging from (0.55 to

0.60 %), compressive resistance is (3 to 5 %) lower than originally. The results appear when added the V_f of PP over 40 %, it negatively effects on compressive strength, but adding a low V_f (0.1 to 0.35 %) appears improved in compressive strength.

(Sumer, B, 2012) Various mineral admixtures and fibers are added to improve some properties of concrete. Bottom of silica is added. Adding silica fume at optimal amount of concrete reduces hydration heat, achieves high target strength and low permeability, control alkali silica reaction and sulfate effect. And so on. The silica fume additive tightens the aggregate-dough interface area to provide more void-free and more durable concrete. However, it also has negative effects such as reducing the machinability of silica fume. The optimum amount of silica fume in concrete is determined by the relative values of these effects and is also influenced by such factors as cement, aggregate, fluidizing additive types and amounts and maintenance conditions. Polypropylene fibers are the most commonly used and most commonly used additives, which are added to concrete from polymer fibers. By forming a three-dimensional micro reinforcement network inside the polypropylene fiber concrete, Betonda can naturally reduce the deficiencies and weaknesses that are accepted as being present and improve some properties of the concrete. In this study, the effects of silica dust, which is an industrial waste material, on the concrete properties of the site concrete were investigated and the effects on the concrete properties were investigated by adding polypropylene fiber to improve the negative effects of silica smoke on the concrete. With the addition of polypropylene fiber to concrete, changes in pressure resistance were observed. The compressive strength of concrete containing 0.1%, 0.5% and 1% polypropylene fiber reinforced 10% silica fume was determined in 28 day cube samples. As the amount of polypropylene fiber and silica fume increased, the compressive strength increased. The compressive strengths of 5% and 10% silica fume added concrete increased by 23% and 35% respectively, compared to witnessed concrete.

(Sutheesh, 2016) In his study, many different dosages of PP fibers were tried to reach the optimal dose that gives higher compression resistance. Three different grades of concrete (25M, 30M, 35M) were produced with and without PP fibers and fibers were added in four different ratios 0.15, 0.20, 0.25 and 0.30 % of the cement weight used in his study. The dimensions of the models were 150X150X150 mm. The results showed that adding 0.25 % to all three seasons gave the highest resistance to compression in seven days. The trend was similar in 28 days.

(Vikrant S. Vairagade, 2012) In their study, compressive resistance was tested for a set of cube and cylindrical models where the dimensions of the cubes were 150X150X150 mm, while the cylinder dimensions was 800X100 mm and the PP was added by 0 % and 0.25 % and the length of PP is 15, 20 and 24 mm. The result showed the compression resistance of the cubes and cylinders increased slightly when used the different length of PP.

2.5.2 Split tensile strength

The tensile strength of concrete is only about 10 % of its compressive strength. It is clear that the addition of fibers to a concrete mixture is beneficial to the tensile properties of concrete. The fibers act as crack arresters in the concrete matrix prohibiting the propagation of cracks in plastic state and propagation of cracks in a hardened state. Once the splitting occurred and continued, the fibers bridging across the split portions of the matrix acted through the stress transfer from the matrix to the fibrers and, thus, gradually supported the entire load. The stress transfer improved the tensile strain capacity of the fiber-reinforced concrete and, therefore, increased the splitting tensile strength of the reinforced concrete over the unreinforced control counterpart. The deformation characteristics of cementitious matrices in tension are distinguished according to their post cracking deformation behavior. Brittle matrices, such as plain mortar and concrete, lose their tensile load-carrying capacity almost immediately after formation of the first matrix crack (Figure 2.3) (Fischer, 2004).

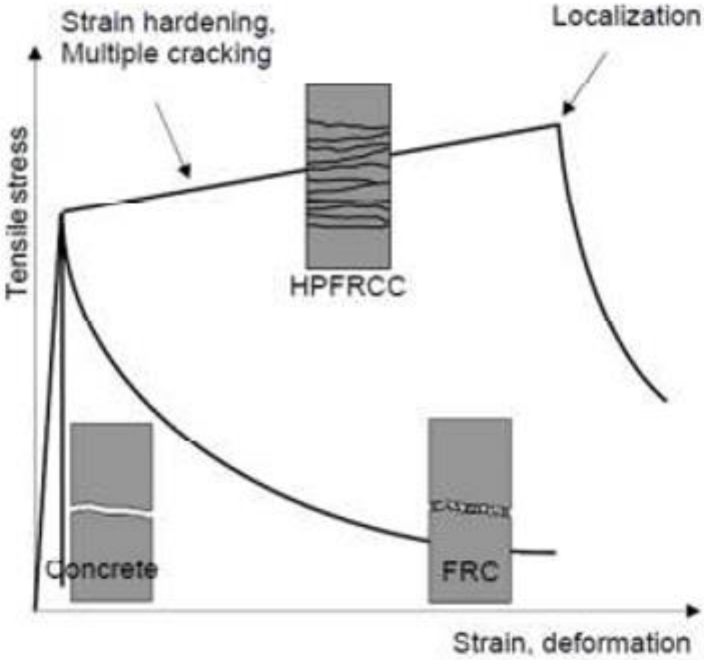

Figure 2.3 Schematic stresses-strain behavior of cementitious matrix in tension

(Kolli.Ramujee, 2013) His study, the samples were produced with dimensions of 150 X 150 X 150 mm, as well as cylinders with a height of 300 mm and a diameter of 150 mm, the fiber was added by 0, 0.5, 1, 1.5 % of the volume. The length of the fiber section used was 12 mm and the percentage of water added to cement was 0.50 %. Tensile tests were performed on cylinders and cubes at a constant strength of 2000. It was observed that it was less than 2 % of the fiber content. The tensile strength in the main mixture was 28 days 2.52 kN and 0.5 % 3.22 kN, 1.0 % 3.4 kN and 1.5 % 3.52 kN and in the ratio of 2 % decreased the tensile strength of the concrete became 2.9 kN.

The tensile strength was tested in a set of cylindrical models, where the dimensions of cylinders were 800 X 100 mm and the PP fiber was added by 0 and 0.25 %, the length of fiber is 15, 20, 24 mm. Three cylinders were tested and their average value was calculated. The result shown the tensile strength increased when used PP with length 24 mm (Vikrant S. Vairagade, 2012).

2.5.3 Flexural strength

The flexure strength can be defined as the ability of beam or plate to resist failure in bending. It is one of the tensile strength measures of concrete and is measured by loading non-reinforced concrete beams with a three-depth depth. The strength of the flexural can be expressed as a Modulus of Rupture (MR) in psi. Flexural MR is about 12 to 20 percent of the compressive strength. However, the best correlation for specific materials is obtained by laboratory tests.

(Alhozaimy, 1996) studied the effect of fractions of different sizes of PP fiber and different types of folders on the rigidity and stability of the compound. The design was based on ASTM C78 for the two points bearing and noted that the size of the fractures was lower and that the fiber was not affected by the flexural strength of FRC. PP fibers influence the flexural toughness significantly. The flexural toughness increased by 44, 271, and 387 % when addition of 0.1, 0.2, and 0.3 % volume fraction of fibers respectively.

(Yadav, 2017) poured prism samples with dimensions 100X100X500 mm and added PP by (0, 1.2, 1.6, 2 %). The longitudinal section of fiber used was 36 mm and the concrete mix was designed according to IS: 10262-2009 for M25 grade of concrete. After 28 days, the models were tested at a load rate of 0.7 N/mm^2/ minute, it is observed an increase in resistance to flexure from 6.1 to 6.8 for models.

2.6 Ductility

Ductility is a structural design requirement in most design codes. In steel RC structures, ductility can be defined as the ability of the beams to hold the deformation before failing, this ability has to be in the inelastic range without decreasing in beam strength, mathematically, ductility factor can be evaluated by dividing the ultimate deformation by yield deformation. Due to the linear-strain-stress relationship of FRP bars, the traditional definition of ductility cannot be applied to structures reinforced with FRP reinforcement. Several methods, such as the energy based method and the deformation based method, have been proposed to calculate the ductility index for FRP reinforced structures by (Wang & Belarbi, 2005).

(Naaman, Harajli, & Wight, 1986) conducted an analytical and experimental study on the ductility of partially prestressed concrete members. They some modifications to the concept of reinforcing index and the definition of yield curvature. Based on these modifications, they developed a nonlinear analytical model for investigation of ductility in partially pre-stressed concrete beams. In their experimental study, they tested twelve partially pre-stressed concrete by the beams were simply suPPorted on a 5 m span, and each had a cross section of 114 X 228 mm. They concluded that for all kinds of steel reinforced, pre-stressed and partial pre-stressed concrete beams, ductility decreases with an increase in the reinforcing index. Furthermore, they noted that increasing the compressive strength of concrete decreases the ductility.

(Tan, 1994) Studied the ductility, according to Figure 2.4, the region in load deflection curve that defines the deflection at first crack (δ_{cr}), deflection at yielding (δ_y), and also deflection at ultimate (δ_u) corresponding to the cracking load (P_{cr}), yield load (P_y) ,and ultimate load (P_u) for slabs tested.

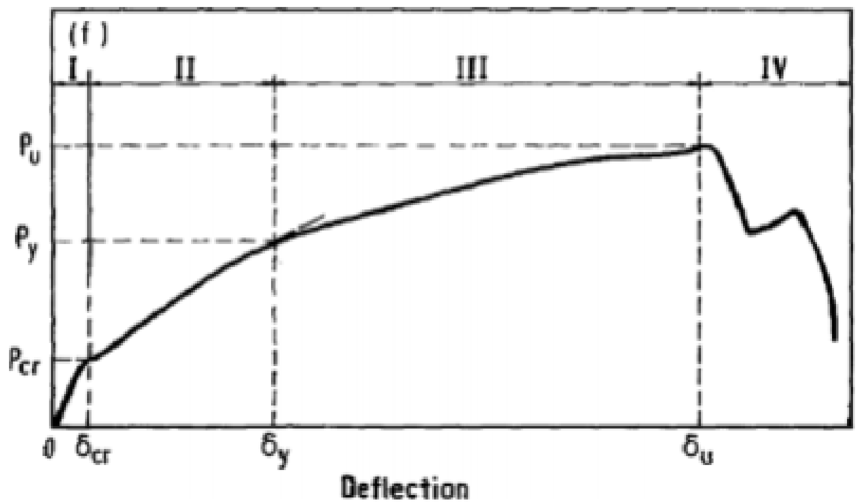

Figure 2.4 Load-deflections under punching shear

In fact, the cracking load was determined from the load-deflection curve and confirmed by steel-strain reading. The yield load (P_y) was obtained from the intersection of linear portions of regions II and III as shown in Figure 2.18. The same procedure is applied when getting the ultimate load (P_u) which was obtained from the intersection of region III and IV.

(Grace, Soliman, & Abdel-Sayed, 1998) tested 7 rectangular beams and 7 continuous T-section beam. Reinforcing bars and stirrups were made of steel, glass, and carbon fiber reinforced polymer (GFRP). It was concluded that the use of GFRP stirrups led to significant shear deformations that increased beam deflections and reduced ductility. Also, GFRP stirrups changed the failure mode from flexural to shear or flexural-shear, depending on the type of reinforcement bars (FRP or steel). Furthermore, the use of FRP reinforcement in continuous beams increased deformation. At the service load level, this increase remained small and acceptable, but significantly increased near failure. While different FRP reinforcement arrangements were found to have the same load capacity as steel reinforcement in conventional beams, failure modes and ductility differed. Failure mode was governed by both the type of reinforcing bars and the type of stirrups. Additionally, the dowel effect influences the load carrying capacity of FRP reinforced continuous beams. A method for evaluating the ductility was energy method. The theoretical results obtained using the suggested method were substantiated experimentally.

(Duthinh & Starnes, 2001) investigated strength and ductility of concrete beams reinforced with carbon FRP and steel. They tested seven concrete beams reinforced internally with varying amounts of steel and externally with carbon fiber-reinforced polymer (FRP) laminates applied after the concrete had cracked under service loads under four-point bending. Strains measured along the beam depth allowed computation of the beam curvature in the constant moment region. Test results indicated that FRP is very effective for flexural strengthening. As the amount of steel increases, the additional strength provided by the carbon FRP laminates decreases. Compared to a beam reinforced heavily with steel only, beams reinforced with both steel and carbon had adequate deformation capacity, in spite of their brittle mode of failure. Clamping or wrapping of the ends of the laminate enhanced the capacity of adhesively bonded FRP anchorage.

(park & al, 2009) cast and tested six reinforced beams included one control beam, two beams strengthened with externally bonded (EB) reinforcement method, and three beams strengthened with near-surface mounted (NSM) reinforcement method with different AFRP types and strengthening area to evaluate the behavior and ductility of these beam specimens. The results indicated that the biggest increase in the load when the strengthening area is expanded showing a brittle aspect, and eventually the premature failure occurred. With regard to the methods, it is found that the NSM reinforcement method is more effective to strengthen the structure, and the uneven surface causes ductile failure

(Iffat, Maina, & Noor, 2011) tested nine simply supported beam specimens subjected to two point loading system. The beams were with three different reinforcement ratio (equal to ρs = 0.007, 0.009 and 0.0128) and three different concrete strengths (equal to f'c = 5.25 ksi, 6.5 ksi and 7.25 ksi). The experimental results showed that the flexure strength and stiffness is increased with the increase of steel ratio.

Beams with steel ratio 0.009 and 0.007 had ductility ratio more than 4, but the beam with steel ratio 0.0128 had ductility ratio less than 4. So low steel ratio beams give the required minimum level of flexural ductility. The low steel ratio gives more ductility than high steel ratio, therefore; in ductility based design it is very important to keep the steel ratio low. No significant effect of compressive strength of concrete on moment-curvature relationships and ductility were observed

(Aryan, 2014) concluded that reinforced concrete beams with PP fibers were more ductility than concrete beams that did not contain these fibers by studying the behavior of those symptoms with and without fibers. Their energy absorption capacity and ductility coefficient were calculated by using the formed load – displacement curves on the beam samples with dimensions of 30 X 20 X 200 mm and fiber was added to two items by 0.6 and 0.84 and was also produced two items without fibers for comparison, it was conducted concrete analytical modeling beam armed with Abaqus program.

(Park, 1988) States four definitions for each deformation. Figure 2.5 depicted these definitions.

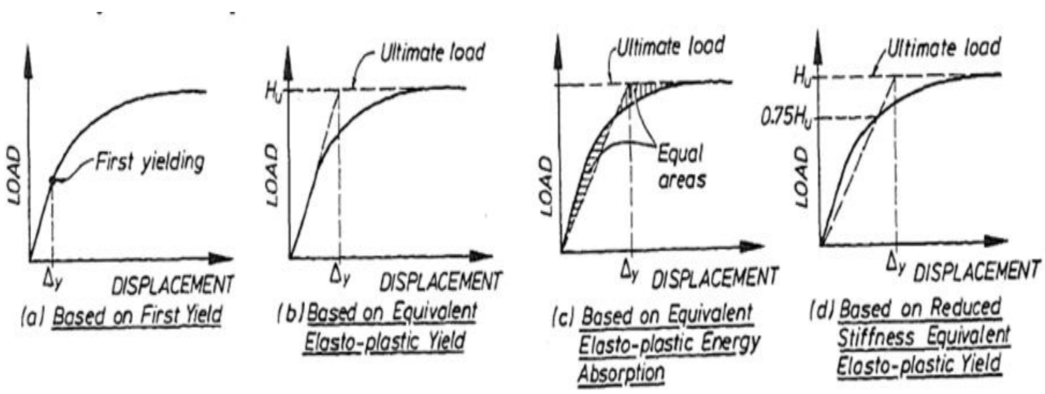

Figure 2.5 Yield displacement definition according to park

2.7 Crack Pattern

(Sutheesh, 2016) studied the effect of PP on the crack pattern, Figure 2.6 shows the crack pattern in concrete beams. He noted that the number of cracks in concrete beams containing PP and normal beams was approximately equal, but the cracking rate of beams containing PP was slower than the spread of cracking in normal beams. This is due to the reason that the development of major cracks is controlled by the bond strength between main reinforcement and concrete, while the rate of propagation of crack in PFFRC beams were controlled by the strong fiber-matrix bonding. It was observed that, once the fiber matrix bond breaks, the rate of crack propagation increases till the ultimate load is reached.

Figure 2.6 Crack pattern beam under flexure

(Kwak, 2002) found that the addition of steel fiber to concrete significantly affects the pattern of concrete cracking by a/d ratio of 2%. Figure 2.7 shows three bundles where beam A did not contain steel fiber. The cracks were first formed in the fixed torque area and returned in the middle of the beams. Then, two cracks appeared in the shear near a quarter point in the continuous shear areas.

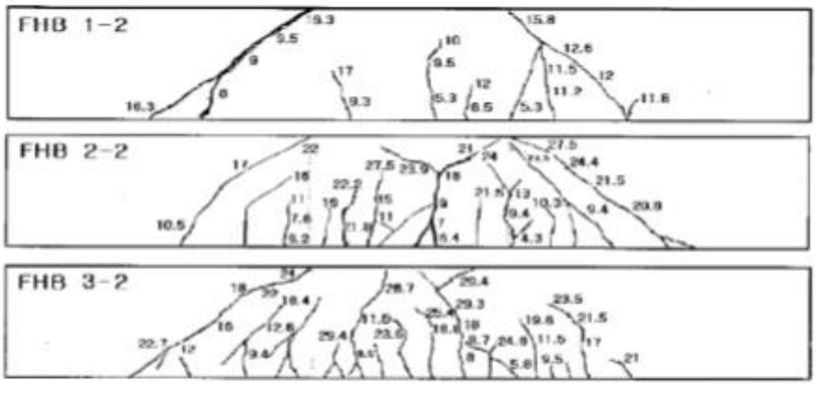

Figure 2.7 Typical crack patterns (a/d = 2), (Kwak, 2002)

Moreover, the result shows that 0.50 % was added to FHB 2-2 and 0.75 % was added to the model FHB 3-2 where the failure mode was changed from shear to total shear and flexure. In similar failure cases, significant diagonal shear cracks and vertical flexural cracks are both happened, which combine and cause final failure, The flexural and shear cracks were distanced nearly as the V_f increased, for example, in concrete beams containing a slit spacing fibers from 80 mm to 90 mm, while after slit in concrete beams that do not contain fibers of 90 mm to 170 mm.

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CHAPTER 3

EXPERIMENTAL WORK

3.1 Introduction

This chapter presents a preparation of the specimens with casting and curing process. The properties of the materials used in concrete are described in this chapter together with specifying their mix proportions. The experimental work was conducted at the Structural and Materials Laboratories at the University of Gaziantep.

3.2 Mix Design and Materials Properties of Concrete

3.2.1 Mix design

According to previous research's and studies, the mixing of fibers with a mixture of fine aggregates was more efficient than mixing fibers with coarse aggregates. Thus, the ratio of fine aggregates and coarse aggregates in the concrete mix used in the production of concrete beams was 63.24 %, 36.76 % sequentially from total aggregate volume, the mix designs are shown in Table 3.1. All materials are same but only percentages of PP are changing.

Table 3.1 Mix design

<table>
<tr><th>Mix code</th><th>V_f %</th><th>PP (kg)</th><th>Cement (kg)</th><th>Sand (kg)</th><th>Gravel (kg)</th><th>S.plasticizer (kg)</th><th>Water (kg)</th><th>S.fm (kg)</th></tr>
<tr><td>PP</td><td>0</td><td>0</td><td rowspan="4">12.995</td><td rowspan="4">32.696</td><td rowspan="4">19.003</td><td rowspan="4">0.184</td><td rowspan="4">6.036</td><td rowspan="4">0.978</td></tr>
<tr><td>0.5PP</td><td>0.5</td><td>0.182</td></tr>
<tr><td>1PP1</td><td>1</td><td>0.36</td></tr>
<tr><td>1.5PP</td><td>1.5</td><td>0.546</td></tr>
</table>

3.2.2 Material Properties

Cement: in this study the type of cement used is called cem II / A-LL 42.5 R. It is obtained from Limak Gaziantep cement factory. Which is the portland cement of limestone and the composition of this cement is from 80 to 94 % clinker and contains 6 to 20 % limestone and 0 to 5 % minor components.

Fine aggregate: The sizes of the sand particles used are ranged from 0.075 mm to 4.75 mm. Table 3.3 and Figure 3.2 show the sieve analysis of fine aggregate used.

Table 3.2 Grading of fine (river sand) aggregate

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

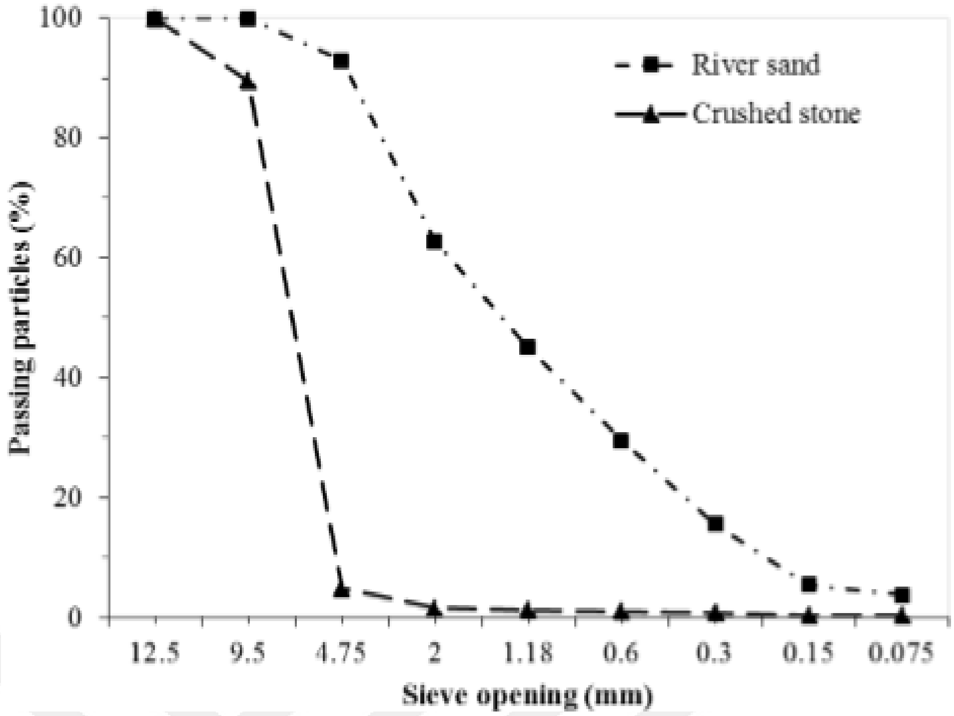

Figure 3.1 Sieve analysis

Coarse aggregate: a graded crashed stone are used in the mixture. The maximum size of the particles was 9.5 mm, as it can be seen in Table 3.4, it is shown that there are a gap between particles of 4.75 mm and 9.5 mm.

Table 3.3 Grading of coarse (crashed stone) aggregate

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

Superplasticizer: the production capacity of the mixture has a low workability due to the high amount of fine aggregates added to the concrete mix. Therefore, a constant percentage of the high water reduction is added to the mixture. A superplasticizer under traditional name Glenium 51 are used, which is complied with ASTM C 494 Types A.

Polypropylene fiber: The longitudinal section of the PP fibers used in this mixture was 12 mm. As shown in Figure 3.3، these fibers are in the form of threads that are intertwined with each other. This fiber is manufactured by Ahmed Company from Istanbul, and is placed in bags weighing approximately 600 g.

Figure 3.2 A sample of Polypropylene

Silica fume: is an amorphous (non-crystalline) polymorph of silicon dioxide, silica. It is an ultra fine powder collected as a by-product of the silicon and ferrosilicon alloy production and consists of spherical particles with an average particle diameter of 150 nm.

Steel reinforcement : The steel bars used are of 8 mm diameter. Steel reinforcement distribution in the compression zone was similar in all beams 2Ø8, while steel reinforcement distribution in the tension zone was variable, in the first group 2Ø8, in the second group 3Ø8, and in the third group 4Ø8. Also steel reinforcement for stirrups are used consisting of 10Ø5.3 mm as shown in Figure 3.3.

Water: Tap water was used throughout this work for both mixing and curing of concrete.

Figure 3.3 Steel reinforcement of beams

3.2.3 Mixing and pouring of concrete

As a first step, the steel structure of the beams is made where the steel bars were cut by using the iron cutter as well as preparing the stirrups, then reinforcing steel was connected together using an steel wire. After that, the mold was greased to prevent the adhesion of the concrete to the wood mold and prepared in which the samples will be poured، then the weights of the materials were prepared using an electronic balance.

Dry materials (gravel, sand, cement and silica fume) were added to the vertical rotation mixer where the materials were mixed dry to obtain a homogeneous mixture by moving the four mixer arms as shown in Figure 3.4.

Figure 3.4 Mixer

The first stage of mixing process lasted about five minutes in slow movement to prevent the volatilization of light materials such as silica fume and cement and then water is added to the mixture gradually and continue to rotate the mixture for a period of five minutes. After the plasticizer is thrown into the mixture, the mixer is rotated at the maximum speed at this stage and then PP fibers were slowly added to the mixture where the PP fiber threads are unplugged manually to prevent the formation of heterogeneous blocks within the mixture.

The mixer rotation continues for a few minutes so that the mixture is completely homogeneous, then the mixture is ready to be poured, where the resulting mixture is transferred to the mold after making all the arrengements such as placing the reinforcing steel in the mold with taking in concider lifting the reinforcing steel from the base of the mold 1 cm distance to maintain the concrete shell at the bottom of the mold.

After pouring the concrete in the mold a vibrator was used. The vibrator was placed in the middle of the mold and on the outer side of the mold to make sure that the mixture's reachs every space of the mold.

In addition, two types of cylinders were casted the first one is a standard cylinders with a diameter of 100 mm and a length of 200 mm and the second was 70 mm diameter and length 140 mm, vibrators were used on the outer face of the cylinders containing PP fibers on the other hand the cylinders with normal concrete were poured with three layers, all the layers was secured by a steel rod, the vibration of the concrete continued until the air bubbles were eliminated from the concrete.

The cast cylinders were used to measure the compressibility of the concrete f' and the modulus of elasticity E and tensile strength f_{sp}, three cylinders were poured for each concrete mixture to obtain average results from the tests.

After the concrete was poured into the mold, the outer surface of the concrete was leveled and smoothed by the trowel. It can be observed that the concrete mixture containing the fiber needs to be done more in the process of settling using the slurry than the regular concrete that needs simple work in the leveling

After that, the molds were moved to a place where the temperature was constant at normal (room temperature). After 24 hours the molds were opened and concrete beams were transferred to the water basins.as shown in Figure 3.5.

Figure 3.5 Cast beams and cylinders

3.2.4 Slump test

There are many effects that are observed in the concrete when adding fiber to it. The most obvious effects are to reduce the operability when the volume of fiber is increased. The ability to operate fibrous concrete is the main focus in determining the quality of this concrete. There are several secondary factors that determine the level of operability such as the V_f of fiber, the length of fiber to diameter and the size of the components of cement paste (cement and water).

A slump test was used to check the consistency and straightness of the concrete. This was done through the use of a special cone for measuring the landing and determining the viability of the concrete (Workability) also to determine the amount and the percentage of water needed for the mixture.

Reducing the slump when adding fibers does not necessarily mean the difficulty of compressing the concrete with the vibration, as well as the fiber makes the mixture drier as the surface area increases. Due to the constant value of the w/c water ratio and the addition of a fixed amount of plasticizer to all mixtures, the value of the slump is kept between (50 - 100 mm). Figure (4-1) shows that there is an inverse relationship between increase in fiber ratio and slump value, where the higher the V_f of fiber from (0.5 to 1.5 %) decrease the value of slumping.

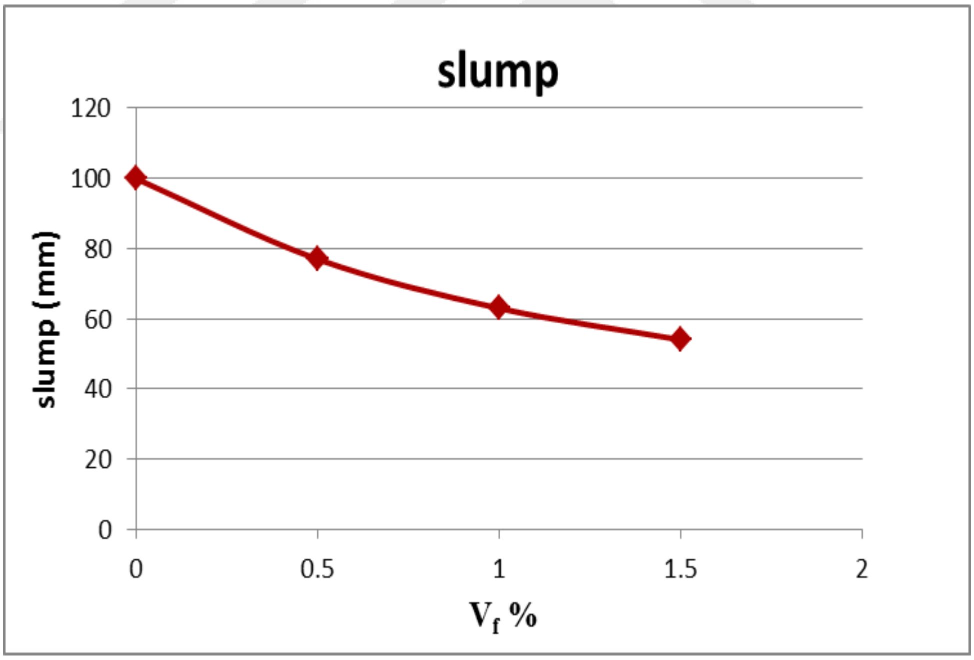

Figure 3.6 The relationship between the V_f % of PP fiber and the slump value

3.3 Curing process

After twenty-four hours from the pouring of the concrete beams, concrete beam and cylinders were transferred to the water tank.

The atmosphere was cold at the time, so a heater was used to maintain a temperature of 25 °C as shown in Figure 3.7, The treatment lasted for 28 days, after which the samples were removed from the water tank.

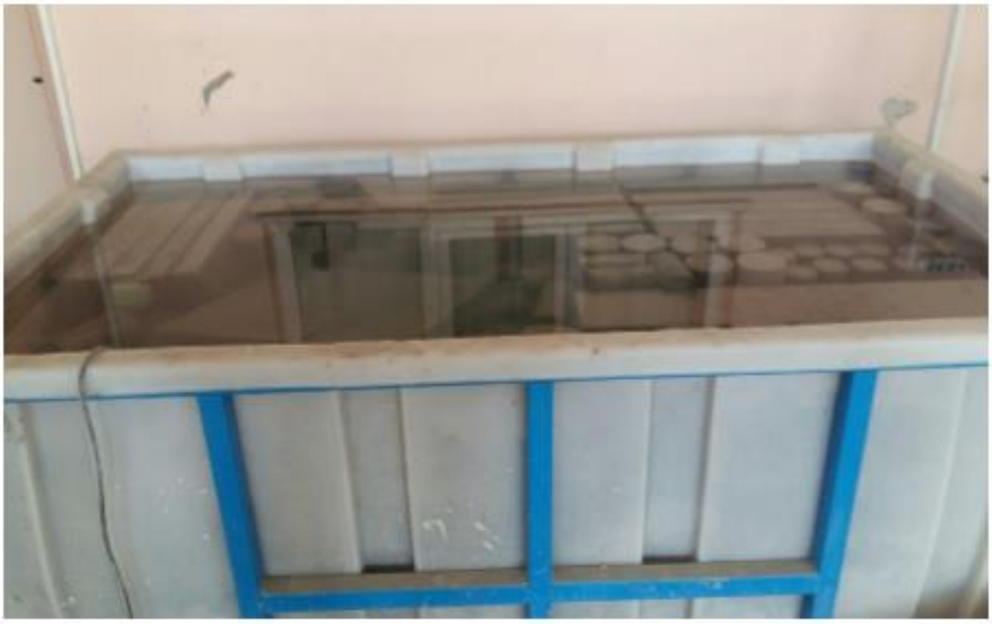

Figure 3.7 Curing tank

3.4 Mechanical Properties of PP Fiber Concrete

The mechanical properties of the concrete mixtures were obtained by tested the cylinders. The cylinders and the beams similar in mixture were tested on the same day to obtain accurate results. Sulfur was used to make a cover for concrete cylinder to get perfectly flat surface.

3.4.1 Compressive strength

Compression strength is the one of the most important mechanical properties of rigid concrete, through which many mechanical properties can be calculated**.** The models were treated with water for 28 days after that the cylinders were prepared for examination and placed inside the machine, it were subjected to compressive load until it reached the stage of failure. This was based on (ASTM C39, 1997) which explains in detail how to examine and calculate the compression resistance of concrete cylinders، as shown in Figure 3.8.

Figure 3.8 Cylinder compressive test

The cylinders were tested and taken the average of the three models. The results shown in Figure 3.9 showed that the addition of PP fiber improved the compression resistance values as the increase started with the addition of 0.5 % of the fiber and and increased slightly when added PP by 1.0 %. while the resistance increased further when adding 1.5 % of PP. We concluded that by increasing the fiber ratio (0.5, 1.0, 1.5 %) the compressive strength was increased by 22, 28, 40 % compared with normal concrete as shown in Figure 3.12. The reason for the increase in compression resistance when adding PP is that these fibers work to increase the cohesion of the concrete by binding the particles of the mixture together and make them more hardness and resist to a large extent cracks in the zone of tension and breadth is one of the reasons that increase the load borne by concrete so failure.

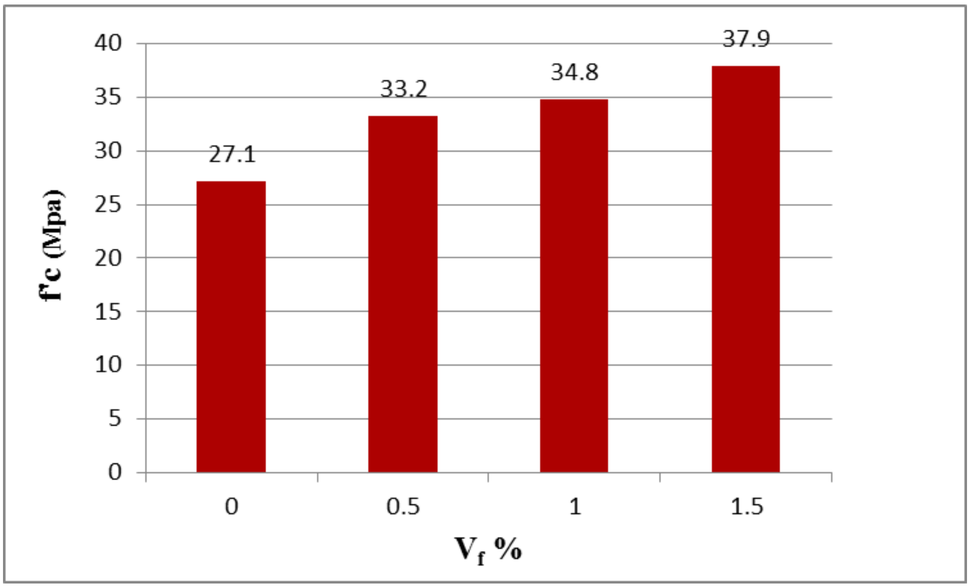

Figure 3.9 Effect of PP on the compressive strength

3.4.2 Splitting Tensile Strength

The cylinder was placed horizontally inside the test frame and wooden strips were used under and above the cylinder. A steel strip was placed on both sides of the cylinder to fix and prevent movement. The test frame was then placed inside the test machine then the pressing force was placed on the center of the cylinder. (ASTM C496, 2004) was used in the configuration process and calculated the results of the test, where the longitudinal pressure was placed along the cylinder until the failure stage، as shown in Figure 3.10

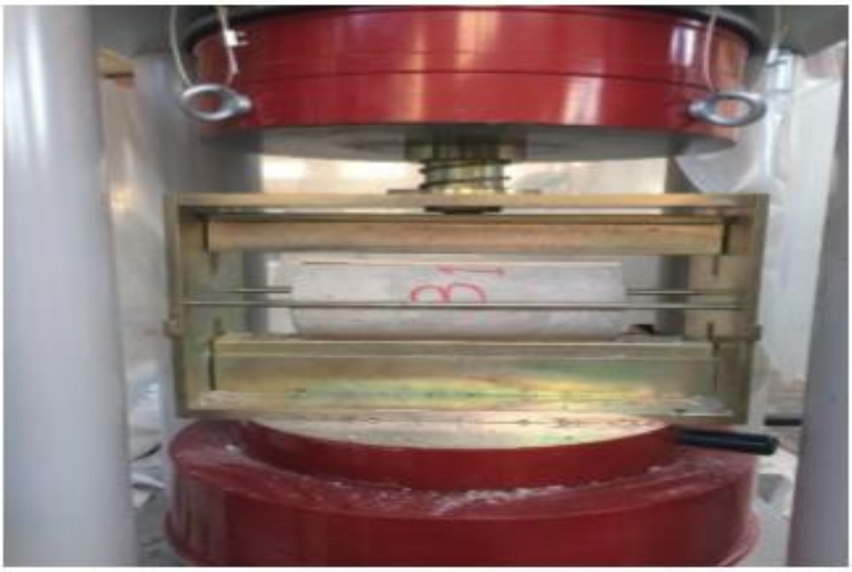

Figure 3.10 Splitting tensile test

The rate of tensile strength values obtained from the splitting tensile test for three cylindrical models is shown in Figure 3.11. PP fibers increased the resistance of the concrete to the tensile strength. The results showed that the increase was significant in cylinders containing fiber size by (0.5, 1.0, 1.5 %) with a tensile strength (13, 25, 30 %) respectively compared to normal concrete as shown in Figure (3.12). The increase in tensile strength in the presence of PP fiber lies in the ability of this fiber to resist the creation of cracking as well as its expansion and by linking these cracks effectively by providing a conveyor medium for stresses that delay the expansion and development and also helps the fiber to carry and redistribute the stresses placed on the cylinder.

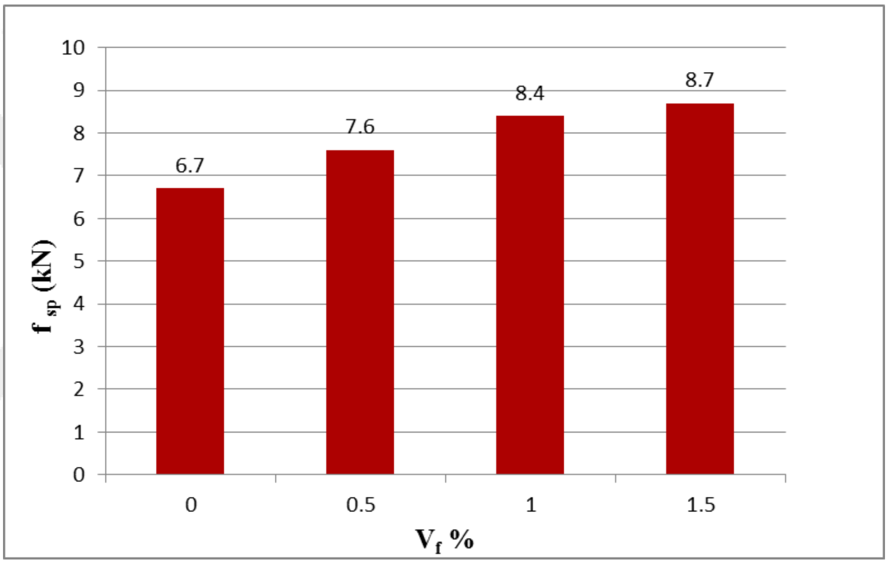

Figure 3.11 Effect of PP on the splitting tensile strength

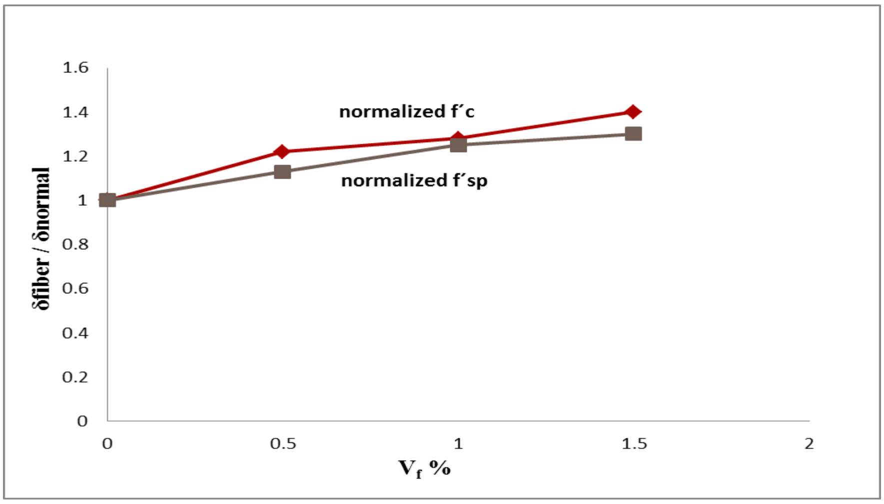

Figure 3.12 Effect of PP on concrete strength effective PP-FRC compressive and splitting tensile strength as a unity of normal concrete

3.5.3 Modulus of elasticity test

Modulus of elasticity is defined as the ratio of the stress applied to the body or substance to the resulting strain within the elastic limit. (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 3.13

Figure 3.13 Modulus of elasticity test

There are many studies that have shown there is a direct relationship between the modulus of elasticity and the compressive strength of the concrete, where the modulus of elasticity increases when the compressive strength of the concrete increases (Gencel et al 2012, Siddique 2004).

The cylinder reinforced with PP and normal concrete are tested after 28 days and the results were compared. From Figure 3.14 it can be noted that increasing the V_f % of PP the modulus of elasticity increases too.

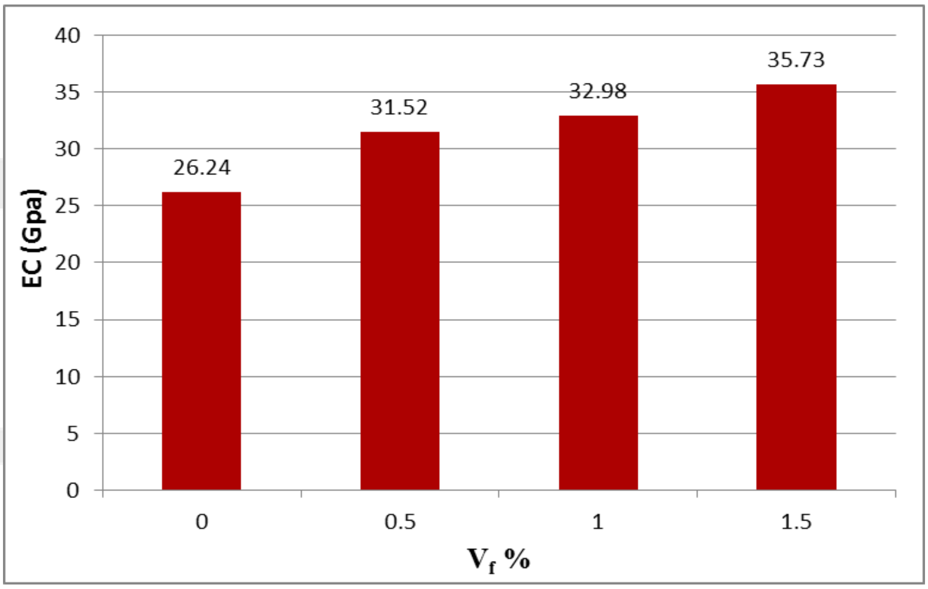

Figure 4.14 Effect of PP on the modulus of elasticity

CHAPTER 4

STRUCTURAL BEHAVIOR OF FRC BEAMS

4.1 Introduction

The main objective of the present study is to investigate the structural behavior of reinforced concrete thresholds with different percentages of PP fibers and compare them with the ordinary concrete beams.

In addition measure the effect of addition of PP fibers and the percentage of reinforcing steel on ductility, the ultimate strength of the beams, the results of the test of the behavior of the load-deformation, and its effect on the first crack also .In this chapter, the results obtained from the practical program of this study.

Twelve concrete beams were cast and divided into three groups. Each group contain one beam without PP fiber and three other beams with different percentages of PP. Each group was reinforced by a different reinforcement than the other ،all beams tested under four point loads until the failure as shown in table 4.1. All beams in groups have the same length and cross-section details.

Table 4.1 Study groups

Group	ρ %	V_f = 0 %	V_f = 0.5 %	V_f = 1.0 %	V_f = 1.5 %
1	0.5 (2R)	0 PP-2R	0.5 PP-2R	1.0 PP-2R	1.5 PP-2R
2	0.75 (3R)	0 PP-3R	0.5 PP-3R	1.0 PP-3R	1.5 PP-3R
3	1.0 (4R)	0 PP-4R	0.5 PP-4R	1.0 PP-4R	1.5 PP-4R
Where V_f is the volume fraction. 2R two longitudinal reinforcement , 3R three longitudinal reinforcement 4R four longitudinal reinforcement					

4.2 Specimens Geometry

To check the beam ductility and ultimate load, twelve beams were cast and tested, all beams have the same dimensions (150×150×850 mm), same conventional reinforcement is used in the compression zone in all beams, (2Ø8) but used different conventional reinforcement bars are placed in tension zone (2Ø8, 3Ø8, 4Ø8) as shown in Figure 4.1. The difference V_f of PP fibers are adding to beams. Also for all specimens stirrups are used consisting of 10Ø6.3 mm with cover of 15 mm, the yielding strength of Ø8 mm and the Ø6.3 mm bars were 503 MPa and 558 MPa respectively.

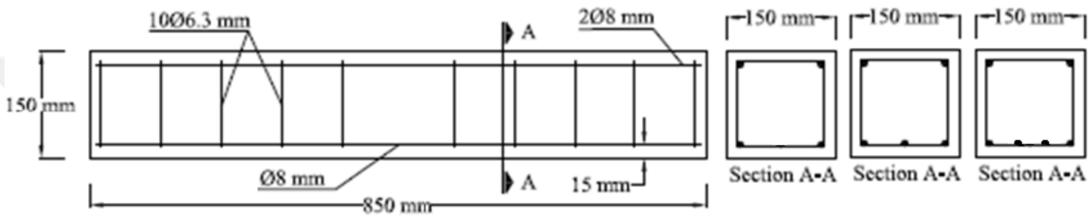

Figure 4.1 Beams geometry and reinforcement details reinforcement steel

4.3 Specimen Test Setup

In the beginning, the front face was painted for all concrete beams in white color. The face was divided into several boxes with a distance of 5 X 5 cm to help identify the starting areas of the cracks and to observe the length of those cracks, as well as to help accurately install the LVDT (Linear variable differential transformer) below the sample.

Three pieces of steel support were pasted into the bottom of the concrete beam by adhesive material. The first support was affixed in the center of the beam and the second and third were 12.5 cm from center to right and left to install the three LVDT under it. The concrete beam was placed on the machine and the supports were placed under the beam at 37.5 cm from the center on both ends of the beam. The three LVDTs were placed below the steel pieces affixed to the beams and the LVDT was installed on the test machine frame by the magnet located at the bottom it, The LVDT in the center was connected directly to the machine. The LVDTs which are located under the two sides of the beams were connected to the data recorder, Figure 4.2 shows the LVDT used in the test.

Figure 4.2 LVDT (Linear variable differential transformer)

Test machine (Instron 5590R) with a ultimate capacity of 250 kN was used as shown in Figure 4.3 shows the details of the tested sample and test machine.

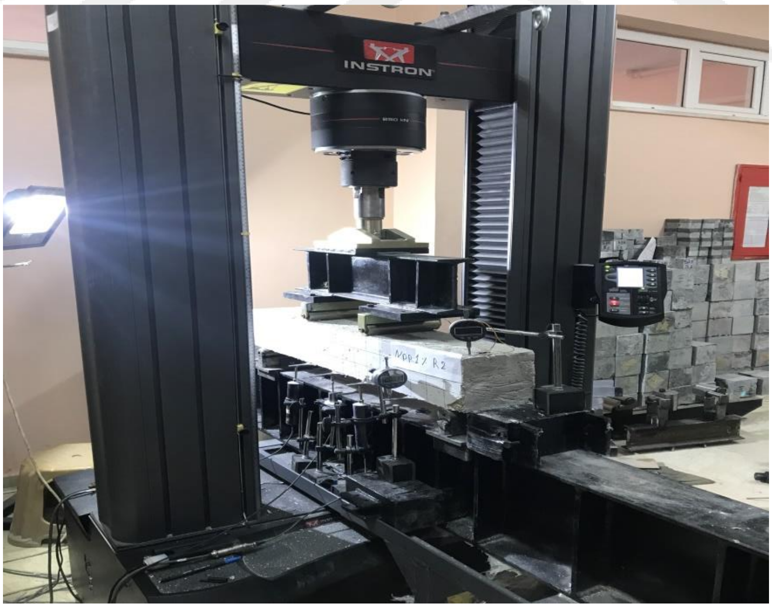

Figure 4.3 Testing machine (Instron 5590R)

The load applied in all tests was 0.4 mm/min, the initial cracking lines were marked to identify when the first crack began, and the test machine was stopped after reaching the final load where the tested model failed.

Then the test machine jack was lifted to allow to take images of the final failure patterns and cracks, then the sample was removed from the machine and the final crack lines are set as shown in Figure 4.4. After that the sample is photographed, a new sample is placed on the test machine.

Figure 4.4 Sample of marking the tested beams

4.4 Ultimate Beam Strength

4.4.1 Effect of PP fiber percentage on the ultimate beam strength

Table 4.2 summarizes the final strength of the beams divided into three groups. The results of the first group showed that the addition of PP fibers by 0.5, 1.0 and 1.5 % of concrete has improved the final strength of all samples by 4.83, 13.56, 18.20 % respectively compared to normal concrete as shown in Figure 4.5.

The addition of PP by 0.5, 1.0, 1.5 % to the second group reinforced with reinforcing steel by ρ 0.75 % has improved the final strength of the beams by 7.6, 10.95, 12.46 %, respectively as shown in Figure 4.6.

Table 4.2 Experimental ultimate beam strength results

Groups	Specimen	ρ %	PP fiber V_f (%)	Pu (kN)	Percent improvement %
Group1	Normal concrete-2R	0.5	0	70.54	Control
	0.5 PP-2R		0.5	73.95	4.83
	1.0 PP-2R		1	80.10	13.56
	1.5 PP-2R		1.5	83.37	18.20
Group2	Normal concrete-3R	0.75	0	90.75	Control
	0.5 PP-3R		0.5	97.65	7.60
	1.0 PP-3R		1	100.69	10.95
	1.5 PP-3R		1.5	102.06	12.46
Group3	Normal concrete-4R	1	0	109.9	Control
	0.5 PP-4R		0.5	107.8	-1.91
	1.0 PP-4R		1	122.6	11.56
	1.5 PP- 4R		1.5	130.85	19.06

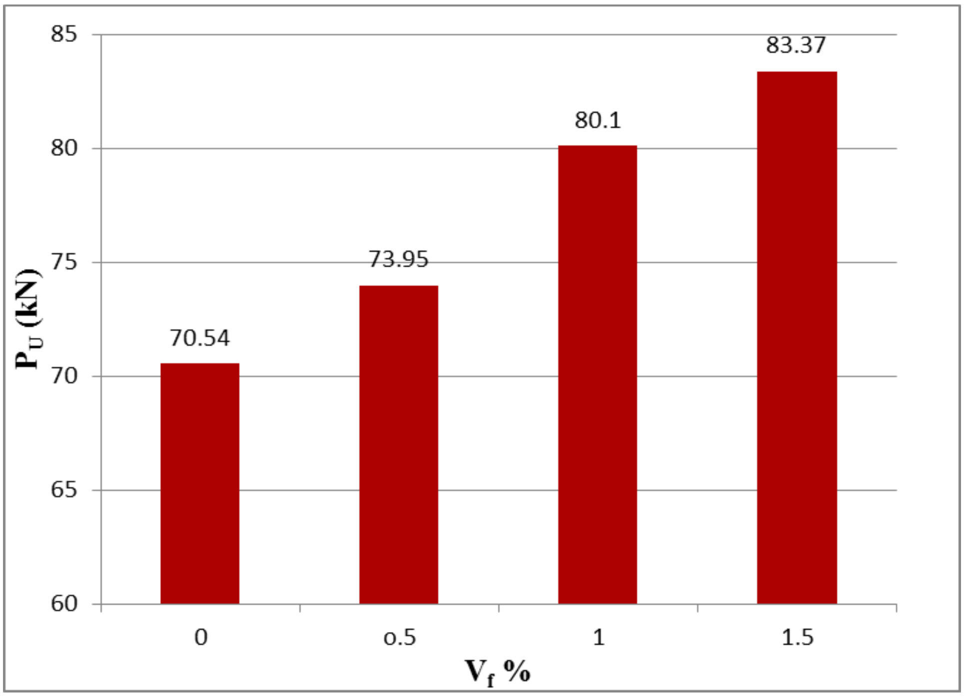

Figure 4.5 Effect of PP dosages on the ultimate beam strength (Group 1)

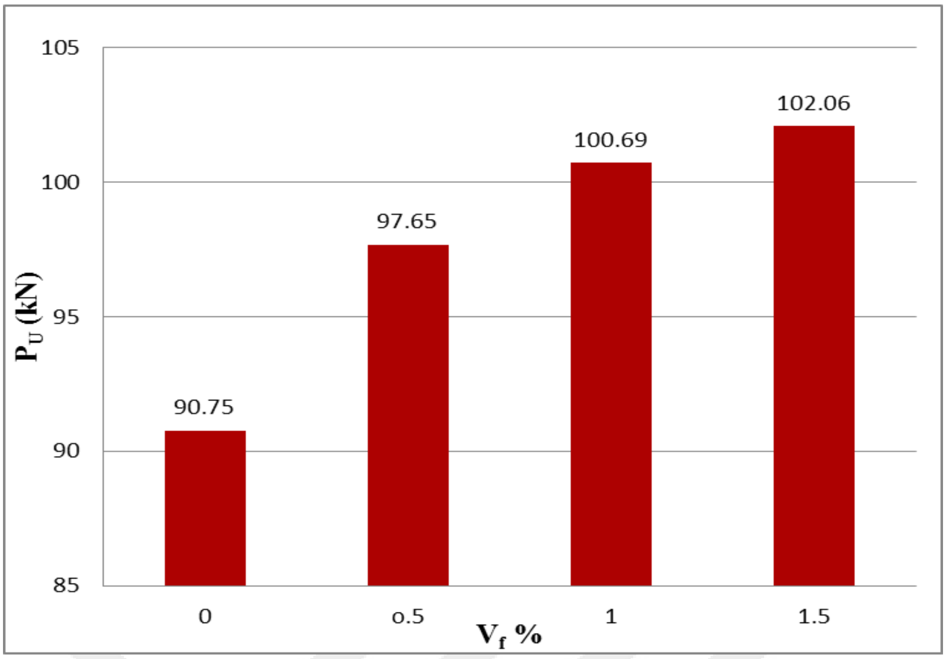

Figure 4.6 Effect of PP dosages on the ultimate beam strength (Group 2)

The third group, which was reinforced by ρ 1 %, the final strength of the beams containing PP 1 and 1.5 % was improved by 11.56 and 19.06 % respectively as shown in Figure 4.7. However, the beam containing 0.5 % PP gave a final strength less than the normal concrete, this is due to the irregular failure of the beam. It is believed that the cause of this failure is to move the steel structure of the beam from its proper place and the failure occurred at the predator instead of the middle of the beam and Figure 4.8 shows the form of failure in the beam containing 0.5 % PP.

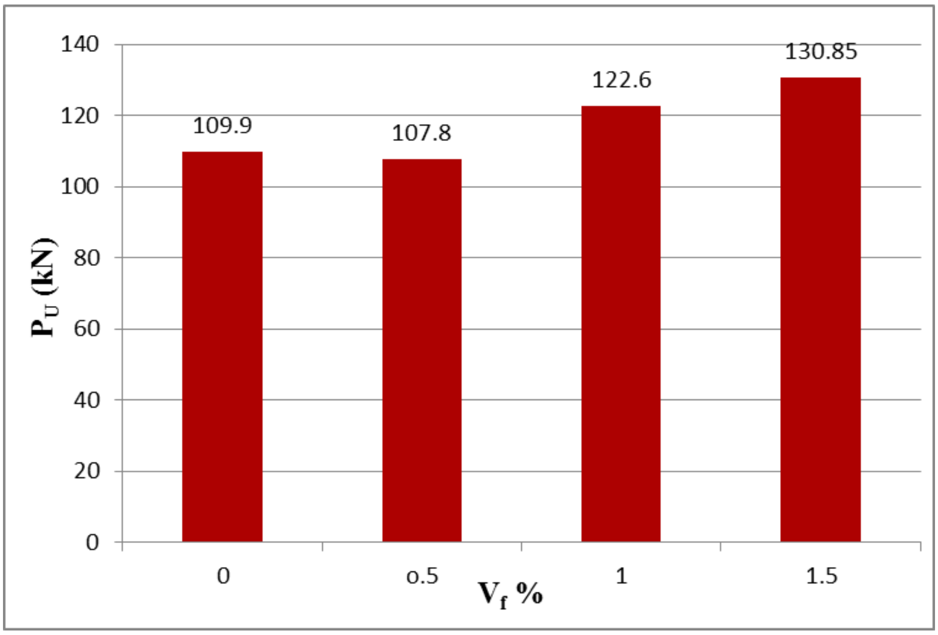

Figure 4.7 Effect of PP dosages on the ultimate beam strength (Group 3)

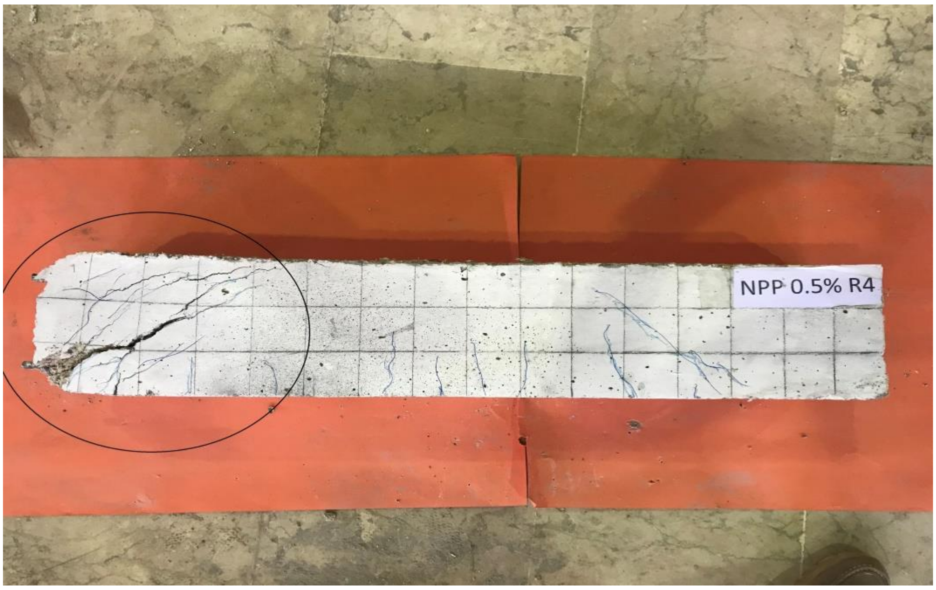

Figure 4.8 The failure in the beam containing 0.5 % of PP.

The results of the current study show that the addition of PP fiber has a good effect on the maximum load resistance of the beams. These improvements are more pronounced by increasing the volume fraction of fibers. This result is expected for PP fiber due to its obvious effect on the tensile resistance of the cylinders and the modulus of elasticity of concrete.

4.4.2 Effect of reinforcement ratio on the ultimate beam strength

When considering the effect of reinforcement ratio on concrete beams with different percentages of reinforcing steel, the final strength of the concrete beams is increased by increasing the reinforcement ratio as shown in Table 4.2.

As a comparison between normal concrete beams (V_f =0.0) with different ρ (0.5, 0.75, 1.0 %), there was an increase in the final resistance of these beams (70.54, 90.75, 109.9 %) respectively, as shown in Figure 4.9.

For concrete beams containing 0.5 % PP and reinforced by different reinforcing steel ratios (0.5, 0.75, 1.0 %), the increase in final strength was 73.95, 97.65, 107.8 respectively as shown in Fig. 4.10, the final strength of the beams containing steel reinforcement (0.75, 1.0 %) was improved by 32 % and 46 % respectively, compared to the beam reinforcing with ρ 0.5 %.

The maximum strength of the beams containing PP 1.0 % increased by 80.1, 100.69, 122.6 kN with increased steel reinforcement ratio. The improvement rate was 26 % for the beam reinforced by ρ 0.75 % and 53 % for the beam reinforcement with ρ1 % compared with the beam reinforcing with ρ 0.5 % as shown in Figure 4.11.

As well as for beams containing PP by 1.5 %, where the final strength of the reinforced beams ρ 0.75, ρ 1.0 % were improved by 23, 57 % respectively compared with the beam by ρ 0.5 % as shown in Figure 4.12.

It is clear from the above that there is a direct relationship between the reinforcement ratio of (ρ) and volume fraction of fiber (V_f) from the side and the maximum resistance to the beams, when the higher the proportion of reinforcement with iron and fiber increased maximum resistance to beams increased too, Where the beam (0.5 PP-4R) reinforced with the highest percentage of reinforcing steel (ρ 1.0 %) band the highest fiber ratio (V_f 1.5 %) was given the highest ultimate resistance (130.85 kN) compared to other beams.

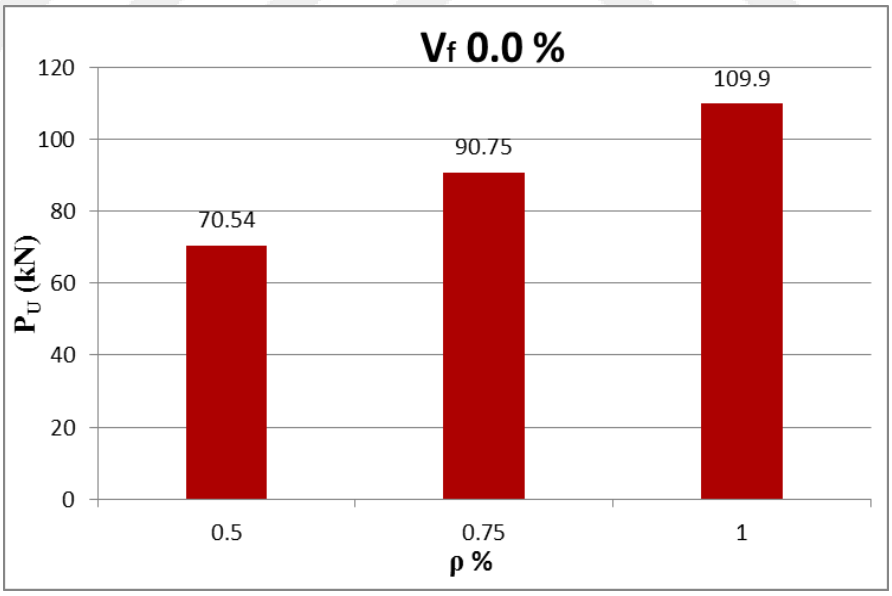

Figure 4.9 Effect of reinforcement ratio on the ultimate beam strength (V_f 0.0 %)

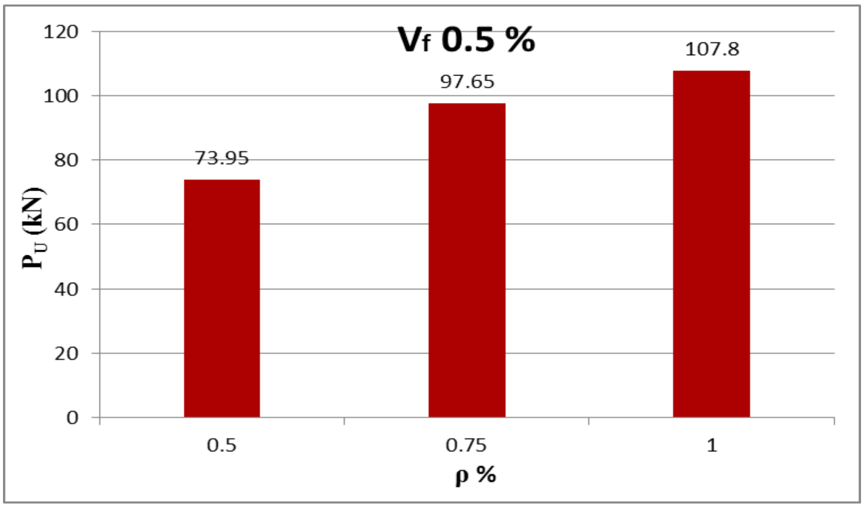

Figure 4.10 Effect of reinforcement ratio on the ultimate beam strength (V_f 0.5 %)

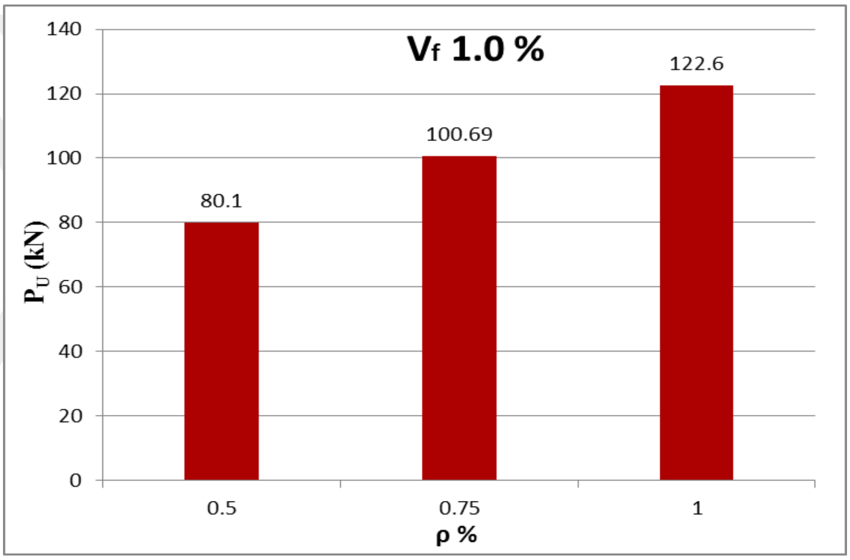

Figure 4.11 Effect of reinforcement ratio on the ultimate beam strength (V_f 1.0 %)

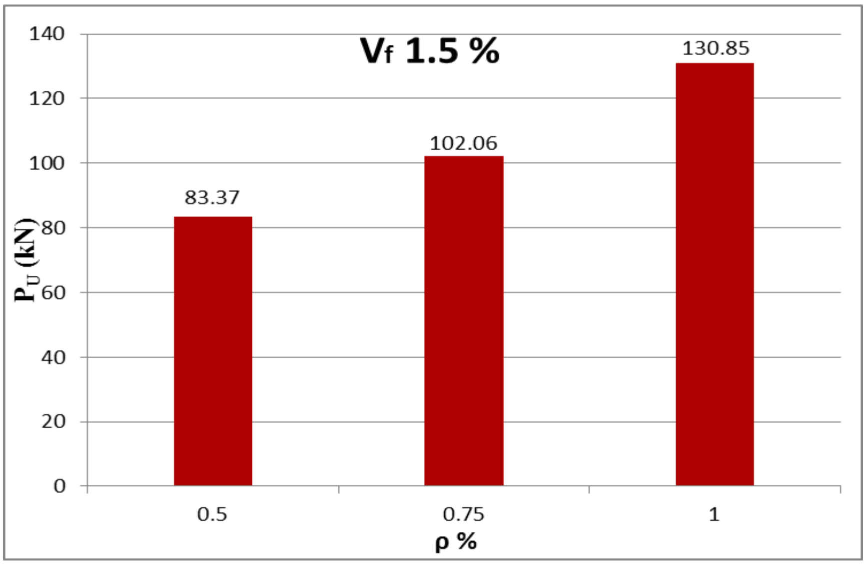

Figure 4.12 Effect of reinforcement ratio on the ultimate beam strength (V_f 1.5 %)

4.5 First crack strength

4.5.1 Effect of PP fiber percentage on the first crack beam strength

Table 4.3 summarizes the first crack strength of the beams divided into three groups. The results of the first group showed that the addition of PP fibers by 0.5, 1.0 and 1.5 % of concrete has improved the first crack strength of all samples by 43.56, 61.90, 75.40 % respectively compared to normal concrete As shown in Figure 4.13.

The second group was the improvement rate in beams containing fiber 0.5, 1.0, 1.5 % is 55.10, 59.85, 72.94 % respectively, as shown in Figure 4.14. As well as in the third group where the addition of fiber by 0.5, 1.0, 1.5 % improved the onset of initial cracking by 21.84, 64, 70 % compared to the normal concrete, as shown in Figure 4.15.

Table 4.3 Experimental first crack beam strength results

Groups	**Specimen**	**ρ %**	**PP V_f (%)**	**P_{cr} (kN)**	**Percent Improved (%)**
Group1	Normal concrete-2R	0.5	0	13.43	Control
	0.5 PP-2R		0.5	19.28	43.56
	1.0 PP-2R		1	21.74	61.90
	1.5 PP-2R		1.5	23.56	75.40
Group2	Normal concrete-3R	0.75	0	16.59	Control
	0.5 PP-3R		0.5	25.73	55.10
	1.0 PP-3R		1	26.52	59.85
	1.5 PP-3R		1.5	28.69	72.94
Group3	Normal concrete-4R	1	0	27.60	Control
	0.5 PP-4R		0.5	33.63	21.84
	1.0 PP-4R		1	45.26	64.00
	1.5 PP- 4R		1.5	46.92	70.00

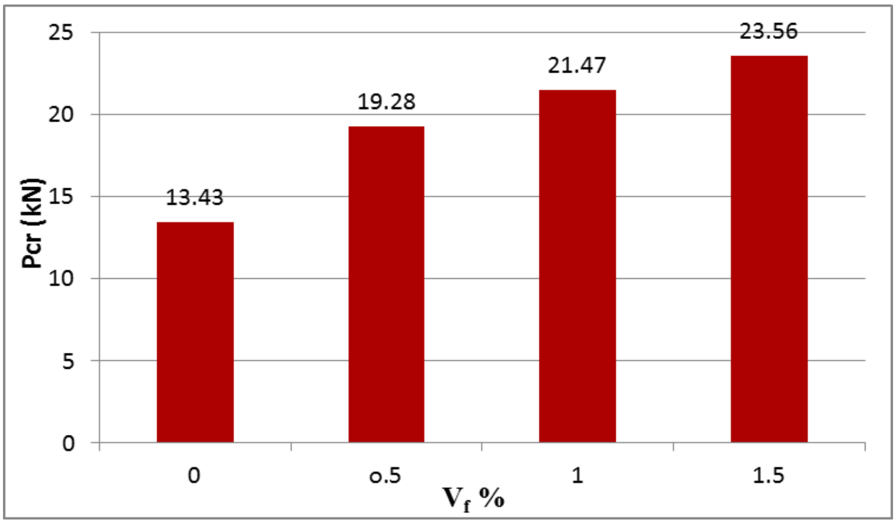

Figure 4.13 The effect of PP dosages on first crack beam strength (Group 1)

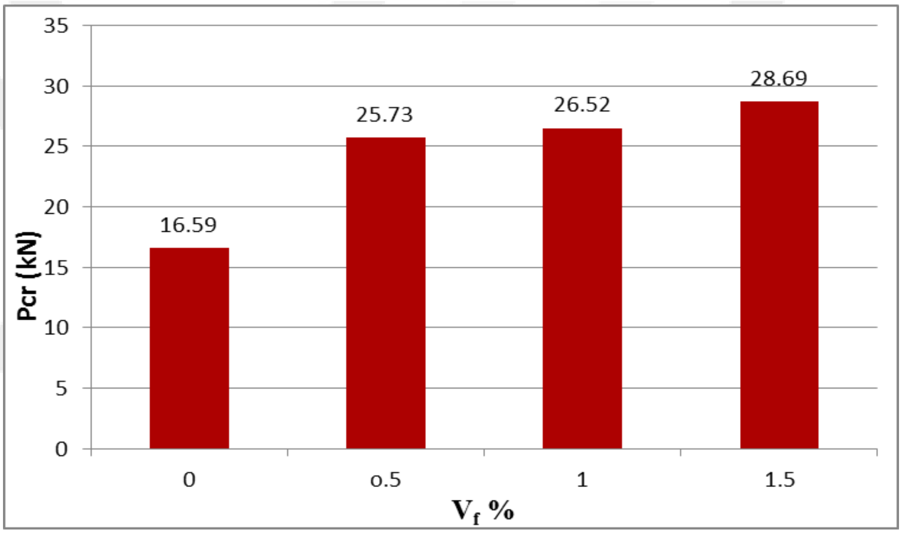

Figure 4.14 Effect of PP dosages on the first crack beam strength (Group 2)

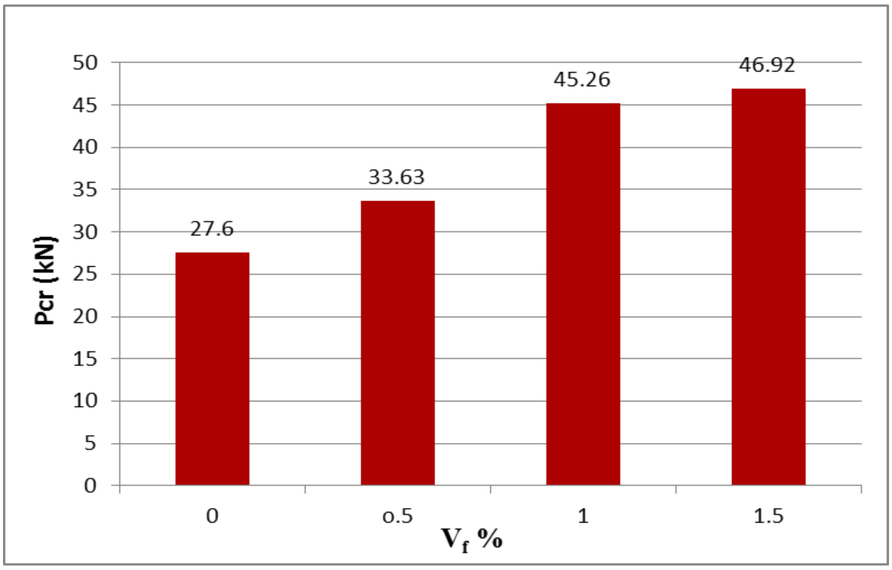

Figure 4.15 Effect of PP dosages on the first crack beam strength (Group 3)

The above results indicate that increasing the volume ratios of PP fibers greatly improve the resistance of the first crack compared to the ordinary concrete because the fiber works to connect the concrete parts together and make them more cohesive. In addition to making the beams more elongated, thus reducing the appearance of cracks in the early tensile area.

4.5.2 Effect of reinforcement ratio on the first crack

Table 4.3 clearly indicates that the increase in the reinforcement iron ratio reinforced the beam resistance of the initial cracking point for the normal concrete beams. The beams containing the ρ by 0.75 and 1.0 % increased the initial crack resistance by 24 % and 105 %, respectively shown in Figure 4.16.

For the beams contain PP 0.5 % and reinforced with ρ 0.75 and 1 % increased the first crack strength 33 % and 75 % respectively, compared with beam reinforced by ρ 0.5 % as shown in Figure 4.17.

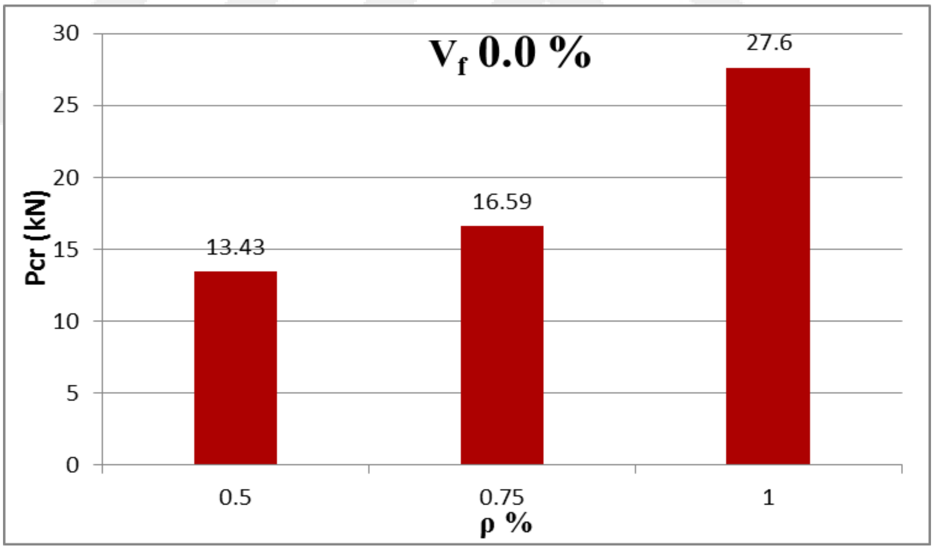

Figure 4.16 Effect of reinforcement ratio on the first crack beam strength (V_f 0 %)

For the beams contain PP 1.0 % and reinforced with ρ 0.75 ,1 % increased the first crack strength 23 % and 108 % respectively, compared with beam reinforced by ρ 0.5 % as shown in Figure 4.18.

For the beams contain PP 1.5 % and reinforced with ρ 0.75 and 1 % increased the first crack strength 22 and 99 % respectively, compared with beam reinforced by ρ 0.5 % as shown in Figure 4.19.

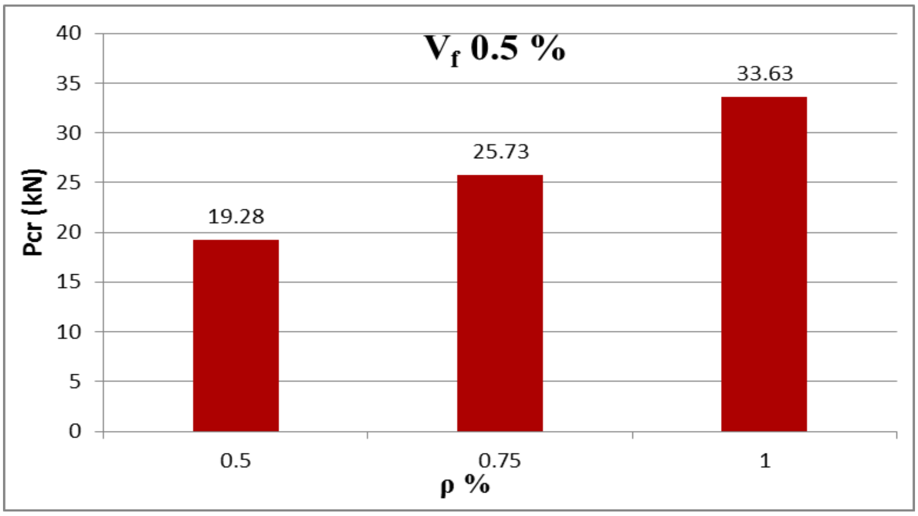

Figure 4.17 Effect of reinforcement ratio on the first crack beam strength (V_f 0.5 %)

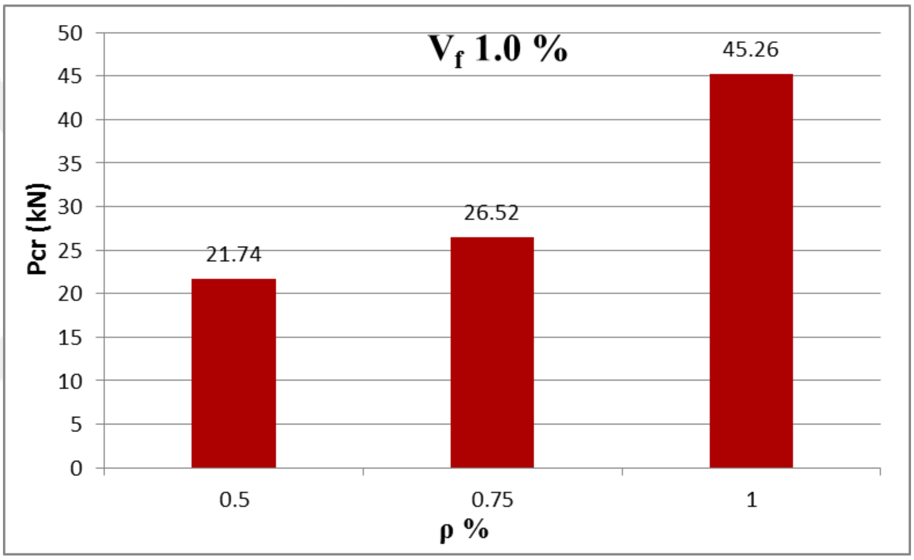

Figure 4.18 Effect of reinforcement ratio on the first crack beam strength (V_f 1.0 %)

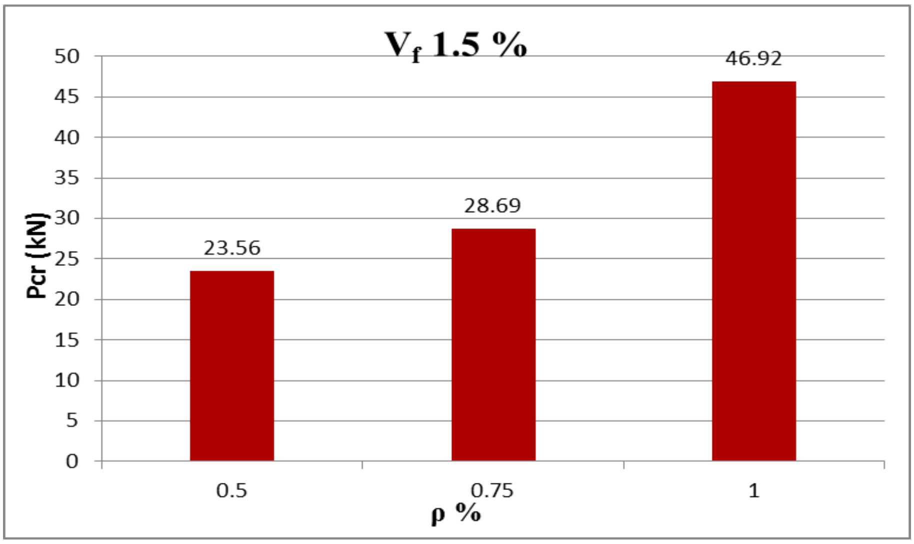

Figure 4.19 Effect of reinforcement ratio on the first crack beam strength (V_f 1.5 %)

4.6 Load-Deflection Behavior

The data load-deflection behavior is collected from LVDT attached to the beam at mid-span of bottom side Table 4.4 shows the mid span deflection of the tested beams at the different load levels with the addition of variable percentages of PP and the ratio of reinforcing steel.

Table 4.4 Experimental results of the load - deflection curve

	First crack		Yield		Ultimate				
Spec.	P_{cr} **(kN)**	δ_{cr} **(mm)**	P_y **(kN)**	δ_y **(mm)**	P_u **(kN)**	δ_u **(mm)**	$\frac{P_{cr}}{P_u}$	$\mu\frac{\delta u}{\delta y}$	$\frac{\mu\, fiber}{\mu\, normal}$
Group 2, ρ 0.5 %									
0 PP	13.43	2.23	51.48	6.83	70.54	13.55	0.19	1.98	1
0.5PP	19.28	2.03	52.99	3.85	73.95	9.16	0.26	2.38	1.20
1.0PP	21.74	1.90	60.34	4.03	80.10	10.15	0.27	2.52	1.27
1.5PP	23.56	1.79	56.30	3.81	83.37	11.52	0.28	3.02	1.53
Group3, ρ 0.75 %									
0PP	16.59	1.19	78.77	5.36	90.75	9.20	0.13	1.71	1
0.5PP	25.73	2.01	82.62	4.68	97.65	10.27	0.26	2.19	1.28
1.0PP	26.52	2.31	87.78	4.88	100.69	11.26	0.26	2.31	1.35
1.5PP	28.69	2.29	85.35	4.43	102.06	11.02	0.28	2.48	1.45
Group 4, ρ 1 %									
0PP	27.60	2.51	99.12	5.93	109.9	7.91	0.25	1.33	1
0.5PP	33.63	2.31	85.7	4.02	107.8	5.43	0.31	1.35	1.02
1.0PP	45.26	2.78	111.93	5.26	122.6	9.37	0.36	1.78	1.33
1.5PP	46.92	2.86	115.42	5.19	130.85	9.87	0.36	1.90	1.42

The results of deflection of the samples reinforced with ρ 0.5 % and with different percentages of PP can be observed from Table 4.4 and Figure 4.20. The results indicate that the increase in fiber ratios leads to a decrease in the deflection values in the first crack load. The slope of the curve was slightly changed after the first crack.

As the load increases, the deflection also increases linearly until yield load where the deflection in beams with PP was decreased compared with beam without PP, after yield load the deflection was non-linear until ultimate load.

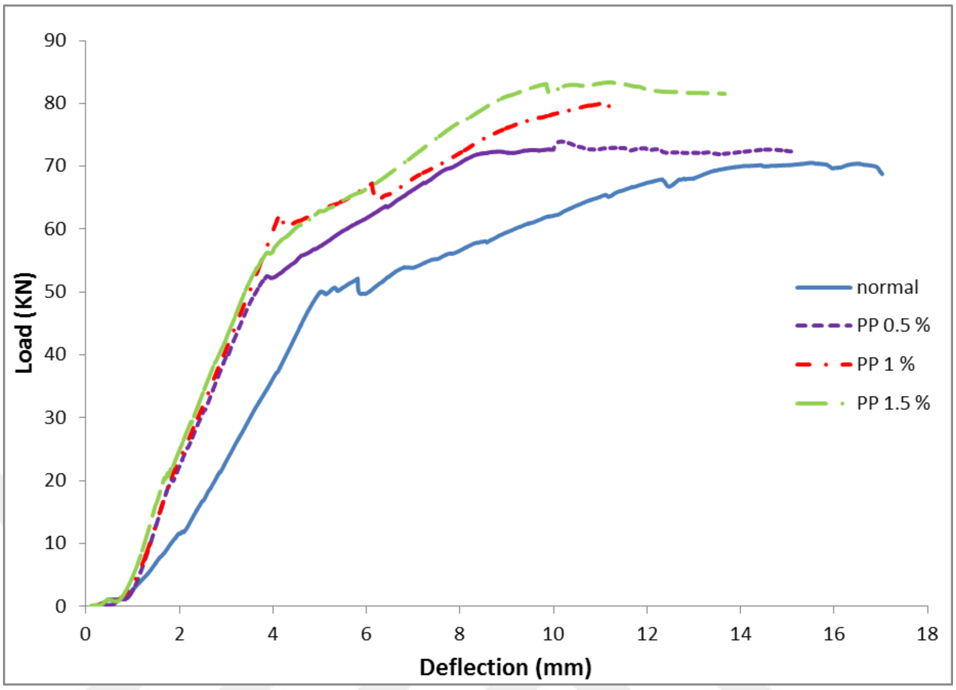

Figure 4.20 Effect of PP on load deflection curve(Group 1)

As shown in Table 4.4 and Figure 4.21 the load deflection curve starts similarly and linearly in all specimens in group 2 reinforced with(ρ 0.75 %) until the yield load where the deflection in beams reinforced with PP was decreased compared with the normal concrete beam at this point, after that the deflection curve were becoming non- linearly until the ultimate load.

For Group 3 reinforced with (ρ 1 %), the deflection results can be seen in Table 4.4 and Figure 4.22 indicates that when the increasing the PP fiber dosages causes slightly lower deflection values compared with the normal concrete beam in the yield load point, after the yield zone, the shape of the deflection is nonlinear and continues until the maximum load.

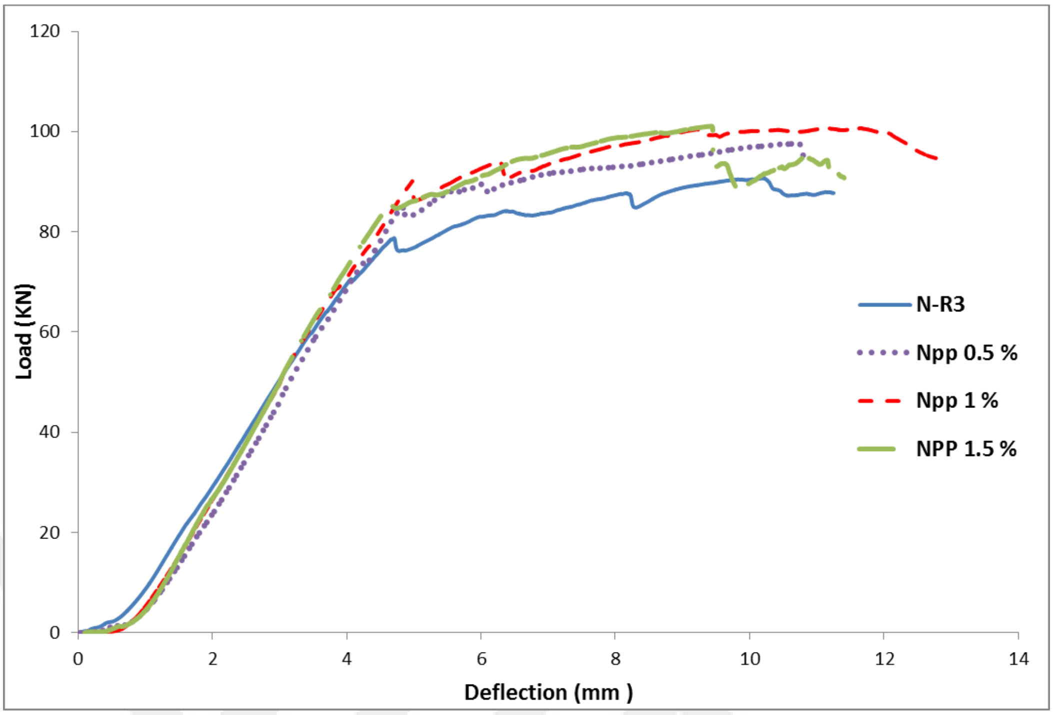

Figure 4.21 Effect of PP on the load deflection curve (Group 2)

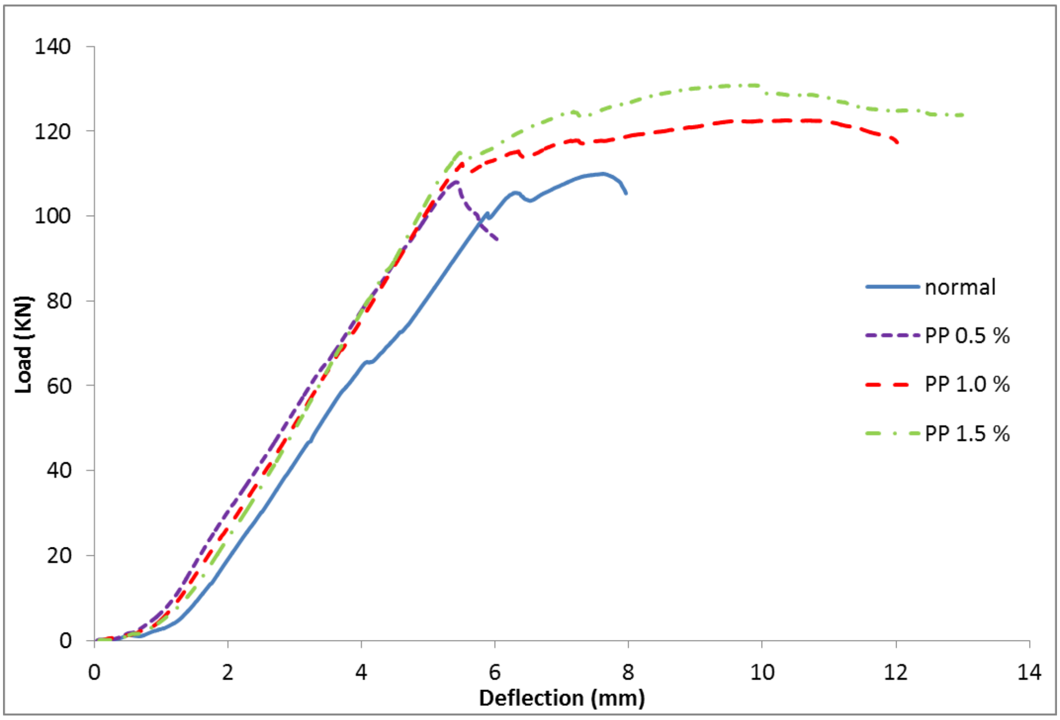

Figure 4.22 Effect of PP on the load deflection curve (Group 3)

4.7 Ductility of PP-FRC Beams

Concrete is a brittle material (fail suddenly), the matter of ductility becomes a great concern. Unless ductility requirements are satisfied, FRP materials can be used to test the effects on ductility in structural engineering applications. The term ductility describes the ability of a member to undergo large deformation without rupture as a failure occurs. Ductile structures may bend and deform excessively under load, but they remain, in general intact. This capability prevents total structural collapse and provides safety to occupants of the structure. PP and Steel reinforced concrete elements in flexure are ductile because their energy absorption are due to the capacity of the fiber and steel to deform. Ductility factors are indices to express deformation capacity and consequently show the energy absorption.

In this section, study of the ductility comparisons of beams are made with normal concrete. The main variables in these comparisons are the percentage of PP fibers and reinforcement ratio of the steel. The ductility factor (μ) defined herein, as the ratio of the ultimate deformation (δ_u) to the yield deformation (δ_y), where the ultimate deformation is that the deformation corresponding to the maximum resistance load, and the yield deformation is that the displacement corresponding to the yield load. Figure 4.23 demonstrates the evolution of ductility factor (μ) considered in current work.

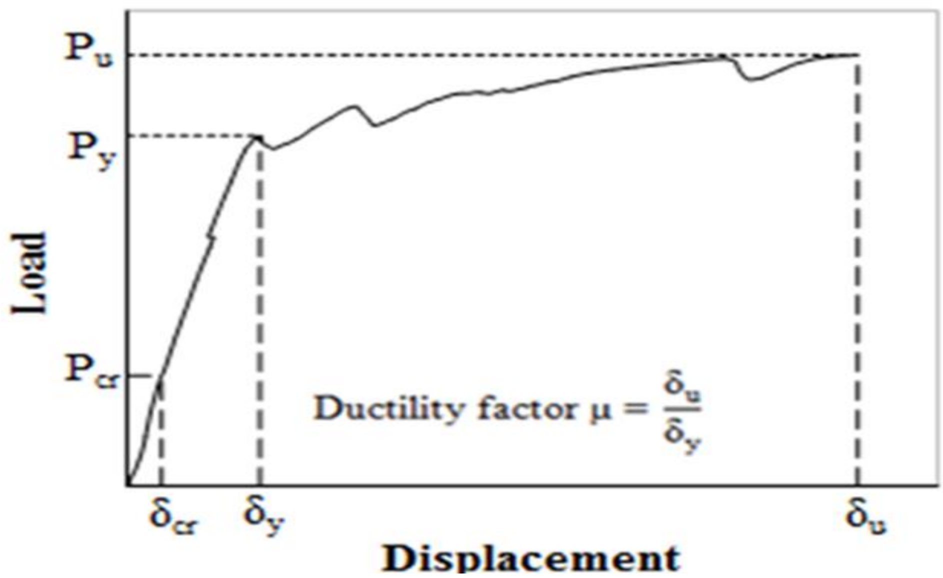

Figure 2.23 Definition of the ductility factor (μ) of the beams

4.7.1 Effect of PP fiber percentage on the ductility

The ductility of beams are presented in Table 4.4. According to Figure 4.24 these results show that the more ductile behavior is found in beams with PP fibers compared with normal concrete beam, so the increased of the volume fraction is given a better ductility, where 0.5 % of PP increases the ductility by 20 %, duplicating the volume of PP is not significantly altered of ductility 27 % compared to 0.5 % V_f. While the addition of 1.5 % improved the ductility significantly 53 % compared to normal concrete.

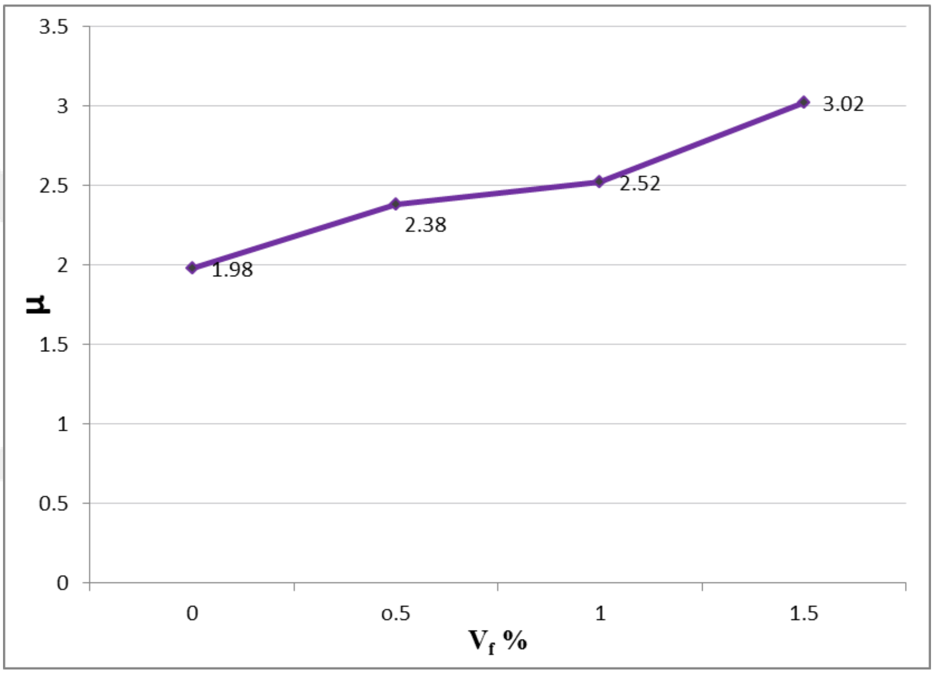

Figure 4.24 Effect of PP on the ductility factor (μ) (ρ 0.5 %)

For group 2 all beams with PP (0.5, 1.0 ,1.5 %) had improved the ductility indices by (28, 35, 45 %) respectively compared with beam without PP fiber as shown in Figure 4.25.

For Group 3 as shown Figure 4.26 indicates that the increasing of the PP fiber dosages causes increased the ductility factor compared with the normal concrete beam.

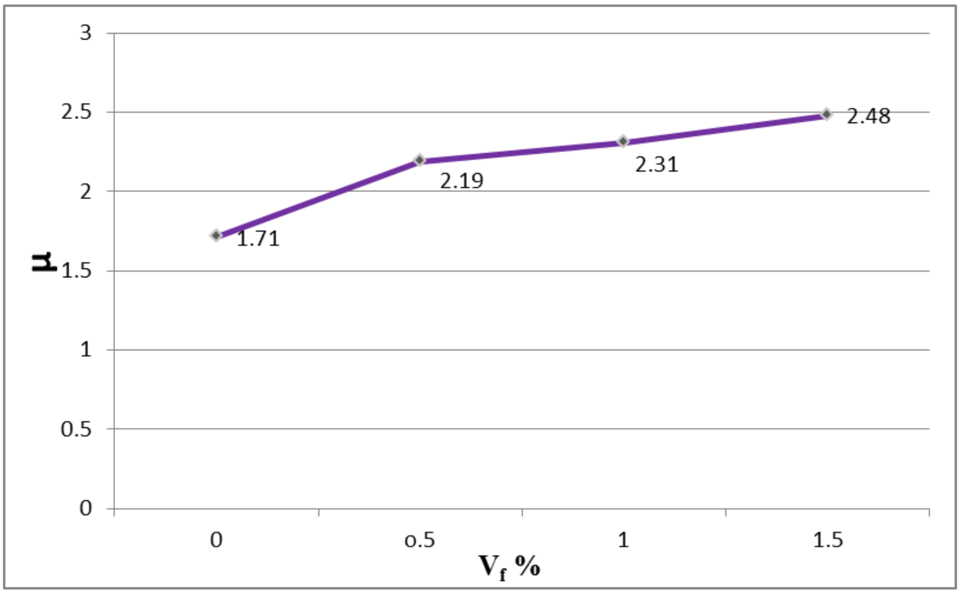

Figure 4.25 Effect of PP on the ductility factor (μ) (ρ 0.75 %)

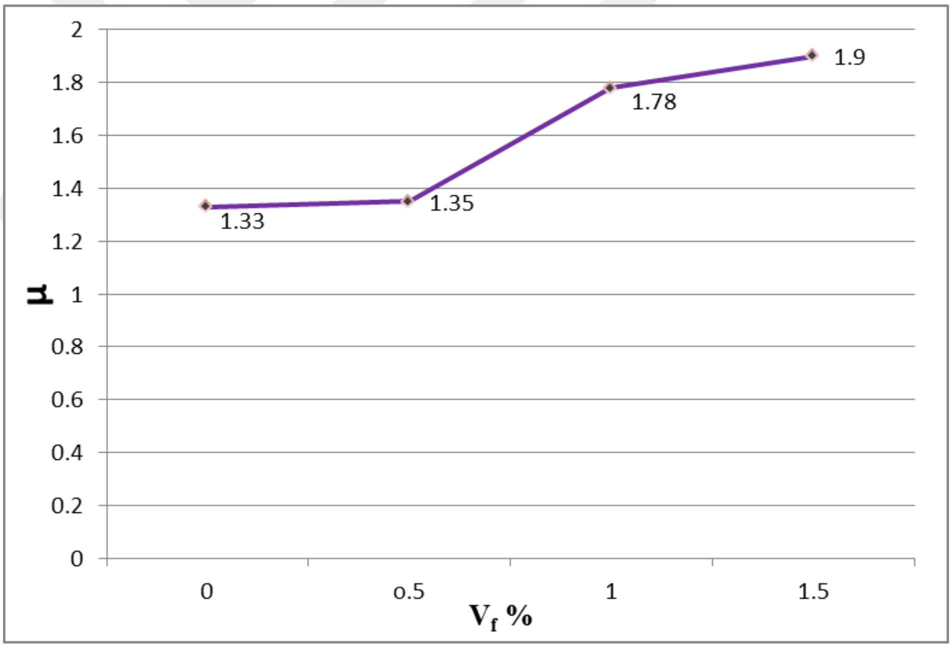

Figure 4.26 Effect of PP on the ductility factor (μ) (ρ 1.0 %)

4.7.2 Effect of reinforcement ratio on the ductility

The effect of the reinforcement ratio on ductility is shown in Table 4.4. This table shows that the most brittle behavior is found in the beams reinforced with four steel rebars in the tension zone which corresponds to ρ = 1.0 %. All ductility indices values show that for a higher reinforcement ratio this ratio reduces.

This result conforms to (Iffat et, al 2011) results, which proved that the Beams with steel ratio 0.009 and 0.007 had ductility ratio more than 4, but the beam with steel ratio 0.0128 had ductility ratio less than 4. As showed in Figure 4.28.

In normal concrete beams reinforced by different strengthening steel ratios (0.5, 0.75, 1.0 %), the ductility was 1.98, 1.71, 1.33 respectively as shown in Figure 4.28, the ductility of the beams reinforced by ρ (0.75, 1.0 %) was decreased the ductility factor by 16 % and 49 % respectively, compared to the beam reinforcing with ρ 0.5 %.

For the beams contain PP 0.5 % and reinforced with ρ 0.75 and 1.0 % decreased the ductility factor 9 and 76 % respectively, compared with beam reinforced by ρ 0.5 % as shown in Figure 4.29.

As well as for beams containing PP by 1.0 %, the ductility of the beams reinforced by ρ 0.75 and 1.0 % were decreased by 9, 42 % respectively compared with the beam reinforced by ρ 0.5 % as shown in Figure 4.30. Also the beams reinforced with PP 1.5 % give lower ductility when increased the steel reinforcement as shown in Figure 4.30.

The most ductile behavior is found in beams reinforced with (2R). This behavior is in agreement with the expected results for steel reinforced beams in which the highest reinforcement ratio would lead to the lower ductile behavior.

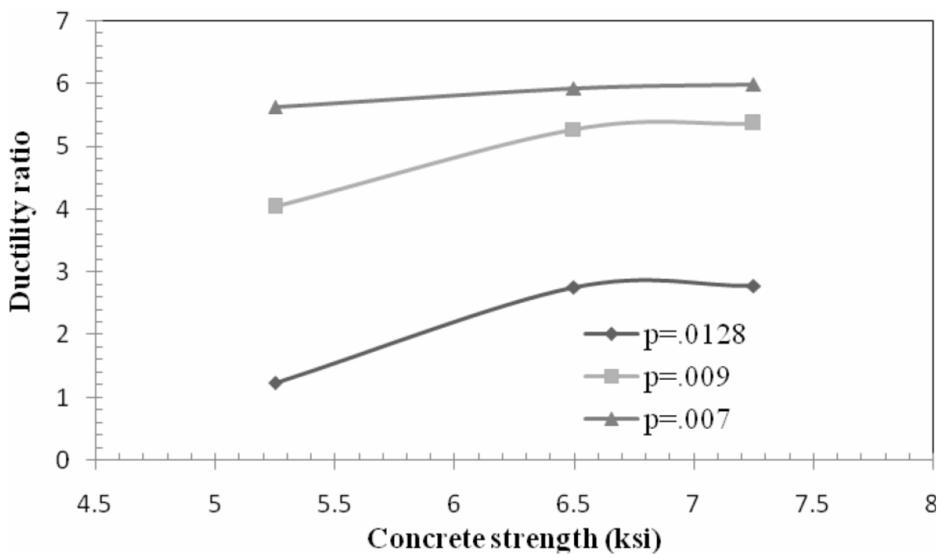

Figure 4.27 Change in concrete strength with ductility ratio by (Iffat et, al 2011)

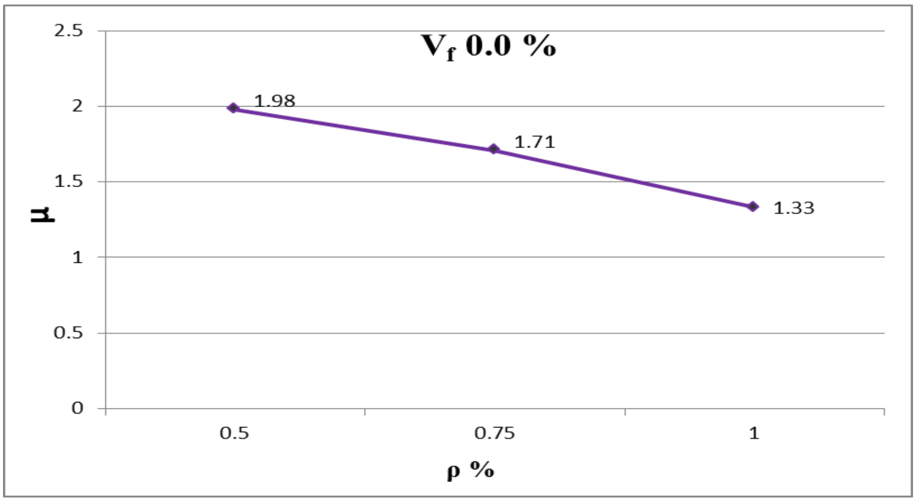

Figure 4.28 Effect of reinforcement ratio on the ductility (V_f 0.0 %)

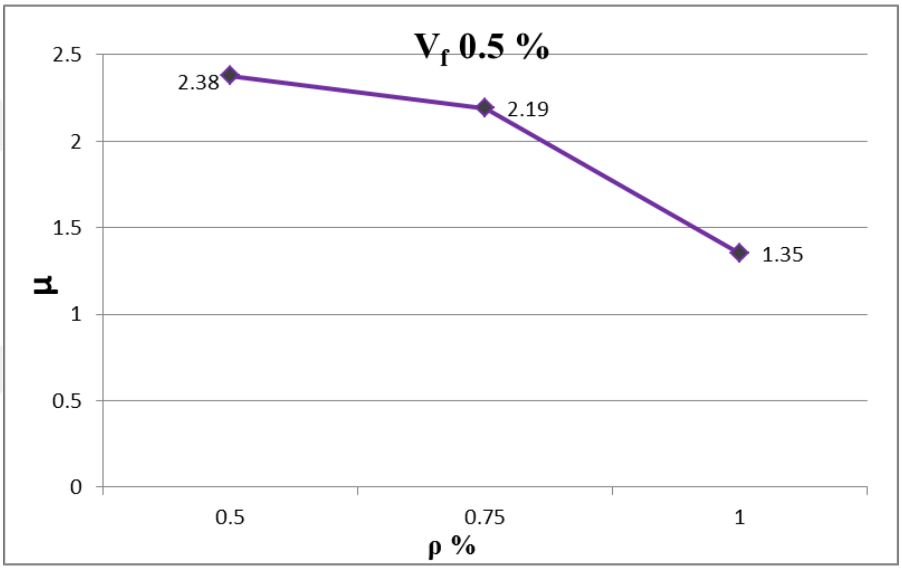

Figure 4.29 Effect of reinforcement ratio on the ductility (V_f 0.5 %)

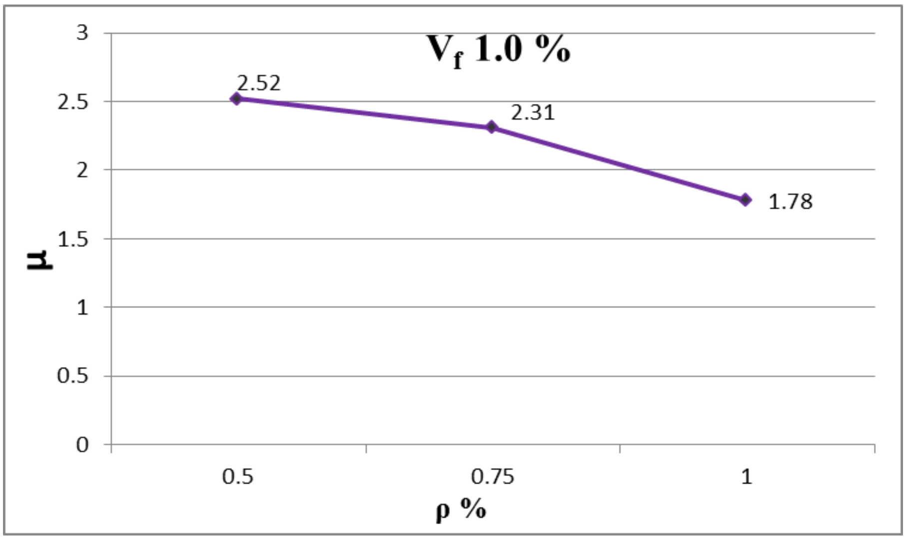

Figure 4.30 Effect of reinforcement ratio on the ductility (V_f 1.0 %)

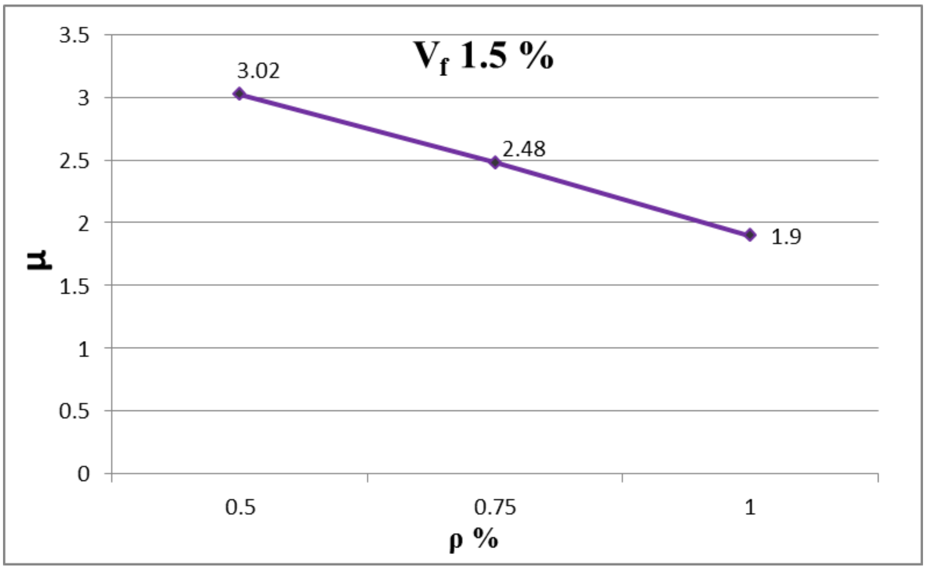

Figure 4.31 Effect of reinforcement ratio on the ductility (V_f 1.5 %)

4.8 Failure Patterns

All the beams were tested based on 4-points flexural test, the load is applied beyond the maximum resistance load and continued until the specimen fail. The camera is programmed to take a picture every 5 minutes. As it appears from the taken pictures, the load required to initiate first crack in the compression zone (area between the applied load rollers) is given in Table 4.5. It shows that the addition of PP is not just improved the ultimate load resistance, but also increasing the load required to initiate the cracks at the compression zone (top edge of the beam). Also from test results, it was observed that all of the beams developed a number of cracks. However, the number of crack that was developed in the PP fiber-reinforced specimens, was more than normal concrete specimens. This phenomenon indicates a better behavior in stress redistribution, which leads to reducing the stress on compression zones. The shear cracks on normal concrete beam are extended from the support up to the load points, while inclusion the fibers are decreasing the shear effect, this can be recognized from the uncompleted shear cracks in beams of PP-FRC (Figure 4.31).

Table 4.5 Initiation and shape of first crack at compression zone

Groups	Specimens	Load to initiate first compression crack (kN)	Crack distance from upper edge (mm)
Group 1	Normal concrete-2R	64.35	47
	0.5 PP-2R	66.13	25
	1.0 PP-2R	71.25	23
	1.5 PP-2R	75.72	18
Group 2	Normal concrete-3R	87.34	45
	0.5 PP-3R	88.45	30
	1.0 PP-3R	91.21	19
	1.5 PP-3R	96.47	12
Group 3	Normal concrete-4R	100.40	38
	0.5 PP-4R	98.73	12
	1.0 PP-4R	103.24	40
	1.5 PP- 4R	106.14	50

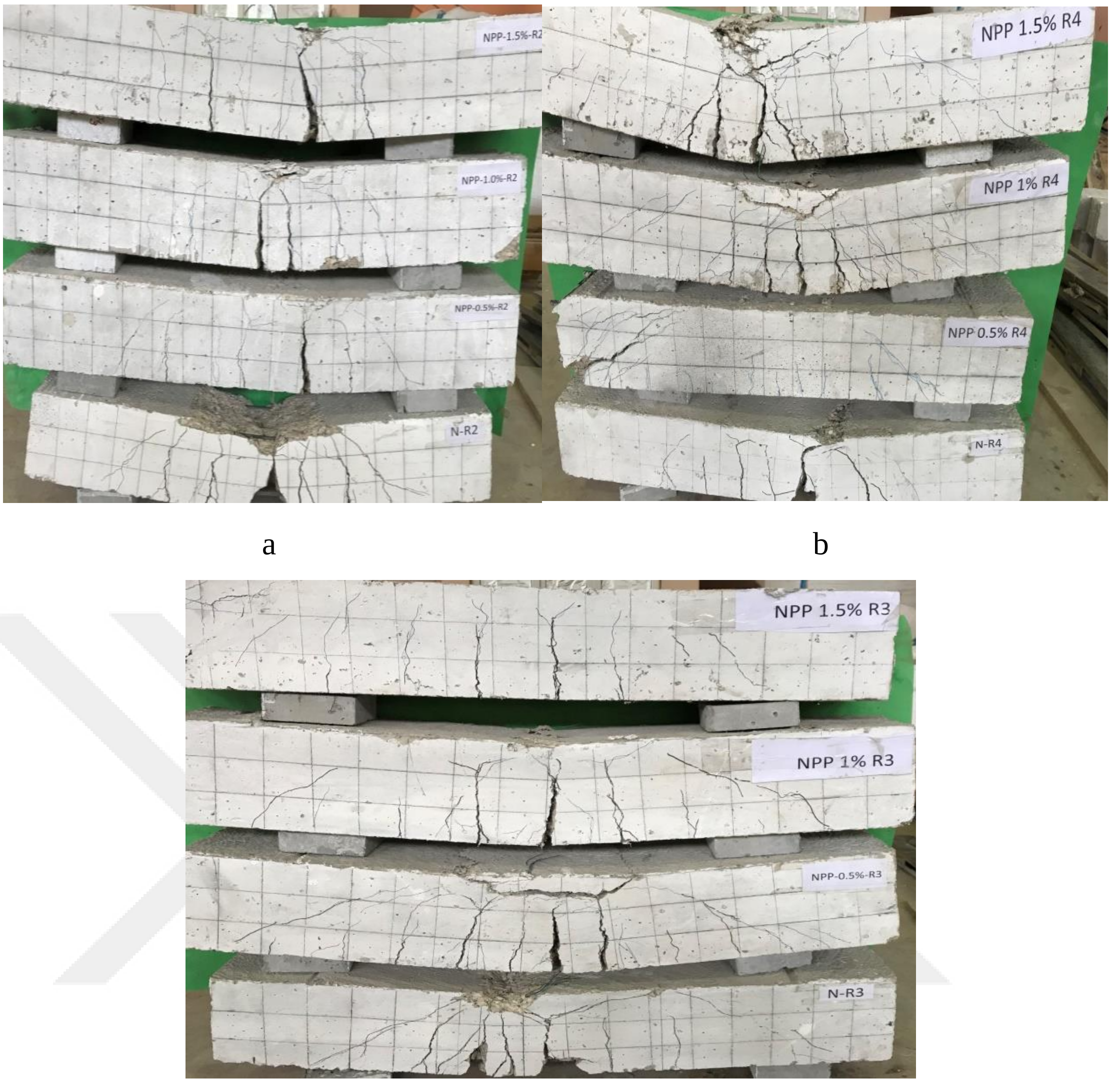

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Figure 4.32 Crack patterns of the tested beams with different reinforcement ratio (a.2R, b.4R, c.3R)

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

In this chapter, the most important conclusions will be presented through the practical study conducted in addition to proposals that could be adopted in subsequent studies.

5.1 Conclusions

The following conclusions are obtained from analysis results of PP fiber reinforced beams of current work:

1. By increasing the V_f % of PP fiber in concrete, the workability of concrete reduces. Where concrete mix containing 1.5 % of PP fiber makes the concrete like a solid block and shows the difficulties on the compaction process.
2. PP fiber has a great influence on improving the mechanical properties of concrete such as compressive strength, splitting tensile strength, modulus of elasticity.
3. PP fiber in concrete made by more fine aggregate percentages are increasing the load required to initiate the first crack.
4. The addition of PP fiber to the normal concrete significantly improves the maximum load value. When adding 1.5 % PP, the maximum load of the beam reinforced by ρ 0.5, 0.75 and 1.0 % increased by 18.20, 12.64 and 19.06 % respectively.
5. The results showed that increasing the percentage of reinforcement steel has delayed the initiations of first crack in the tension zone. Where the first cracks in the beam enhanced by ρ 1.0 % appeared at 27.6 kN while appeared in the beam enhanced by ρ 0.5 % at 13.43 kN.
6. Increasing the percentage of steel reinforcement improved the maximum load resistance, where the maximum resistance of beam reinforcement by ρ 1.0 % was 130.85 kN while it was 70.54 kN in the beams reinforced by ρ 0.5 %.

7. The results indicate that the increase in fiber ratios leads to a decrease in the deflection values in the first crack load, yield point and ultimate load compred with normal concrete.
8. Results show that the more ductile behavior is found in beams with PP fibers compared with normal concrete beam, so the increased of the volume fraction is given a better ductility. Where the ductility in beam 1.5 PP-2R has improved by 53 %.
9. Results showed that increased steel reinforcement ratio reduces the ductility of beams, where the ductility less by 48 % in beams with ρ 1.0 % compared for beam with ρ 0.5 %.
10. Compression resistance is increased with increasing the volume fraction of fiber, additionally the compression cracks failure also varying in its shape and distance from the upper edge.

5.2 Recommendations

1. Add higher amounts of fiber percentages and study their effect on the compression strength, tensile strength, ultimate strength and ductility of concrete.
2. Study the effect of using different lengths of PP fiber in beams and compare results as well as study the effect of heat on them.
3. Study the structural behavior of different construction members (walls, columns, composite thresholds) and these thresholds with different sections or container hallow within the section and the effect of adding fibers to it with same or different volume from the current study.
4. Study the addition of PP fibers in the tension zone only with different layers and the effect of fiber on the mechanical behavior of the thresholds.

REFERENCES

Ahmed, S. B. (2006). A study on properties of polypropylene fiber reinforced concrete. In 31st Conference on Our world in Concrete and Structure, 1-11.

Alhozaimy. (1996). Mechanical Properties of Polypropylene Fiber Reinforced Concrete and the effect of Pozzolanic Materials. Cement & Concrete Composites.

Aryan, A. (2014). Polipropilen lif takviyeli betonarme kirişlerin deneysel ve analitik olarak araştırılması. (Doctoral dissertation, Selçuk Üniversitesi Fen Bilimleri Enstitüsü).

Balaguru, P. a. (1992). Fiber-Reinforced Cement Composites. New York: McGraw-Hill Inc.

Banthia, N. M. (2008). Toughness Characterization of Fibre-Reinforced Concrete: Which Standard to Use . *Testing and Evaluation,* ***32*****(2)**, 1-5.

Bedi, M. K. (2014). Experimental study for flexure strength on polypropylene fiber reinforced concrete. *Journal of Mechanical and Civil Engineering (IOSR-JMCE)* .

Bentur, A. a. (2006). Fibre reinforced cementitious composites. CRC Press.

C39, A. (1997). Standard test method for compressive strength of cylindrical concrete specimens. Annual book of ASTM standards.

C469, A. (2002). Standard test method for static modulus of elasticity and Poisson’s ratio of concrete in compression. Annual book of ASTM standards, 4.

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

Duthinh, D., & Starnes, M. (2001). Strength and ductility of concrete beams reinforced with carbon FRP and steel. Maryland.: US Department of Commerce.

Fischer, G. (2004). Characterization of fiber-reinforced cement composites by their tensile stressstrain behavior and quantification of crack formation. 6th RILEM Symposium on Fiber-Reinforced Concretes (FRC) - BEFIB .

Grace, N., Soliman, A., & Abdel-Sayed, G. (1998). Behavior and ductility of simple and continuous FRP reinforced beams. *Journal of Composites for Construction*, ***4*****(2)**, 186-194.

Hannant, D. J. (2000). Cement-based composites. UK: University of Surrey-Gildford.

Iffat, S., Maina, K., & Noor, M. (2011). Member ductility experiment with high strength steel and concrete. In 4th Annual Paper Meet & 1st Civil Engineering Congress of IEB, 244-250.

Kolli.Ramujee. (2013). Strength properties of polypropylene fiber reinforced concrete. *International Journal of Innovative Research in Science, Engineering and Technology* .

Krenchel, H. (1974). Fiber Reinforced Brittle Matrix Materials, In Fiber Reinforced Concrete. *American Concrete Institute*, 45-68.

Kwak, Y. E. (2002). Shear strength of steel fiber-reinforced concrete beams without stirrups. *ACI Structural Journal*, ***99*****(4)**, 530-538.

Löfgren, I. (2005). Fibre-reinforced concrete for industrial construction. Göteborg: Chalmers.

Mehta, P. K. (2006). Concrete: microstructure, properties, and materials. McGraw-Hill Publishing.

Naaman, A., Harajli, M., & Wight, J. (1986). Analysis of Ductility in Partially Prestressed Concrete Flexural Members. *PCI Journal*, ***31*****(3)**, 64-87.

park, J., & al, e. (2009). Evaluation of Behavior and Ductility of Reinforced Concrete Beams Strengthened With AFRP. *Journal of the Korea institute for structural maintenance and inspection*.

Park, R. (1988). Ductility evaluation from laboratory and analytical testing. In Proceedings of the 9th world conference on earthquake engineering, **8**, 605-616. Tokyo-Kyoto, Japan.

Soroushian, P. K. (1992). Mechanical Properties of Concrete Materials Reinforced with Polypropylene or Polyethylene Fibers. *ACI Materials Journal*, ***89*****(6)**, 535-540.

Sutheesh, S. (2016). Behaviour of Polypropylene Fibrillated Fibre Reinforced Concrete (PFFRC). *International Journal of Science and Engineering Research (IJ0SER)*.

Tan, K. (1994). Punching shear strength of steel fiber reinforced concrete slabs. *Journal of Materials in Civil Engineering*, **6(2)**, 240-253.

Tepfers, R. (2010). Fiber-reinforced concretes with a high fiber volume fraction—a look in future. *Mechanics of Composite Materials*, ***46*****(3)**, 323-330.

Vikrant S. Vairagade*, K. S. (2012). Investigation on Compressive and Tensile Behavior of Fibrillated Polypropylene Fibers Reinforced Concrete . *Vikrant S. Vairagade, Kavita S. Kene, Dr. N. V. Deshpande / International Journal of Engineering Research and APPlications (IJERA)* .

Vikrant S. Vairagade, K. S. (2012). Investigation on Compressive and Tensile Behavior of Fibrillated Polypropylene Fibers Reinforced Concrete . *International Journal of Engineering Research and APPlications (IJERA).*

Wang, H., & Belarbi, A. (2005). Flexural behavior of fiber-reinforced-concrete beams reinforced with FRP rebars. *In 7th International Symposium on Fiber-Reinforced (FRP) Polymer Reinforcement for Concrete Structures*, ***230***, 895-914.

Yadav, A. K. (2017). Properties of Polypropylene Fiber Reinforced Concrete and Structural Behaviour of Beam. *International Journal of Innovative Research in Science, Engineering and Technology*.