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# FLEXURAL BEHAVIOR OF FIBROUS RC ONE WAY SLABS INCORPORATING PET WASTE AS SUSTAINABLE SAND REPLACEMENT

By

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# ABSTRACT

This study investigates the effects of using waste polyethylene terephthalate (PET) as a partial substitute for fine aggregates in concrete mixtures. The study assesses both the mechanical and physical properties of the concrete and its influence on the flexural performance of fiber-reinforced concrete slabs with steel reinforcement as well as slabs without reinforcement. The study is structured into two main parts. The first part examines how replacing a portion of sand with PET waste affects the mechanical and physical properties of the concrete. The experimental program included seven different PET replacement ratios: 0%, 5%, 10%, 15%, 20%, 30%, and 50%, along with an addition of 1.5% polypropylene fibers by volume of the concrete mix. A reference mix was also prepared for comparison. Mechanical tests were carried out at the ages of 7, 28, and 90 days, focusing on compressive strength, splitting tensile strength, flexural strength, and the modulus of elasticity. Physical tests included measuring the concrete's density, water absorption, and ultrasonic pulse velocity. The results showed that replacement ratios between 5% and 10% resulted in improvements in mechanical performance, with compressive strength increasing from 19.21% to 29.06%, tensile splitting strength from 20.83% to 37.5%, and flexural strength from 22.5% to 37.5% when compared to the reference mix. The optimum PET replacement ratio was determined to be 10%. Beyond 15% replacement, however, there was a noticeable decrease in mechanical properties (compressive strength, splitting tensile strength, and flexural strength). Additionally, the modulus of elasticity, density, and ultrasonic pulse velocity decreased, while water absorption increased as PET content in the mix increased.

The second part of the study evaluates the impact of replacing sand with PET waste on the flexural behavior of fiber-reinforced concrete slabs. Fourteen slabs, each with dimensions of 1500 × 500 × 80 mm, were cast. These slabs were divided into two groups: one group of seven slabs with steel reinforcement and another group of seven slabs without reinforcement (two slabs for each PET replacement level), along with two reference slabs. The slabs were tested for their ultimate load capacity, ultimate deflection, energy absorption, stiffness, ductility index, and strain. Crack patterns were also analyzed, including the load at which the first crack appeared. The results were compared to those of the reference slabs to determine the influence of PET waste on flexural behavior. The results indicated that increasing the PET content in the steel-reinforced slabs led to significant improvements in several properties. The ultimate load capacity increased from 4.22% to 26.55%, ultimate deflection from 12.94% to 77.97%, ductility index from 3.52% to 105.03%, strain from 6.29% to 25.24%, energy absorption from 18.80% to 80.36%, and the load at first crack from 7.14% to 171.43%. However, initial and secant stiffness decreased, with reductions of 3.85% to 31.54% and 7.60% to 60.46%, respectively. For the unreinforced slabs, improvements were also observed. The ultimate load capacity increased from 26.67% to 53.33%, ultimate deflection from 8.91% to 41.01%, strain from 7.10% to 39.81%, and energy absorption from 21.50% to 68.24%.

## SUPERVISOR CERTIFICATION

I certify that the preparation of this thesis entitled (**Flexural Behavior of Fibrous RC One Way Slabs Incorporating PET Waste as Sustainable Sand Replacement)** was presented by **(Zahraa Ahmed Sabar)**, and prepared under my supervision at The University of Misan, Department of Civil Engineering, College of Engineering, as a partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Structural Engineering).

Signature:

Supervisor: **Prof. Dr. Abbas Oda Dawood**

Date: / /2024

In view of the available recommendations, I forward this thesis for discussion by the examining committee.

Signature:

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Date: / /2024

# EXAMINING COMMITTTEE'S REPORT

We certify that we, the examining committee, have read the thesis titled **(Flexural Behavior of Fibrous RC One Way Slabs Incorporating PET Waste as Sustainable Sand Replacement)** which is being submitted by (**Zahraa Ahmed Sabar**), and examined the student in its content and in what is concerned with it, and that in our opinion, it meets the standard of a thesis for the degree of Master of Science in Civil Engineering (Structures).

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# DEDICATION

I praise and thank Allah, first and foremost, for His guidance and grace that have accompanied me at every step.

To the sahib alzaman, may Allah hasten his reappearance, whom we await to bring forth hope and peace.

To my dear parents, who have provided me with unlimited support and have been my support in life.

And to my dear brother and sister, for whom words are not enough to thank them for their continuous support.

I dedicate this study to all these dear ones, hoping from Allah that it will be a source of goodness, knowledge, and benefit for society.

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I extend my heartfelt thanks to Allah Almighty for providing me with the opportunity to successfully complete this study.

I would like to express my sincere thanks and gratitude to my supervisor**, Prof. Dr. Abbas Oda Dawood,** for his unlimited support and valuable guidance during my study period. Your advice and guidance have been a true source of inspiration and have contributed greatly to guiding me and completing this research. Thank you for your patience and understanding and for your tremendous efforts that made this achievement possible.

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| | |
|---|---|
| $\varepsilon_c$ | Compression Strain |
| D.I | Ductility Index |
| E | Modulus of Elasticity in GPa |
| *fc`* | Cylinder concrete compressive strength in MPa |
| $f_{cu}$ | Cube Compressive Strength in MPa |
| *fr* | Modulus of rupture in MPa |
| *ft* | Tensile strength in MPa |
| *fy* | Yield strength in MPa |
| ɣ | Density in $Kg/m^3$ |
| I.S | Initial Stiffness in kN/mm |
| Pcr | First Crack Load in kN |
| Pu | Ultimate Load in Kn |
| PY | Yield load |
| S.S | Secant Stiffness in kN/mm |
| LVDT | Linear Variable Displacement Transformer |
| Δu | Deflection in mm |
| Δy | Deflection at Yield load |
| S0%0%R | Slab 0% PET 0% Polypropylene Fiber Reinforced |
| S0%0%U | Slab 0% PET 0% Polypropylene Fiber Unreinforced |
| S0%PF1.5%R | Slab 0% PET 1.5% Polypropylene Fiber Reinforced |
| S0%PF1.5%U | Slab 0% PET 1.5% Polypropylene Fiber Unreinforced |

# LIST OF ABBREVIATIONS

| | |
|---|---|
| Ab | Absorption |
| ACI | American Concrete Institute |
| ASTM | American Society for Testing and Materials |
| BS | British standard |
| EN | European Standard |
| PET | Polyethylene Terephthalate |
| PP | Polypropylene |
| SP | Superplasticizer |
| UPV | Ultrasonic Pulse Velocity |
| 0%PET+0%PP | 0%PET+0% Polypropylene Fiber |
| 0%PET+1.5%PP | 0%PET+1.5% Polypropylene Fiber |
| W/C | Water to cement ratio |

# CHAPTER ONE:INTRODUCTION

## 1.1 General

Despite the fact that plastic has many practical uses in modern life, its production has been steadily increasing in recent years. However, the waste products of this industry are ecologically harmful since they are not biodegradable and contain poisonous chemicals. According to the UNEP, out of a total yearly plastics output of 400 million tons, almost 87%, or 350 million tons, end up as waste. In 2015, the plastic packaging business generated about 141 million tons of single-use plastics, or 47% of all plastic waste. It is common for large amounts of single-use plastics to be recycled, littered on streets, discarded carelessly in landfills, or burned. According to recent evaluations, only approximately 9% of all plastic garbage has been recycled, while 79% ends up in landfills or the environment. Also, only around 12% has been burned. Concrete is the second most used substance in the world, just after water, due to its physical strength and relative ease of handling. Over time, the quick rate of development and urbanization has resulted in the overexploitation and depletion of natural resources that are used in the manufacturing of concrete. The most common of these materials are cement (limestone), sand, and gravel. The amount of aggregates, which make up around 65 to 80% of concrete, determines the material's strength, porosity, density, workability, and durability. In order to make massive amounts of concrete every year, the globe needs huge quantities of both fine and coarse aggregates. Using recycled materials in concrete is an eco-friendly and long-term solution to the problems associated with waste disposal. A prime example of a plastics recycling strategy is the repurposing of polyethylene terephthalate (PET) into composites used in the construction of buildings and roads. By using this method, we may replace the quickly diminishing natural resources with reusable plastics without sacrificing quality, which helps with attempts at conservation. One important thing that these plastic scraps do for the building sector is to lower the deadweight and density of the concrete that is made, which makes it less vulnerable to earthquakes. Some other advantages include better thermal insulation, lower initial building costs, and shorter production and handling times [1].

## 1.2 Plastic Waste

Plastic, a solid, synthetic polymer derived from hydrocarbons, is ubiquitous and has many everyday uses, including but not limited to: food and drink containers, water bottles, and shopping bags. Paper, cardboard, metal, and glass have all been supplanted by plastic. The many benefits of plastic over these other materials are the root cause of this displacement. In addition to its good strength and corrosion resistance, plastic is inexpensive, lightweight, and simple to work with [2].

While plastic has several disadvantages [2]:

A) Decomposition: The main disadvantage of plastic is how long it takes for it to break down. For example, an average plastic bottle takes 500 years to break down. Depending on factors like the product's shape, the surrounding environment, and the type of landfill, the process can be especially harmful.

B) Non-renewable: Plastics created from gasoline are not renewable, and plastic consumption has reduced the quantity of natural gas that may be utilized or stored for other purposes. Some common applications for natural gas include heating homes and cooking.

C) Difficult to use: Traditional throwaway plastic bottles are only good for one use, making plastic difficult to work with. For instance, most people reuse water bottles around the home, but eventually they are discarded due to their decreasing durability.

D) Difficult recycling methods: although glass bottles are easily recyclable and used as tin cans, plastic bottles present a significant challenge. Because most plastics cannot be recycled and recovered bottles are not used to produce new bottles, the majority of plastics in recycling bins are not recycled at all. On the other side, lactic lumber, t-shirts, and parking lot bummers are made from non-recyclable plastic bottles. This means that, in contrast to materials like tin and glass, which are readily recyclable, more resources are required to make new plastic.

## 1.3 Polyethylene Terephthalate

Most thermoplastic polyesters are bottles made of polyethylene terephthalate (PET), which is ideal for keeping both carbonated and noncarbonated drinks. Excellent mechanical characteristics and dimensional stability under varying loads characterize this visible polymer. All things considered, PET is a semi-crystalline thermoplastic polyester that is long-lasting, has low gas permeability, is thermally and chemically stable, is simple to work with, resistant to wear and tear, and does not biodegrade. The material's adaptability has led to its use in many other products, including clothing, movies, and athletics. The food processing sectors choose PET because of its sanitary properties, strength, and lightweight design. Evidently, it may be used for a variety of purposes. PET is a kind of thermoplastic that makes up around 18% of all polymers made on Earth, with more than 60% of that amount going into synthetic textiles and bottles. Which utilizes around 30% of the worldwide PET requirement [3].

Figure 1.1 PET Waste (Shredded).

### 1.4 Options for Waste PET Recycling

The problem of recycling PET waste must be addressed. Worldwide, there has been a noticeable rise in concern about waste PET management and recycling. Research is currently being made to find new ways to recycle PET waste. One of these novel ideas is the use of recycled PET in the concrete production process. First, it may be used to make polymeric concrete; second, it can be used as aggregate in concrete; and third, it can be utilized as reinforcement in concrete. Chemical depolymerization of recycled PET bottles into unsaturated polyester resin is a key step in making polymeric concrete. The finished product is a high-quality polymer concrete that is very resistant to bending and compressing. Nevertheless, substantial and consistent PET use in a specific region is necessary for the project to be economically feasible. Shredding the PET into flakes and then melting them into monofilaments is the initial step in using PET waste as reinforced fibers for concrete. The final result is a product that effectively manages shrinking. This is a highly expensive method that is usually out of reach because of the heat procedure required.

Lastly, waste PET may be used as an aggregate substitute in concrete by simply shredding it into small particles and then adding them to the aggregate mixture, which can also include sand, gravel, or crushed stone. There are two major advantages to using recycled PET as aggregate: first, it drastically reduces the amount of waste going into landfills; and second, it partially substitutes natural aggregate, which lessens the impact on our finite supply of natural resources. As a result, we may save energy and natural resources while substantially lowering the environmental effect of disposal of waste [4].

## 1.5 Fiber Reinforced Concrete

Fiber-reinforced concrete (FRC) is a composite material consisting of aggregate, fibers, and hydraulic cement, designed to enhance tensile strength, durability, crack resistance, and hardness. The performance of FRC is influenced by the type of fiber used, which should be durable, easily dispersible, and possess good mechanical properties for optimal effectiveness. Fibers play a key role in controlling shrinkage-induced cracks, significantly improving the strength and durability of the concrete [5].

Polymer fibers have shown better performance than steel and glass fibers due to their superior resistance to corrosion, alkali reactions, rust, and salts. This makes them advantageous for reducing structural weight while improving mechanical properties. Polymer fibers can be manufactured as monofilaments, multifilaments, or fibrillated bundles, with their effectiveness depending on factors such as crystallinity and fiber diameter [5].

Hybrid FRC, which combines two or more types of fibers, leverages the unique properties of each fiber to achieve improved mechanical performance compared to single-fiber systems. When the hybrid mix is designed effectively, this integration significantly improves crack resistance and enhances the overall durability of the concrete [5].

### 1.5.1 Polypropylene Fiber

Polypropylene (PP) fibers, invented in 1954, are extensively used in packaging, automotive, and consumer products. They are made by polymerizing propylene gas derived from petroleum at high temperatures and pressures, then spinning the material into fibers. PP fibers have low resistance to environmental stress cracking and impact resistance at low temperatures [5].

With a global production of 4 million tons annually, PP fibers have a density of 0.91 $g/cm^3$, a tensile strength of 500-700 MPa, and a modulus of elasticity of 2800 MPa. Although their strength and modulus are lower than steel fibers, PP fibers help mitigate plastic cracking due to their ductility and fine dispersion properties. They are primarily used to control shrinkage in concrete, enhancing its ductility, durability, and impact resistance [5].

PP fibers are hydrophobic, resistant to plastic shrinkage cracking, and stable in concrete's alkaline environment, but they have drawbacks such as low modulus, poor fire resistance, and sensitivity to sunlight. They improve compressive strength in lightweight aggregate concrete, reduce workability, bridge cracks in self-compacting concrete, and enhance fracture toughness and corrosion resistance in fiber-reinforced concrete [5].

## 1.6 Effects of Polymer Fibers on the Properties of Concrete

Polymer fibers are widely used in construction for their impact resistance, low weight, and concrete strength. Their performance depends on fiber length—shorter fibers are pulled out under tensile stress, while longer fibers break, with strength determined by the fiber's tensile strength. Proper anchorage ensures effective stress transfer within the cement matrix [5].

These fibers not only reduce plastic shrinkage cracking but also enhance mechanical properties, even at low volumes such as 0.1%. They improve toughness, impact resistance, and fatigue performance. Low-modulus fibers like PA and PP are particularly effective in minimizing cracking. PVA fibers offer higher toughness and flexural strength, but their hydrophilic nature can decrease workability [5].

## 1.7 The Aims of the Research

The main aims of this study are to address the problem of PET waste that causes many environmental problems and to benefit from it as a substitute for sand in concrete in partial proportions because it is an available and cheap material with the addition of fibers to it increasing its efficiency and quality. Adding PET waste to concrete achieves two main benefits. The first is an economic benefit represented by reducing the cost of materials, and the second is an environmental benefit represented by solving some of the solid waste problems caused by waste and saving energy.

## 1.8 The Objectives of the Research

the objectives of the scientific research focused on the following:

1. There are several proportions of additives to evaluate the effect of the amount and form of recycled PET on the behavior of concrete when used as a partial replacement for sand in concrete mix. Evaluation of the effect of adding PET particles on the physical and mechanical properties of fibrous concrete mix.

2. Study the behavior of fiber concrete slabs containing PET waste as a substitute for sand. Finally, this study aims to know the optimum percentage of PET plastic waste to be used as a partial substitute for sand in concrete.

## 1.9 Thesis Layout

This study consists of five chapters:

- Chapter One: this chapter provides a general introduction to PET waste material, its use in concrete, and its environmental problems. The chapter also discusses adding fibers to concrete, identifying the types of fibers, their applications in concrete, and identifying the objectives of this research.

- The second chapter includes a review of the results of previous studies and research and the effect of PET plastic waste on the properties and behavior of concrete mixtures. Some studies were reviewed for its use as a partial substitute for fine or coarse aggregate or as fibers added to the mixture. Other studies reviewed its use in structural members of two types of beams and panels where it is used as reinforcement for these members. Other studies were also reviewed on each type of fiber.

- In chapter three, the specifications of the materials used in the research, devices, tests, and mixing ratios were presented. The work steps, details of the samples, the method of preparation and processing, the tests conducted on these samples, and the tests of concrete samples.

- In chapter four, the results and relationships in this work were presented, in addition to discussing these results.

- Chapter five explains the most important conclusions reached through the results of the tests during this study, in addition to some recommendations and suggestions that document this study and ways to achieve scientific benefit from future studies.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 General

Research and studies conducted in the past few decades were aimed at studying the behavior of concrete samples after combining them with recycled materials. Different materials with different forms of particles and fiber are used. One of the most common materials in the recycled concrete research is polyethylene terephthalate waste (PET). This chapter summarizes the most important and recent experiences and developments on which researchers worked and reviewed their results in this field. In this chapter, the use of polyethylene terephthalate (PET) waste in different forms and percentages will be reviewed. Other studies were also reviewed on each type of fiber.

## 2.2 Using of PET for Different Structural Purposes

Polyethylene terephthalate (PET) is the most recycled plastic re-used in construction. In this paragraph, the different purposes of using polyethylene terephthalate (PET) were mentioned.

The researchers focused on PET usage in concrete mixtures by replacing a certain amount of weight of sand or gravel or adding by volume to the mixture, as well as PET used in structural members as reinforcement.

### 2.2.1 Using of PET Waste as Partial Replacement of Fine Aggregate

In this field, most of the research studied the effect of replacing fine aggregate in the concrete mixture with PET waste particles on the behavior of concrete. Most of this research has adopted cutting and chopping PET waste bottles into small particles by various techniques and specialized machines.

In 2008, Z.Z. Ismail et al. [6], used PET bottles as a partial replacement of fine aggregate in the concrete mixture in a percentage of (0, 10, 15, 20) % by weight of sand with dimensions (0.15-12 mm length and 0.15-4 mm width) as shown in Figure 2.1 with mixing proportion (380 kg/m$^3$ cement: 715 kg/m$^3$ sand: 1020 kg/m$^3$ gravel) and W/C of 0.53. The tests were carried out for fresh and hardened concrete at ages of 3, 7, 14, and 28 days and observed that the slump decreases sharply as a plastic waste percentage increases. In addition, the compressive and flexural strengths of the hardened concrete are reduced by increasing the proportion of plastic waste used.


Figure 2.1 Sample of Plastic Waste [6].

In 2013, E. Rahmani et al. [7] presented two sets of control samples containing PET bottle waste as a fine aggregate partial replacement in the concrete mixture with percentages of 5%, 10%, and 15% by volume with two water-to-cement ratios of 0.42 and 0.54. The maximum size of PET bottle waste particles was 7 mm, as shown in Figure 2.2. These sets of PET samples were compared with the mentioned controlling samples. The fresh and hardened concrete tests were carried out. They observed that using 5% PET bottle waste as a replacement of sand gave optimum compressive strength when w/c was 0.42, and replacing sand with 10% PET waste particles produced compressive strength similar to reference samples without PET particles with low elastic modulus. This means more ductile behavior. Also, they observed that the slump decreases as a plastic waste percentage increases.

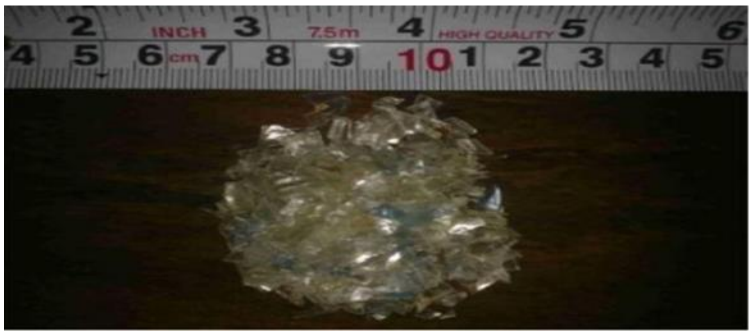


Figure 2.2 Sample of Plastic Waste [7].

In 2014, P.G. Prabhu et al. [8] used PET bottles as a partial replacement of fine aggregate in the form of fiber in the concrete mixture in a percentage of (0.5,1.0,1.5)% by volume with three dimensions (50*3 mm, 100*3 mm, and 150*3 mm) with a mixing proportion of 1:1.48:2.54 and a W/C of 0.45. Compressive and flexural strength tests were carried out at ages 3, 7, and 28 days. They observed that the dimension of fiber (100*3 mm) gives the higher strength, and 1.0% replacement of sand by volume fraction was the optimum percentage for both compressive and tensile strength.

In 2015, A. Khanna et al. [9] used PET waste plastic fibers as a partial replacement of fine aggregates in concrete mixtures. The percentages of PET waste that was used as a sand partial replacement were 10%, 20%, 30%, and 40% (by volume). Fly ash was used as a partial replacement of cement with percentages of 5%, 10%, and 15% by weight. The water-to-cement ratio was 0.45. For each mix, the superplasticizer ratio was 0.01. They concluded that the compressive strength decreased with increasing PET waste fiber amount and fly ash content. Also, they concluded that maximum increase in compressive strength was found when fly ash content was 10% with a partial replacement of PET waste plastic fibers, even up to 30% by volume.

In 2020, I. Almeshal et al. [10] investigated the impact of incorporating PET particles on the physical and mechanical properties of hardened concrete. They used PET as a sand replacement with a maximum size of 0.075–4 mm and a thickness of 1-1.5 mm, as shown in Figure 2.3. The ratio of partial replacement and mixing proportions were 10%, 20%, 30%, 40%, and 50%, and (1 cement: 1.6 sand: 3.37 gravel) with a 0.54 water to cement ratio. The result showed a reduction in the variables of slump, dry density (31.6% decreased at 5% PET) and ultrasonic pulse velocity (which dropped from 4.5 to 1.9 km/s at 50% PET). In addition to the decrease in compressive strength, splitting tensile strength and flexural strength by 90.6%, 85.5%, and 84.2% at 50% replacement ratio.

Figure 2.3 Crushed Plastic Used [10].

In 2021, A.O. Dawood et al. [11] replaced the fine aggregate by PET of bottle waste with a maximum size of 4.75 mm as shown in Figure 2.4 and ratios of 5%, 7.5%, 10%, 12.5%, 15%, and 20% by weight of sand. The proportions of mix were 1 cement, 1.5 fine aggregate, and 3 coarse aggregate. They used w/c and admixture (superplasticizer) equal to 0.41 and 0.4%, respectively. The results were contained on the positive side by increasing the values of compressive, splitting tensile, and flexural strengths by 26.8%-43.64%, 18.6%-26.9%, and 18.1%-30.2%, respectively, when the ratio of replacement was increased from 5% to 12.5%. Also, showed a decrease in workability, density, ultrasonic pulse velocity, and elastic modulus. On the other hand, an increase in water absorption and ductility occurs when the percentage of plastic increases in the concrete mixture.

Figure 2.4 Particles of PET Waste [11].

In 2022, R.S. Falih et al. [12] used PET waste to investigate its impact on the structural behavior of reinforced concrete beams. The same material, ratio of replacement, and mix proportions were used in [11]. The results of this study showed the ultimate failure load of the reference beam was very close to all ratios of beams used. At a maximum substitution ratio of 20%, they also observed increases in maximum deflection, ductility, compression strain, energy absorption, and load at first crack when the percentage of added PET increased by 97%, 91.37%, 1140%, 2749%, and 121.19%, respectively.

### 2.2.2 Using of PET Waste as a Coarse Aggregate

Few researchers presented the PET wastes as a partially alternative to coarse aggregate. It will be reviewed some studies with their findings in this field, and they were as follows:

In 2014, G. Tapkire et al. [13] used polyethylene terephthalate (PET) wastes as a partial replacement of the coarse aggregate in the concrete mix. The percentage of replacement was 10%, 20%, and 30% by weight of coarse aggregates with a maximum size of 10 mm. The mixing proportion was 1: 2.56: 3.26 as (cement, sand,

and gravel) respectively, and w/c was 0.5. The researchers showed that the maximum percentage of recycled PET that can be used as a replacement for coarse aggregate in concrete without affecting its properties was 20%.

In 2014, P.S. Patil et al. [14] used recycled plastic polyethylene terephthalate (PET) as coarse aggregate in the concrete mixture with percentages of 0%, 10%, 20%, 30%, 40%, and 50% by volume of aggregate in the mix. The tests were carried out for hardened concrete compressive and flexural strength at 7 and 28 day ages. They observed that when the PET plastic waste percentage increases, the compressive strength decreases. Also observed was that using PET waste as a replacement of coarse aggregate up to a percentage 20% gives resistance within the limits, and when the replacement percentage was 10%, the results of compression resistance at 7 and 28 days were satisfied.

In 2016, M.J. Islam et al. [15] made a comparison between PET waste aggregate concrete (PAC) and natural aggregate concrete (NAC) according to compressive strength, unit weight, and workability. They were selected five types of mixtures. Brick chips were used as coarse aggregates, while (PCA) PET waste was used as a volumetric coarse aggregates partial replacement with percentages of 0%, 20%, 30%, 40%, and 50% as shown in Figure 2.5. Three water-to-cement ratios (w/c) of 0.42, 0.48, and 0.57 were used. They observed that PAC has high strength with replacement percentages up to 20% so it can be useful in structural concrete, especially with a low w/c ratio and a small amount of PCA concrete aggregate, and the density for PCA was 4–10% reduced compared to the NAC.

Figure 2.5 PET as a Coarse Aggregate [15].

### 2.2.3 Using of PET Waste as Fibers

PET fibers represented one of the most commonly used forms of PET waste in experiments and research of recycled concrete, where the studies focused on the fiber shape, dimensions, and percentages for using in concrete mixes. A lot of researchers had addressed this area of the use of PET waste as the fibers. The modern studies in this area had been reviewed as shown below:

In 2010, S.B. Kim et al. [16] used recycled PET fibers from waste PET bottles in concrete mixtures to study the basic properties of materials, concrete resistance, and drying shrinkage, in addition to studying the strength, failure mode, and ductility of concrete mix. Three fiber percentages of 0.5%, 0.75%, and 1% by volume were used. The w/c ratio and fly ash / cement substitution by weight were 0.41 and 10.1%, respectively. Coarse aggregate (crushed gravel) maximum size was 25 mm, and river sand fine aggregate was used. They added an air-entraining / water-reducing agent to achieve an air content of 4.5 ± 1.5% and appropriate workability. The technique represented the manufacturing of recycled PET fiber as shown in Figure 2.6. They tested seven specimens at 28 days for flexural strength with dimensions of 2000*200*300 mm. They showed that the PET fibers enhanced tensile strength, delayed crack formation, and increased ductility and ultimate load capacity. Also, they observed a slight decrease of 1–9% in compressive strength and modulus of elasticity when PET fiber content increased. The maximum deflection at mid-span was larger than the specimens without fibers by approximately 400%.

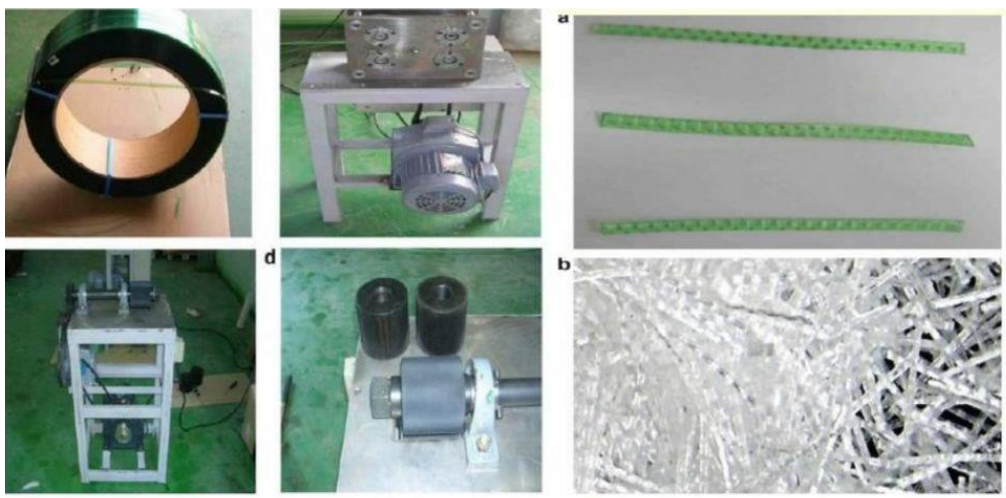


Figure 2.6 Manufacturing System of Recycle PET Fibers and Geometry of the Recycled PET Fibers and PP Fiber [16].

In 2011, L.A.P.D. Oliveira et al. [17] added PET bottles as fiber to the concrete mixture in a percentage of (0,0.5,1.0,1.5) % by volume in the mixture. PET fiber was shredded into 35 mm length at a constant 2 mm width and 0.5 mm as shown in Figure 2.7. Compressive and flexural strength tests were performed at the ages of 7, 28, and 63 days. Their results showed that the incorporation of fibers in the mixture improved the properties of it and observed that the percentage of 1.5% fibers was the optimum percentage for the performance of the mix.

Figure 2.7 Form of PET Used for Fiber Reinforcement [17].

In 2017, T. Subramani et al. [18] added PET bottles as fiber to the concrete mixture in a percentage of (2,4,6)% by volume with dimensions (30 mm length, 5 mm width, and 0.6 mm thickness). The tests were carried out for fresh and hardened concrete at the ages of 7, 14, and 28 days. They observed that 4 % of PET fiber by volume fraction was the optimum percentage for all tests.

In 2018, N.K. Bui et al. [19] used PET bottle waste as fiber in recycled aggregate concrete. PET bottles were cut into 50–60 mm lengths and 2–3.5 mm widths, as shown in Figure 2.8. The mixing ratio was 1: 1.55: 2 (cement, fine aggregate, and coarse aggregate), respectively, with silica fume (21.4) kg for each cubic meter and (w/c) of 0.45. The percentage of PET fiber that was used was 0.25%, 0.5%, and 0.75% by volume. They found that using PET fiber had been better performed for the mixture; it also enhanced the splitting tensile strength, compressive strength, and shear strength.

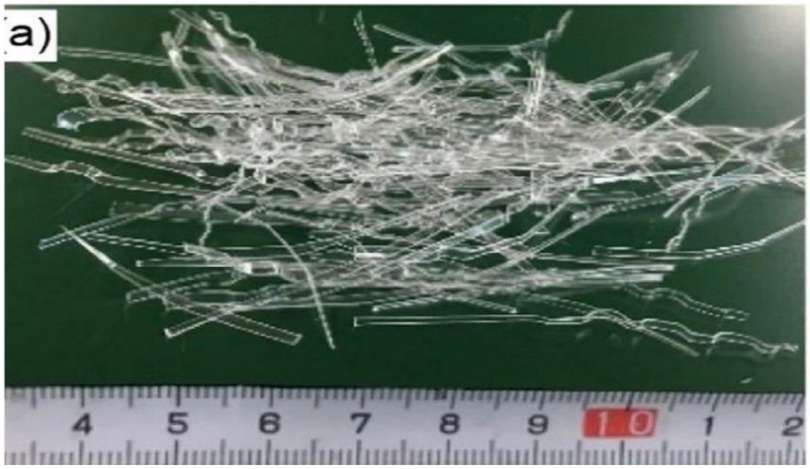



Figure 2.8 Recycle PET Bottle Fiber [19].

In 2019, A. Ismail Al-Hadithi & Ahmed [20] used cutting plastic soft drink bottles (PET) as small fibers with volumetric percentages of 0.25%, 0.5%, 0.75%, 1%, 1.25%, and 1.5%. The PET bottle fiber length was 40 mm, average width of 4 mm, and thickness of 0.35 mm, as shown in Figure 2.9. The mix proportions were 1: 1.62: 2.55 by weight, and the (w/c) and cement content were (0.448) and 430 kg/m$^3$, respectively. The maximum size of gravel used was 14 mm. The results showed that the workability decreased when the percentage of PET fibers increased. Also, they observed that the increase in PET fiber percentage until 1% led to an increase in the compressive and shear strength of concrete. Also, they observed an increase in energy and rising in the first crack load. Finally, they showed that increasing the PET fiber percentage until 1.25% led to an increase splitting tensile strength.

Figure 2.9 The Small Fibers of Soft Drink Bottles(PET) [20].

In 2019, H.M. Hamsa and A.O. Abbas [21] used PET waste fibers with two types of PET bottles, large and small. Two colors of large PET bottles, white and green, were cut by a special machine to a random shape with a maximum size of 25.4 mm, as shown in Figure 2.10, while the small PET bottle fibers were cut manually with dimensions of 40 mm length and 4 mm width. The two types were used in a concrete mixture with volumetric percentages of 1.5% and 3% and a water-to-cement ratio of 0.41. They observed that the machine PET fiber showed a slight increase in compressive strength and drop in flexural strength for both percentages, but the manual PET fibers showed that compressive and flexural strength increased at 1.5% and decreased at 3%.


Figure 2.10 Type of PET Waste Fibers [21].

### 2.2.4 Recycle PET waste as a Reinforcement

There are a few researchers in this field. This research presents different methods and formulas for using PET wastes as reinforcement of concrete beams. It will be reviewed some research and their findings as follows:

In 2013, D. Foti et al. [22] used PET waste fibers as reinforcement of specimens used in concrete beams as a rebar replacement. These PET fibers were produced by cutting the PET bottle. Three forms of PET waste bottles were used, as shown in Figure 2.11. In the first one, PET was in a circular fiber form with a width 5 mm and weight percentages of 0.5%, 0.75%, and 1.0% of concrete. The second form was using half bottles as long strips of PET in concrete beams arranged in a similar position to the rebar in concrete beams, as shown in Figure 2.12. The third type was a bottle strip with dimensions of 45*0.2*300 mm used in specimens as a substitution of steel reinforcement. les into different forms. For tensile stress, they were prepared with 100*100*400 mm prisms reinforced with large strips produced from cutting half PET bottles. Also, they used 100*200*1100 mm beams reinforced with four layers of long overlapping PET waste bottle strips to study a larger element's behavior, while for the slab test they used specimens of 800*800*58 mm. The result showed that the ideal percentage of circular PET waste fibers was 1.0%. Also, they found that the reinforcement forms of PET waste had been successfully given high ductile behavior and concrete-PET adherence to the concrete slabs, which is fundamental to inhibiting complete failure.

Figure 2.11 Forms of PET used (Circular fibers ,half bottles ,and strips) [22].

Figure 2.12 Positioning of half reinforcement [22].

In 2014, M.L.A. Kumar et al. [23] used recycled PET fiber as reinforcement for the concrete beam in four parts of samples with steel bars, without steel bars, with PET reinforcement, and combined steel and PET reinforcement. Seven concrete beams were tested at 28 days for flexural strength with dimensions (100*100*500) mm, and the beams used in seven types of control beams made with plain concrete without any reinforcement; the second type was beam reinforced with PET hollow bars of 48 cm long and 24 mm, 22.8 mm external diameter, internal diameter, the third and fourth types were beams with a single bar and two bars and length 48 cm in the tension zone, beams with a combination of steel and PET reinforcement in the tension zone, beams with steel and PET long strips (strips dimensions were 8 cm long, 0.5 cm width, and 6.6 mm thickness), and the seventh type was beams with PET short strips, which were prepared by replacing 1% fine aggregate with PET short strips (strip dimensions were 4 cm long, 0.4 cm width, and 0.6 mm thickness), as shown in Figure 2.13. The results showed that the fiber-reinforced concrete with different types improved in flexural strength.

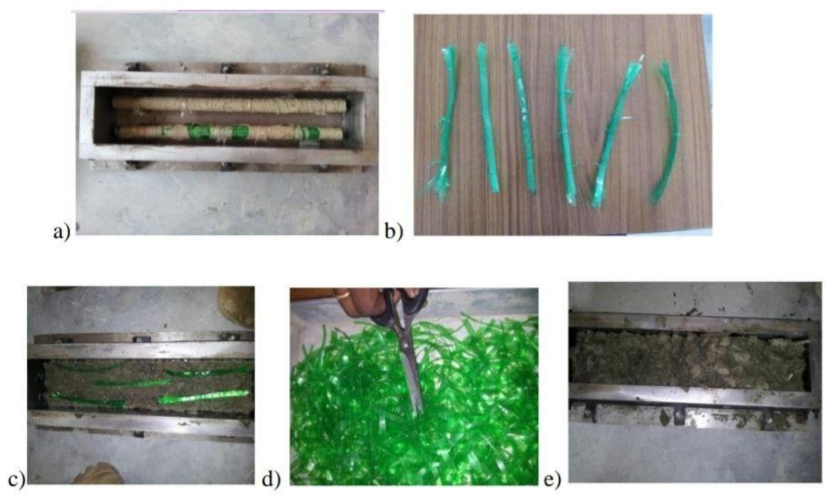



Figure 2.13 :a) PET Hollow Bars, b) PET Long strips, c) PET Long strips as reinforcement along with steel, d) PET Short strips, and e) Concrete with PET Short strips filled in beam mold [23].

In 2014, D. Foti et al. [24] utilized PET as discrete long reinforcement of specimens in concrete in substitution of steel bars arranged as a grid for slabs, where the technique for cutting PET was removing the neck, then longitudinally cutting a 5 cm-wide strip including the base of the bottle and ending on the opposite side, obtaining in this way a strip with a length of about 60 cm. Four 80 cm × 80 cm × 5.8 cm slabs have been prepared, two in non-reinforced concrete and two in concrete reinforced with PET grids, as shown in Figure 2.14.

These slabs were tested for impact load, and based on the result, the reinforcement was successfully given to the concrete slabs a very ductile behavior, which allowed them to avoid the complete failure, thus confirming the improvement of the impact strength.

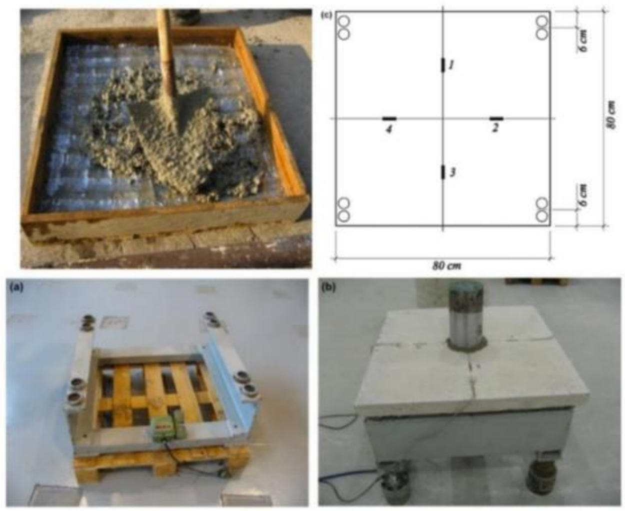


Figure 2.14 Scheme of the Slab with the Position of the Strain Gauges and the Supports [24].

In 2019, A.O. Dawood and H.M. Adnan [25] investigated using PET waste as a tension bar. They used twelve simply supported beams with dimensions of 150*200*1400mm; two of them were reference beams. PET rods were used in various forms. The tension PET bars of the first beam consist of rolled big bottles tied together and filled by wastes of plastic boxes, as shown in Figure [2.15 (A)]. The second beam consists of small bottles of PET putted inside large bottles of PET, as shown in Figure [2.15 (B)]. The third beam contains large and small bottles of PET rolled together, contacted by a bottle neck, and putted inside each other as shown in Figure [2.15(C)]. The fourth beam contains rolled small bottles of PET, covered in the middle by a neck, and filled with wastes of PVC, as shown in Figure [2.15(D)]. The fifth beam contains large bottles of PET divided into two parts, arranged as two layers and connected to stirrups as shown in Figure [2.15(E)]. Other beams are hybrid reinforcement, which is reinforced by rebar in addition to different thicknesses of PET bottle layers (see Figure 2.15(F)). They displayed failed of all specimens that contained PET bars except the specimen that used rebar with PET bottle layers that were cut for two parts, which presented a deflection and ultimate failure load increment of 213.83% and 3.033% compared to reference specimens, respectively.

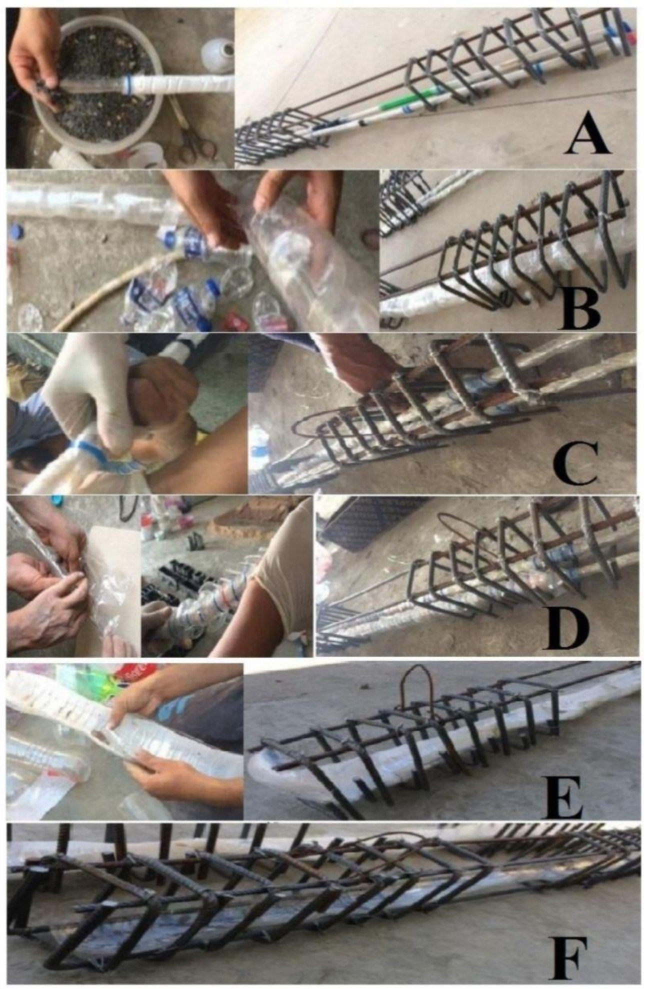



Figure 2.15 Type of PET Waste Bars as a Tension Reinforcement [25].

## 2.3 Fiber Reinforcement Concrete

### 2.3.1 Polypropylene Fiber

In 2006, M. RAS [26] investigated the influence of polypropylene fiber addition on the mechanical characteristics of normal-strength concrete. The volume concentrations of the polypropylene fibers that were introduced were 0.25, 0.50, 1.0, and 1.5%. The white pure polypropylene fibers (CMB FIBER) used in this project have the following specifications: a density of 0.91 $g/cm^3$, a bundle thickness of 2mm, ten fibril bundles, a cut length of 15mm, a tensile strength of 370 $N/mm^2$, and a modulus of elasticity of 3750 $N/mm^2$, as seen in Figure 2.16. The water-cement ratio is 0.45. Various mechanical parameters, including modulus of elasticity, maximum compressive strength, splitting strength, ductility, bond strength, modulus of rupture, and percentage of absorption, were assessed by compression, pull-out, and bending tests. The results of the experiments show that adding more polypropylene fibers to concrete increases its ductility and, to lesser degrees, its maximum compressive strength. While increasing the amount of polypropylene fibers (above 0.5 vol.%) resulted in much more ductile bond behavior, it did not enhance the final bond strength. Polypropylene fibers, when added to the tested concrete examples, significantly increased the percentage of water absorption.

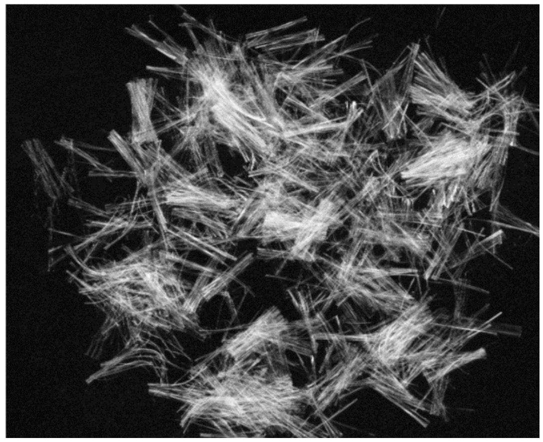


Figure 2.16 Polypropylene fibers that used [26].

In 2013, K. Ramujee [27] investigated the strength characteristics of concrete reinforced with polypropylene fibers. The polypropylene fibers were included at several concentrations (0.0%, 0.5%, 1%, 1.5%) and with a water-to-cement ratio of 0.5. The physical properties of the PP fibers used are detailed in Table 2.1. Tests were conducted on concrete samples with varying quantities of fibers to determine their compressive and splitting tensile strengths. According to the results of the experimental investigations, the slump decreases as the fiber content increases. However, at the dose of 1.5%, the mixture becomes fibrous and difficult to work with. Results from experiments measuring compressive and splitting tensile strengths showed that, compared to the control mix without fibers, the strength rose in direct proportion to the volume ratio of polypropylene fibers. Compressive strength increased by 34% and split tensile strength by 40% as compared to the fiber-free mix. When compared to other samples in this investigation, those with a fiber level of 1.5% performed best.

Table 2.1 Polypropylene Fiber Physical Properties.

| | |
|---|---|
| Specific gravity | 0.91 g/cm$^3$ |
| Width crossing | Circular |
| Cut length | 12mm |
| Water absorption | 0 |
| Melting point | 250 ºC |

In 2015, M. Kumar et al. [28] used PP fibers to evaluate the mechanical characteristics of concrete. The properties of the polypropylene fibers used are listed in Table 2.2, and the shape of the fiber is shown in Figure 2.17. The specimens were made using different quantities of 0.6%, 0.8%, 1%, 1.2%, 1.5%, and 2.0% of the fibers by volume fraction. The presentation includes the experimental procedure and results about the compressive strength of cubes after 3, 7, 28, 56, and 90 days. The flexural and split tensile strengths of the cured concrete were measured after 28 days. The experimental results show that compared to conventional concrete, the addition of PP fibers increases the compressive strength, tensile strength, and flexural strength of the mixture by 20.85%, 27.74%, and 73.33%, respectively. Additionally, there is a notable change in the flexural strength with variation in the amount of PP fibers used. Because of the strong bond between the polymer fibers and the concrete, polymer fiber concrete has a much greater flexural strength than regular concrete. Compared to regular concrete, polypropylene fiber concrete weighs far less, and experiments have shown that using 1.5% PP fibers in concrete produces the best results.

Figure 2.17 A PP Fiber Sample [28].

Table 2.2 Polypropylene Fibers Properties.

| | |
|---|---|
| Fiber length | 6mm |
| Fiber type | Monofilament |
| Density | 0.91 gm/cc |
| Melting point | 160-170 ºC |
| Resistance to acid and alkali | 94.4% |
| Young's modulus | 5Gpa |
| Crack elongation | 15% |
| Tensile Strength | 600Mpa |

In 2016, D.S. Dharan et al. [29] investigated the effects of several percentages of blended polypropylene fibers (0.5%, 1%, 1.5%, and 2% by weight) added to concrete. Mixture types of polypropylene fibers (24 mm, 40 mm, and 55 mm) are used, as shown in Figure 2.18. A mix ratio of 1:1.59:2.52:0.45 was employed, and the water-to-solids ratio was 0.45. Examinations of the specimens' workability, compressive strength, flexural resistance, split tensile strength, and modulus of elasticity were carried out. Afterwards, the data reveal that the concrete reached its maximum strength at a fiber ratio of 1.5 %.

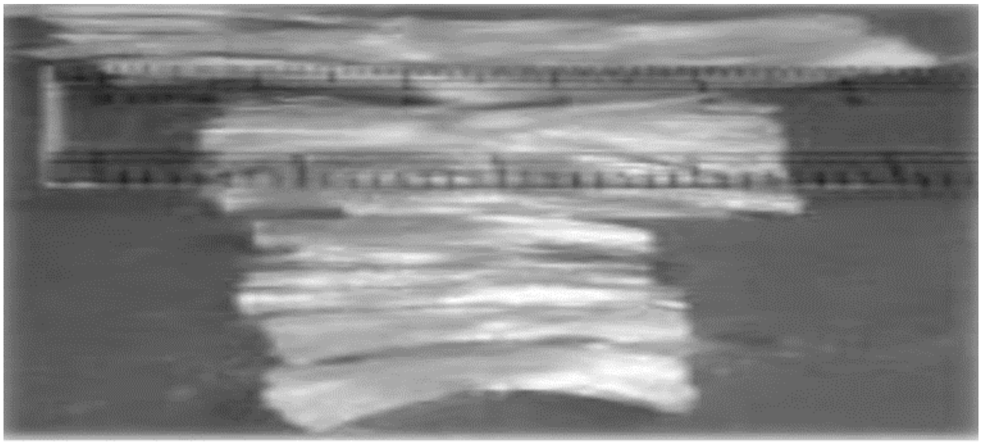


Figure 2.18 Blended (24 mm,40mm,55mm) Polypropylene Fiber [29].

In 2017, A. Nayak et al. [30] examined the properties of polypropylene fiber reinforced concrete in a modern construction setting. Increasing dosages of polypropylene fibers (0.5, 1, 1.5, 2, and 2.5 percent of cement weight) were tested for their effects, as shown in Figure 2.19. Including it in concrete not only reduces plastic shrinkage cracking and thermal cracking but also makes efficient use of the material's flexural and tensile strengths. Using M-30 mix, the experiment was conducted at 7 and 28 days according to normal procedures by applicable codes. Compression, split tensile, and flexural strength tests were also conducted. Results indicated that when compared to normal concrete, concrete containing 1.5% by weight of polypropylene fiber as an addition had the maximum strength and the lowest self-weight. As the amount of polypropylene fiber increased, the strength gradually decreased.

Figure 2.19 Photomicrograph of Polypropylene Fiber [30].

## 2.4 Summary

All uses of PET waste in concrete and the four forms of PET waste that we have provided are subject to a set of variables, including size, shape, dimensions, percentage, and method of use. The results of the researches varied according to these variables, but we can summarize the conclusions that most research participated in each of the four areas as follow :-

1. The researchers used PET waste particles as a partial substitute for fine aggregate with percentages ranging from 0% to50% with a steady increase rate of 0.5% and with different dimensions, coarse with max dimensions of 100 mm and fine with max dimension of 3 mm. the results are varied according to size an percentages of uses. Although it is consistent in some results, such as increasing ductility and reducing workability, but it gave variable results to the mechanical properties of concrete. Results of researches that used large gradations of PET particles showed a decrease in the mechanical properties of concrete. While the results of research that used small gradations of PET waste with limited replacement percentages, they tend to increase in some of the mechanical properties of concrete. In general, it shared that using PET waste as a partial substitute for fine aggregate by more than 10% reduces mechanical properties. So, in this study fine PET waste particles were used to ensure identical results.
2. The using of PET waste as a partially substitute for coarse aggregate reduces workability and reduces the mechanical properties of concrete.
3. Researchers used polyethylene terephthalate waste as fibers in concrete with lengths ranging from 10 to 60 mm, widths ranging from 2 to 5 mm,

and thicknesses ranging from 0.5 to 0.8. The Volumetric percentages of using PET fiber were ranged from 0.25% to 3%, with a steady increase rate of approximately 0.25%. Most of the researches made the following conclusions:-

A- Increase in flexural strength, absorbed energy, enhancing tensile and compression strength when the fiber ratio does not exceed 1%.

B- Increase in the first crack load and ductility, with a decrease in the workability and elastic modulus.

C- The maximum use of PET fibers in concrete should not exceed 1.5% calculated from the total volume.

4. The using of PET waste as reinforcement for concrete beams lead to inhibiting early beam failure, improved the ductile behavior. As for use it as a slab grid, it is given high ductile behavior to the slabs, which lead to avoid the complete failure, but it has negative impact on the ultimate failure load.
5. Studies have shown the impact of adding polypropylene fibers on the mechanical properties of normal-strength concrete, indicating that an increase in fiber content enhances the ductility of concrete while improving its compressive strength. However, fibers above 0.5% did not enhance the final bond strength. Furthermore, research indicated that adding 1.5% of the fibers significantly increased compressive and split tensile strengths, but also reduced workability. Additionally, the results demonstrated that concrete achieves its maximum strength at this fiber ratio. The inclusion of 1.5% of fibers also reduced cracking due to plastic shrinkage and improved the overall strength of the concrete. Overall, a 1.5% content of

polypropylene fibers is considered the most effective for enhancing the mechanical properties of concrete.

The present study differs from previous studies in that the grading of PET waste particles used as a fine aggregate partial replacement was close to that of fine aggregate, and various properties of the concrete mixture were tested. It also evaluates, for the first time, the impact of replacing sand with PET waste on the flexural behavior of fiber-reinforced concrete slabs. Fourteen slabs, each with dimensions of 1500 × 500 × 80 mm, were cast. These slabs were divided into two groups: one group of seven slabs with steel reinforcement and another group of seven slabs without reinforcement (two slabs for each PET replacement ratio), along with two reference slabs.

# CHAPTER THREE:EXPERIMENTAL WORK

## 3.1 General

For the purpose of extensively investigating the behavior of fiber concrete (FRC) for concrete slabs containing percentages of PET waste, several procedures were carried out. That includes material, testing, preparation of mixing ratios, manufacture of molds and tools, and all that was necessary to carry out the research work. These procedures must be carefully performed before pouring fibrous concrete. This chapter includes showing and evaluating the properties of natural and synthetic materials involved in the formation of concrete mixtures. Physical and mechanical properties, material details, proportions, concrete mix design, concrete slabs pouring, and test specimens shown for each proportion. The chapter also includes the use of PET waste as a partial alternative for sand in concrete mixtures reinforced with polypropylene fiber. A volumetric ratio of 1.5% of the fiber from the volume of concrete was adopted in this study. This ratio has been adopted based on most of the results of researchers in previous studies and is considered the best ratio of fibers in concrete. The chapter also contains the details of pouring concrete slabs and casting small specimens for each replacement ratio. In addition to conducting mechanical and physical tests of concrete specimens containing PET waste as an alternative to sand and reinforced with polypropylene fibers. Tests include compressive strength, flexural strength, split tensile strength, absorption, density, ultrasonic pulse velocity, modulus of elasticity for hardened concrete, and slump test of fresh concrete. It was poured (72 cubes), (48 prisms), (72 cylinders with dimensions of 200 × 100 mm), (16 cylinders with dimensions of 150 × 300 mm) for replacement ratios. Also casting (16) concrete slabs, which are two slabs for each replacement ratio. All specimens were cast in the laboratory of the College of Engineering / University of Misan. With all laboratory tests conducted in the construction laboratory of the college, except for the cement and absorption test in the laboratory of the Technical Institute in Architecture.

## 3.2 Experimental Program

The experimental program is divided into two main parts. The first part includes a study of the physical and mechanical properties of concrete containing PET waste as a partial alternative to sand. This part includes the use of (7) different ratios to replace PET waste as a partial substitute for sand, with fibers added in addition to the reference mix. A two concrete slab is poured for each ratio with small specimens. For each ratio (9) specimens of standard cubes (150 × 150 × 150) mm to determine the compressive strength, (9) specimens of cylinders (100 × 200) mm to determine the split tensile strength. (6) specimens of the prism (100 × 100 × 500) mm to determine the flexural strength, and (2) concrete cylinder (150 × 300) mm to calculate the modulus of elasticity, and thus the total number of specimens for testing (208), in addition to casting (36) standard cubes of concrete with different ratios of polypropylene fiber with 10% PET waste in addition to reference mixture (experimental test). As well as casting 16 concrete slabs with dimensions (1500 × 500 × 80) mm, which are two slabs for each ratio. Mechanical tests are performed on the specimens for each ratio to know the resistance to compression, flexural, and tensile, as well as physical tests, including density, modulus of elasticity, absorption, and an ultrasonic pulse velocity test of concrete.  The second part includes a study of the behavior of concrete slabs reinforced with polypropylene fibers containing PET waste as a partial alternative to sand, which are reinforced with steel bars and the slabs without steel reinforcement.

## 3.3 Materials Properties

Locally available natural and synthetic materials are used in this research: ordinary Portland cement, fine aggregate, coarse aggregate, plastic PET bottle waste, pure drinking water for mixing, and micro-polypropylene fiber 12 mm long. As well as the use of the superplasticizer type Hyperplast PC 260 to improve the workability of the mixture and obtain high-density concrete.

### 3.3.1 Cement

In this research, ordinary Portland cement was used in all mixtures of this research. The properties of hardened concrete made using ordinary Portland cement are characterized by less water bleeding and a lower level of permeability with fewer cracks (according to the technical bulletin on the cement bag). Cement bags were kept in a dry place to avoid the effect of moisture. Table 3.1 and Table 3.2 include the results test of the physical properties and chemical composition of cement, as the results showed that this type of cement conforms to the Iraqi standard specifications No. (5) / 1984 [31]. The tests were conducted in the laboratory of the Technical Institute in Al-Amarah / Iraq.

Table 3.1 Physical Properties of Cement

| Physical properties | Tests Results | Iraqi specification limits NO.5 /1984 [31] |
|---|---|---|
| Fineness by using Blain Air Permeability Method $m^2/kg$ | 382 | ≥230 |
| Soundness by using Autoclave method | 0.25 | <0.8 |
| Initial and final setting time by using Vicat method | | |
| Initial hrs:min | 2.08 | ≥45min |
| Final hrs:min | 4.27 | ≤10hrs |
| Compressive strength of cement mortear | | |
| 3 days MPa | 19.9 | ≥15 |
| 7 days MPa | 30.4 | ≥23 |

Table 3.2 Chemical Composition of Cement.

| Oxide compositions | Abbreviations | Content by weight | Iraqi specification Limits No.5/1984[31] |
|---|---|---|---|
| Silica | $SiO_2$ | 21.45 | --- |
| Lime | CaO | 62.88 | --- |
| Alumina | $AL_2O_3$ | 4.67 | --- |
| Sulphate | $SO_3$ | 2.17 | $<2.8\%$ |
| Iron Oxide | $Fe_2O_3$ | 3.24 | --- |
| Magnesia | MgO | 2.85 | $\leq 5\%$ |
| Insoluble residue | I.R | 1.08 | $\leq 1.5\%$ |
| Loss on Ignition | L.O.I | 3.34 | $\leq 4\%$ |
| Lime Saturation Factor | L.S.F | 0.98 | 0.66-1.02 |
| Main Compounds (Bogues Equation) | | | |
| Tetra Calcium Alumina | $C_4AF$ | 9.87 | --- |
| Di Calcium Silicate | $C_2S$ | 18.34 | --- |
| Tri Calcium Aluminates | $C_3A$ | 8.16 | --- |
| Tricalcium Silicatre | $C_3S$ | 50.66 | --- |

### 3.3.2 Fine Aggregate

The fine aggregate (sand) from Basra governorate in the south of Iraq was used. Table 3.3 represents the grading of fine aggregate according to the requirements of Iraqi specifications No. 45/1984 [32], Zone No. 2.

Table 3.3 The Grading of Fine Aggregate

| Standard sieve size | Cumulative Passing % | Cumulative passing % Iraqi specifications limits No.45/1984 [32] |
|---|---|---|
| 10mm | 100 | 100 |
| 4.75mm | 96.6 | 90-100 |
| 2.36mm | 88.05 | 75-100 |
| 1.18mm | 65.2 | 55-90 |
| 0.6mm | 40.75 | 35-59 |
| 0.3mm | 15.02 | 8-30 |
| 0.15mm | 4.5 | 0-10 |

### 3.3.3 Coarse Aggregate

Coarse aggregate gradation (5-20) mm was used as one of the concrete components. It is naturally available in the Chilat region, east of Al-Amarah, southern Iraq. Before using it in concrete, it was washed with water to get rid of the clay materials and salts suspended in the granules. The gradation of aggregates was examined in the concrete laboratory of the College of Engineering/University of Misan, and the result was under the Iraqi Standard specification No. 45/1984 [32]. Table 3.4 includes the results of the gradation test of coarse aggregates.

Table 3.4 Grading of Coarse Aggregate.

| Sieve size (mm) | Passing (%) Coarse aggregate | Iraqi specification No.(45)/1984[32] |
|---|---|---|
| 75mm | --- | ---- |
| 37.5mm | 100 | 100 |
| 20mm | 97.5 | 95-100 |
| 10mm | 41.4 | 30-60 |
| 5mm | 3.22 | 0-10 |
| 2.36mm | --- | --- |

### 3.3.4 Water

In order to obtain salt-free concrete, pure drinking water (RO) was used in the preparation of mixtures and all pouring works in this study. The same pure water was used in the treatment of all concrete specimens during the concrete maturation period until the final hardening stage after the age of 28 days and 90 days.

### 3.3.5 Admixture

Concrete that contains PET waste as a partial substitute for sand is one of the components of the concrete mix that needs to add some improver materials to get acceptable workability and reduce water and porosity. The improvers give good properties to the concrete in its fresh and hard state. One of these plasticizers is the superplasticizer (Hyperplast PC 260), which was used in this study as an additive for fibrous concrete containing PET waste. This material complies with the American Standard ASTM C494 Type A, G [33]. Table 3.5 shows the technical specifications of hyperplast PC 260 material (according to its technical bulletin).

Table 3.5 Technical of the material hyperplast PC260.

| Properties | Hyperplast pc 260 |
|---|---|
| Chemical. Base polymer. | Modified polycarxylates Based. |
| Colors liquid | Light yellowish to. Brownish |
| Freezing point | ≈ -7 $^{o}$c |
| Specific. gravity @25 $^{o}$c | 0.02 ± 1.1 |
| Air content | Less. than 2%. The increase in air content in the concrete mixture compared to the architectural mixture |
| Dosage | 0.5 to 3.0. Liter per100kg of binder |

### 3.3.6 Steel Reinforcement

Deformed steel bars with diameters of 10 mm were used for both lateral and longitudinal reinforcement in slabs. The steel reinforcement characteristics are shown in Table 3.6 [34].

Table 3.6 Characteristics of Reinforcement Bars [34].

| Dia. of bar (mm) | Area of bar $mm^2$ | Yield strength $f_y$ (Mpa) | Tensile strength $f_u$ (Mpa) |
|---|---|---|---|
| 10 | 78.5 | 520 | 629 |

### 3.3.7 PET Plastic Waste as Sand Replacement

Polyethylene Terephthalate PET Bottle Waste is the plastic type that was used in the present study. PET bottles with different sizes and colors were minced to very small diameters and particles passing the sieve No. 4. This means that the maximum particle size is less than 4.75 mm as shown in Figure 3.1. It was brought from the factories and Choppers of Al-Naseri Gropes (Sama Pack) branch from Baghdad city, AL-Tajiat region, which are specialized in recycling PET waste exclusively. A sieve analysis was carried out for PET particles and found that it approximates the sieve analysis of sand according to the Iraqi Specification No. 45/1984 [32] with a difference in fine sieves, as shown in Table 3.7 and Figure 3.2. The specific gravity of PET particles is 1380 $kg/m^3$.

Table 3.7 PET Waste Particles Grading

| Sieve size(mm) | PET percent passing % | Cumulative passing % Iraqi specifications limits No.45/1984 [32] |
|---|---|---|
| 10 | 100 | 100 |
| 4.75 | 95.6 | 90-100 |
| 2.36 | 97.64 | 75-100 |
| 1.18 | 18.72 | 55-90 |
| 0.60 | 2.55 | 35-59 |
| 0.3 | 0.5 | 8-30 |
| 0.15 | 0.19 | 0-10 |

Figure 3.1PET Molecules Produced by Chopping Water Bottles and Soft Drinks.

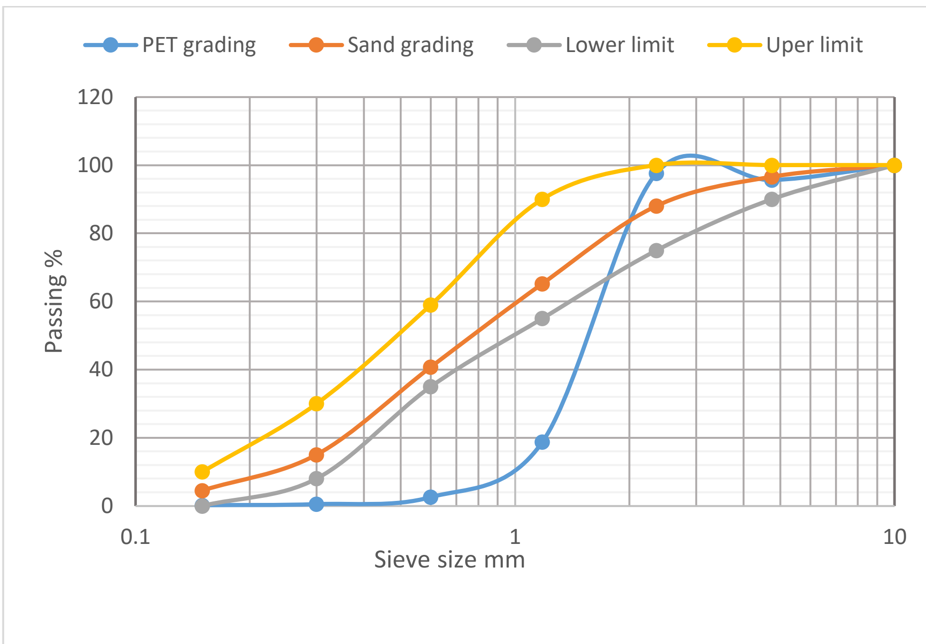



Figure 3.2 Grading Curve for Original Fine Aggregate and PET Waste.

### 3.3.8 Polypropylene Fiber

The reasons for the preference of polypropylene fibers can be listed as easy workability, high strength, low density, and immense chemical resistance [35]. Polypropylene fiber of length (12 mm) and diameter (0.018 mm) was used to be added to the concrete containing the replacement ratio of PET waste because these fibers positively affect the physical, mechanical, and thermal properties of concrete [36]. Figure 3.3 shows the shape of polypropylene fiber used in the research. These fibers have a high young modulus (3700 MPa) and tensile strength (350 MPa). Table 3.8 shows the properties of polypropylene fiber.

Table 3.8 Show the Properties of Polypropylene Fiber.

| Properties | Polypropylene fiber |
|---|---|
| Length (L) | 12mm |
| Diameter (D) | 0.018mm |
| Tensile strength | 350Mpa |
| Specific gravity | 0.91 g/cm$^3$ |
| Aspect ratio (L/D) | 670 |
| Melt point | 160 $^o$c |
| Young's modulus | 3700Mpa |

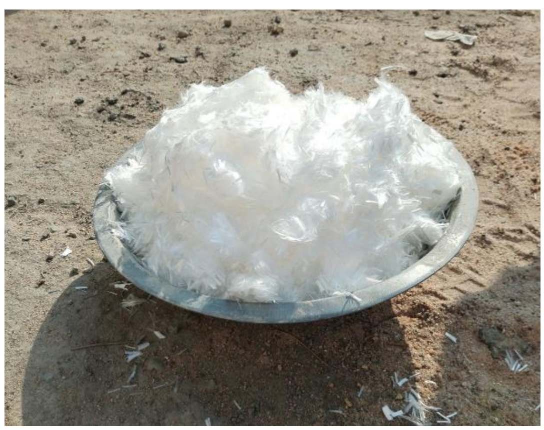


Figure 3.3 The Shape of the polypropylene fiber.

## 3.4 Experimental Work for Fiber-Reinforced Concrete Slabs with PET Waste

Experimental work involves studying the effect of using PET waste resulting from cutting and chopping plastic bottles of water and soft drinks and polypropylene fiber on the mechanical and physical properties of concrete, besides studying its effects on the behavior of reinforced concrete slabs with polypropylene fiber and that containing PET waste as an alternative to sand with and without steel bars. The work in this section is divided into two parts:

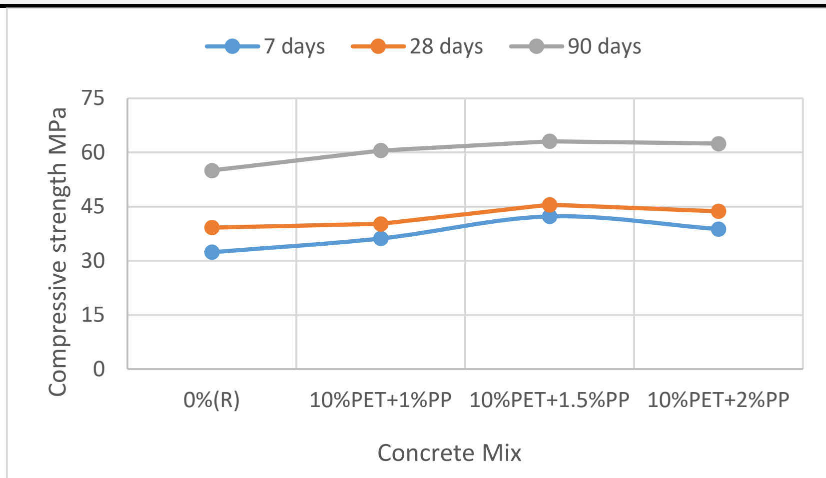
### 3.4.1 Pre-Trail Experiment Work to Select the Optimum Percentage of Polypropylene Fibers with Concrete Mixtures Incorporating PET Wastes

In this study, the experimental work was relied upon to give a priority and specific indication of the properties and behavior of concrete that contains recycled plastic waste and polypropylene fiber, focusing on the quantities and proportions of materials as well as the nature of replacement. The experimental work includes using several ratios of polypropylene fibers with 10% plastic waste, which is the optimal ratio where the mixtures were used to find out the proportions that could be used in the concrete mixture. Three proportions were introduced into the concrete mix of polypropylene fiber: 1%, 1.5%, and 2% of the concrete volume with 10% PET waste in addition to the reference ratio (without PET waste and fiber) as shown in Figure 3.4. The compressive strength and density tests were carried out by casting 36 cubes 150×150×150 mm. nine cubes for each percentage. Three tested at age 7 days, the other three at 28 days, and three at 90 days. The mix proportion is 1: 1.5: 3. The water-cement ratio was 0.4 with the admixture (Superplasticizer) of 0.5%. The results showed that density decreased with PET replacement, and the compressive resistance began to increase gradually, reaching 1.5% of fibers. After that, the compressive strength began to drop below the value of 1.5%; therefore, observe the ratio. 1.5% of polypropylene fiber and 10% PET waste gave the highest compressive strength, which represents the optimum percentage. The results were shown in Table 3.9 and Figure 3.5. As a result of this trail work, the experimental work scope used seven ratios of PET as a partial sand replacement, in addition to the reference ratio, which will be used, namely 0%, 5%, 10%, 15%, 20%, 30%, and 50% with 1.5% PP fiber.


Figure 3.4 The Components of the concrete mixture.

Table 3.9 Results of the Compression and Density at age of 7 ,28 and 90 days for the Concrete Cubes for The Pre-Trail Experiment Work.

| Concrete Mix type | Age 7 days | | Age 28 days | | Age 90 days | |
|---|---|---|---|---|---|---|
| | Compression MPa | Density $Kg/m^3$ | Compression MPa | Density $Kg/m^3$ | Compression MPa | Density $Kg/m^3$ |
| 0% R | 32.4 | 2380.21 | 39.2 | 2375.36 | 55 | 2364.76 |
| 10%PET+1%PP | 36.2 | 2334.52 | 40.2 | 2330.45 | 60.5 | 2311.2 |
| 10%PET+1.5%PP | 42.3 | 2341.7 | 45.5 | 2335.06 | 63.1 | 2326.33 |
| 10%PET+2%PP | 38.8 | 2345.03 | 43.7 | 2265.3 | 62.4 | 2253.1 |



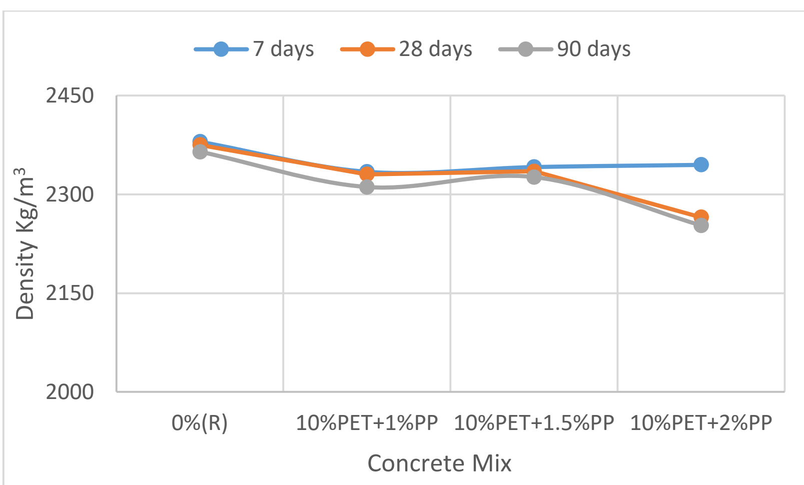




Figure 3.5 Compression Strength and Density of the Concrete Cubes for The Pre-Trail Experiment Work.

### 3.4.2 Part One: Using PET Waste as a Partial Replacement of Sand in the Mixture of Concrete

#### 3.4.2.1 Mixture of Concrete

The proportion of mixing is 1:1.5:3, which is used as a weight concrete mixture according to trail mixtures. Materials weights are 450 kg/m$^3$, 675 kg/m$^3$, and 1350 kg/m$^3$ for cement, sand, and gravel, respectively. The ratio of water to cement is 0.40 with 0.5% of admixture (superplasticizer) to enhance the workability of the mixture. Seven mixing ratios containing 1.5% of polypropylene fiber with a length of 12 mm and a diameter 0.018 mm were used for the mixture consisting of mixing ratios of PET waste with sand, which are 0%, 5%, 10%, 15%, 20%, 30%, and 50%, in addition to the reference mixture without PET waste and polypropylene fiber. This part of the work focuses on the mixture proportions and the ratio of replacement. Table 3.10 includes all quantities of material in one cubic meter and percentages of replacement.

Table 3.10 Mixing Ratios Per Cubic Meter with Polypropylene Fiber.

| PET/ Sand% | Cement Kg/m$^3$ | Sand Kg/m$^3$ | Gravel Kg/m$^3$ | Water Kg/m$^3$ | PET Kg/m$^3$ | SP Kg/m$^3$ | W/C | PP Fiber Kg/m$^3$ |
|---|---|---|---|---|---|---|---|---|
| 0%(Ref) | 450 | **675** | 1350 | 180 | **0** | 2.25 | 0.4 | 0 |
| 0% | 450 | **675** | 1350 | 180 | **0** | 2.25 | 0.4 | 13.65 |
| 5% | 450 | **641.25** | 1350 | 180 | **33.75** | 2.25 | 0.4 | 13.65 |
| 10% | 450 | **607.5** | 1350 | 180 | **67.5** | 2.25 | 0.4 | 13.65 |
| 15% | 450 | **573.75** | 1350 | 180 | **101.25** | 2.25 | 0.4 | 13.65 |
| 20% | 450 | **540** | 1350 | 180 | **135** | 2.25 | 0.4 | 13.65 |
| 30% | 450 | **472.5** | 1350 | 180 | **202.5** | 2.25 | 0.4 | 13.65 |
| 50% | 450 | **337.5** | 1350 | 180 | **337.5** | 2.25 | 0.4 | 13.65 |

### 3.4.2.2 Specimens of Experimental Work

In this part of the thesis, the physical and mechanical properties of polypropylene fiber-reinforced concrete that contain replacement ratios of PET waste as an alternative to sand will be studied. The specimens included nine cubes of 150*150*150 mm dimensions for density, compressive strength, ultrasonic pulse velocity, and absorption tests; nine cylinders of 200*100 mm dimensions for splitting tensile strength test; six prisms of 500*100*100 mm dimensions for flexural strength test; and two cylinders of 150*300 mm dimensions for modulus of elasticity test, as shown in Figure 3.6.

Figure 3.6 Molds Work Specimens.

### 3.4.2.3 Mixing Procedure

A mixing machine was used for mixing all concrete mixtures and each mixture was prepared separately in the laboratory of the Faculty of Engineering / University of Misan, according to the following steps:

1- All raw materials included in the composition of each mixture were brought from materials of sand, gravel, PET waste, cement, superplasticizer, and polypropylene.
2- The gravel material was washed with pure water to removing dust and dirt, then dried by leaving them for several days under the sun until it was completely dried.
3- Preparing the mixing machine and cleaning it, along with preparing all the casting equipment from pots and vibrators to expel air from the concrete, as well as workers and others, while taking all safety and prevention measures.
4- Preparation of laboratory standard steel molds, cleaning and lubricating them to prevent adhesion between the concrete and the inner surface of the mold; these molds are used for casting concrete models. They are standard molds for cubes with dimensions (150 × 150 × 150) mm, prisms (500 × 100 × 100) mm, cylinders (150 × 300) mm, and cylinders (200 × 100) mm.
5- All components of concrete mixtures are weighed in advance for each mixture separately and placed in bags with an identification sheet containing the name and weight of the specimen in each bag.
6- Coarse aggregate and fine aggregate consisting of mixing ratios of PET waste and natural sand are added and placed in the bowl of the mixer, then the mixer is running for 2 minutes. Then the cement is added to the mixer, and the ingredients are mixed for another 2 minutes for the purpose of maintaining the maintaining the homogeneity of the dry mixture components. The water

is gradually added with the addition of the superplasticizer to the mixing bowl, the ingredients are mixed for 3 minutes. The mixer is restarted for a period of 2 minutes in order to ensure good homogeneity in the concrete components. Then the polypropylene fiber material is added to the concrete mix, where the fiber is added manually and slowly to the mixer bowl while the mixer bowl continues to rotate in order to avoid its gathering in one block, as shown in Figure 3.7, then mix the concrete components inside the mixer for 5 minutes to disperse the fibers and spread well throughout the concrete mix.

7- After the mixing process is completed, then a specimen of the fresh concrete is taken and a slump test is conducted on it for each mixture. The concrete is then poured into the modeling molds, and the vibrator is operated on it and left for 24 hours after casting to harden.

Figure 3.7 Manually Adding Fibers to The Mixer.

#### 3.4.2.4 Casting and Curing Operations

Concrete is poured into three layers in the mold, each layer with a thickness of 5 cm for specimens, with the use of a standard steel rod with dimensions (2.5 × 2.5 × 38) cm to compact small specimens. After the casting is completed, the specimens are left for 24 hours, then the molds are opened the next day, and the concrete specimens are transferred to water basins for the purpose of concrete maturation for a period of 90 days, with the water changed every 5 days as shown in Figure 3.8. After the concrete curing period with water is over, it is taken out and prepared for testing.

Figure 3.8 Process of Casting and Curing.

**3.4.2.5 Tests on Concrete**

**3.4.2.5.1 Fresh Concrete Test**

**3.4.2.5.1.1 Slump Test**

This test is important for concrete and is carried out on all types of concrete at the worksite before pouring it into the mold. It is used to identify changes that occur in the materials that enter into the production of concrete through it, obtain an indicator of the workability of the fresh concrete, and also guarantee obtaining a homogeneous concrete. For this test, a standard iron mold in the shape of a minus cone is used, with a height of 300 mm and a diameter of 100 mm from the top and 200 mm from the bottom with an iron base and a standard steel rod 600 mm in length and 15 mm in diameter, as shown as shown in Figure 3.9. The slump test is applied to fresh concrete according to ASTM C143 [37].

Figure 3.9 Slump Test for Concrete.

**3.4.2.5.2 Mechanical Tests of Hardened Concrete**

**3.4.2.5.2.1 Compressive Resistance Test**

The compressive strength test of concrete was carried out by using standard cubic iron molds and casting concrete cube specimens with standard dimensions (150×150×150) mm and according to the British Standard BS1881 part 116-89 [38]. Where the cubes were cast with a thickness of 15 cm in the form of layers and each layer was 5 cm thick, and the layers were tamped using a steel rod with dimensions (2.5 × 2.5 × 38) cm or by using a mechanical vibrating device to expel the trapped air inside the concrete, and the compression testing machine for concrete with a capacity of 2000 kN is used. The benefit of this test on cubes is to know the concrete resistance to the compressive applied to it. All specimens were tested in the laboratory of the College of Engineering / University of Misan, as shown in Figure 3.10.

Figure 3.10 Compression Testing Machine for Concrete Cubes.

### 3.4.2.5.2.2 Flexural Resistance Test

For this test, concrete prism specimens with dimensions of 500 × 100 × 100 mm are used to test the flexural strength of concrete according to ASTM - C78 [39]. By applying a linear load in the middle of the beam according to the type of testing machine available in the laboratory. The capacity of the flexural testing device is 5000 kN, as shown in Figure 3.11. By using the following equation to calculate the modulus of rupture:

$$\text{Modulus of rupture (Fr)}=\frac{3pL}{2.b.d.d} \qquad 3.1$$

Modulus of rupture (Fr) in (MPa). P: Maximum Load applied to the beam (N) L: Span Length (mm) from center to center support. b: average width of the specimen (mm), d: average depth of specimen (mm).

Figure 3.11 Flexural Strength Testing Machine For Concrete Prisms.

**3.4.2.5.2.3 Splitting Tensile Strength Test**

To extract the tensile strength of concrete, we used the splitting tensile strength test. To conduct this test, and used concrete cylindrical specimens with dimensions (200 × 100) mm and tested (3) specimens with an age of (7) days, (3) specimens with an age of (28) and (3) specimens with an age of (90) for each concrete mixture. This test is applied according to the American Standard ASTM-C496 [40], and the test is carried out in the same compression test device with a capacity of 2000 kN to determine the splitting tensile strength of a concrete cylinder when it is compressed, causing an indirect (secondary) tensile stress that divides the cylinder into two pieces depending on the kind of concrete mixture as shown in Figure 3.12. To calculate the splitting tensile strength (horizontal tensile stress) of concrete specimens, we use the following equation:

$$\text{Where: } Ft=\frac{2P}{\pi\, DL} \qquad 3.2$$

Ft: splitting Tensile strength (MPa). D: Diameter of specimen (mm).

P: Maximum applied Load on specimen concrete (N).

Figure 3.12 Splitting Tensile for Test Concrete Cylinders.

### 3.4.2.5.2.4 Modulus of Elasticity Test

Modulus of elasticity is carried out according to specification ASTM-C469 [41] by using a compressive machine of 2000 kN capacity. The test is done by using two cylinders with dimensions of 150*300 mm, as shown in Figure 3.13. The modulus of elasticity is determined by applying the following equation:

$$E \frac{S_2-S_1}{\varepsilon_2-50*10^{-6}} \quad 3.3$$

Where:

$S_2$: Stress equivalent to 40% of the ultimate load.

$S_1$: Stress equivalent to longitudinal strain $50*10^{-6}$

$\epsilon_2$: Longitudinal strain founded by $S_2$.


Figure 3.13 Modulus of Elasticity Test for Cylindrical Specimens.

### 3.4.2.5.3 Physical Tests of Hardened Concrete

#### 3.4.2.5.3.1 Dry Density Test

The weight of concrete cubes (150) mm is taken before a compressive test is performed on them for each specimen of the cubes to calculate the dry density of the concrete as shown in Figure 3.14. The test is as per ASTM C642 [42].

Figure 3.14 Dry Density Test of The Concrete Cubes.

### 3.4.2.5.3.2 Absorption Water Test

The absorption water test was carried out by using concrete cubes with dimensions (150 ×150 × 150) mm for all concrete mixtures and according to the American specification ASTM C642 [42]. Where the cubed specimens are placed in the drying oven for 72 hours at a temperature of 100˚C, then the specimens are weighed while they are dry to obtain the dry weight. The specimens are immersed in water for 24 hours, and the weight of the specimens is taken after immersion again. The test was carried out in the laboratory of the Technical Institute in Misan, as shown in Figure 3.15. The percentage of absorption concrete for water is calculated from the following relationship [42]:

$$W.A=\frac{w_2-w_1}{w_1}*100\% \qquad 3.4$$

$W_2$: Weight of specimen after submerged in water.

$W_1$: Dry weight

W.A: Water Absorption rate %.

Figure 3.15 Water Absorption Test of Concrete Cubes Specimens.

### 3.4.2.5.3.3 Ultrasonic Pulse Velocity (UPV)

This non-destructive test is performed on concrete cubes with dimensions (150 × 150 × 150) mm at the age of 28 days and before crushing by testing the compression, three cubes for each concrete mix. The test is carried out according to BS 1881 Part 116 [43]. A (Bundlt Lab) device with an accuracy of 0.1 microseconds is used to do the test. And the path length of the specimen is set between transducers for the device, then a light layer of gel liquid is placed on the face of the test area of the concrete cube. Then, the test is done on all the axes of the cube, this test is used to determine the quality of the concrete, as shown in Figure 3.16.

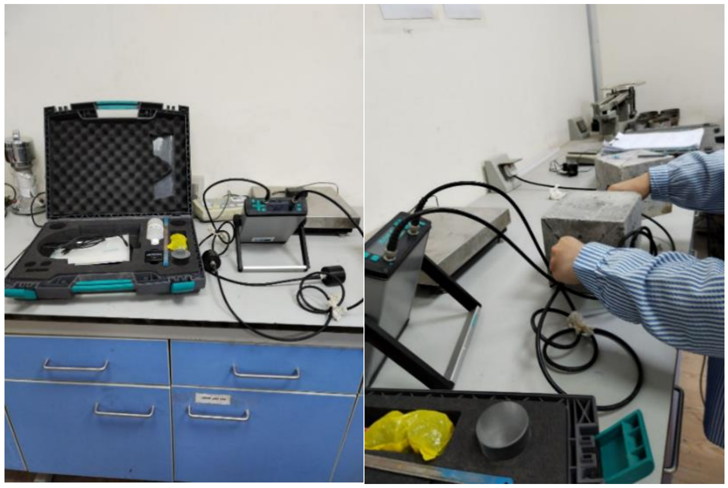


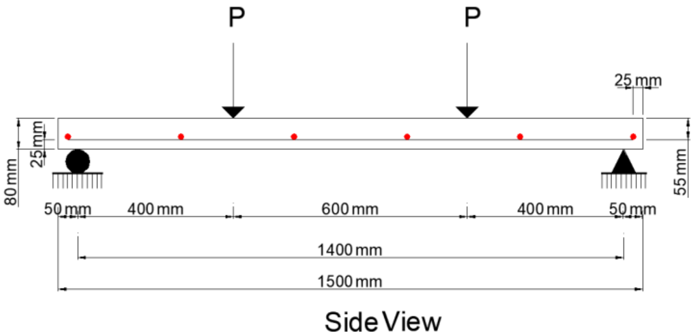
Figure 3.16 Ultrasonic Pulse Velocity (UPV) Test for Concrete Cubes.

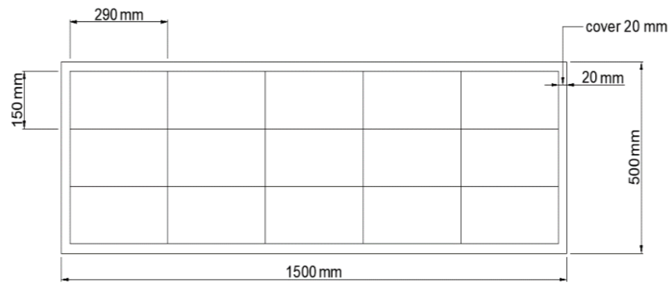
### 3.4.3 Part Two: Specimens of Fiber Reinforced Concrete Slabs Contained PET Waste as Replacement for Sand

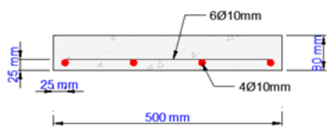
In this part, the same materials as part one were used, as shown previously in Table 3.10. This part, considered with the flexural behavior of reinforced concrete slabs, contained PET waste as sand replacement.

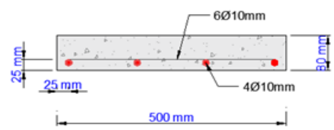
#### 3.4.3.1 Specimens of Reinforced Concrete Slabs

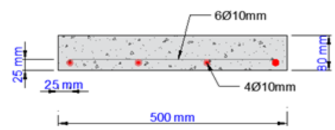
This part of the thesis is concerned with studying the effect of using PET waste on the behavior of concrete slabs reinforced with polypropylene fiber, where fourteen rectangular one-way slabs of Simply supported were cast with dimensions (1500 × 500 × 80) mm and containing different proportions of PET waste. The ratio of length (l) to width (w) of these slabs (l/w) > 2. These slabs are with polypropylene fibers, where two slabs are cast for each replacement ratio, in addition to the two reference slabs (without PET waste and polypropylene fiber (0% PET, 0% PP). The total number of the concrete slabs is 16 slabs, which are divided into 8 reinforced concrete slabs reinforced with 4Ø10@150 mm in the short direction as main reinforcement and 6Ø10@290 mm in the long direction as secondary reinforcement, as shown in Figure 3.17. The rectangular wooden molds were used, consisting of a wooden base with side ribs connected to each other and to the wooden base by means of fixing screws that can be opened. The thickness of the wood used is 18 mm; also, the concrete slab is a rectangular-shaped slab with dimensions of length (l) = 1500 mm, width (w) = 500 mm, and thickness (t) = 80 mm. These dimensions are used in all fiber-reinforced and non-reinforced concrete slabs that contain PET waste. This study used two supports of 1400 mm clear span and two points of load with a distance of 600 mm separated between them. The distance between both points of load and support (a) is equal to 400 mm, and the effective depth of the slab section is equal to 55 mm. Therefore, the a/d value is equal to 7. The same dimensions were used for the eight concrete slabs to be suitable for the test conditions available in the laboratory in terms of the test machine and the width of the axes of the device. From the concrete slabs test, we get the deflection of the slab, the absorption energy, strain, and the maximum failure load of the slab, ductility, stiffness, crack pattern, and study the results, evaluating to get the best performance of concrete.



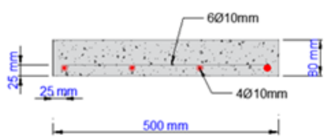



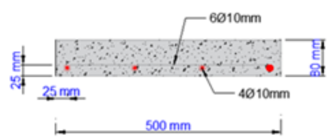



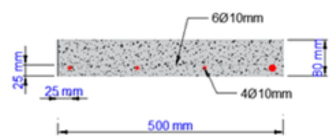



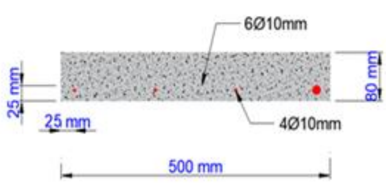

S0%0%R S0%PF1.5%R S5%PF1.5%R

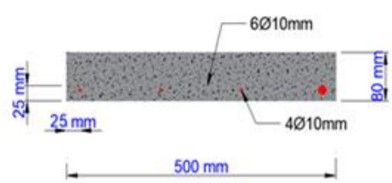



S10%PF1.5%R S15%PF1.5%R S20%PF1.5%R




S30%PF1.5%R S50%PF1.5%R

Figure 3.17 The Details of Reinforcement Concrete Slabs.

### 3.4.3.2 Casting and Curing Procedure of Slabs

Casting and curing procedures of slabs are done according to requirements, as shown in Figure 3.18. Firstly, the interior sides of molds are greased with oil, the cages of reinforcement are entered into the molds, and then the casting process of concrete starts and is compacted by a vibrator. Finally, the upper surface of slabs was smoothed and leveled. After completing the casting of concrete, the curing of slabs is done, for they are covered with pieces of cloth that are characterized by their retention of moisture. These pieces of fabric are soaked with water and placed on the concrete specimens and sprayed with water every day, Figure 3.19.

Figure 3.18 The Details of Slabs Casting.

Figure 3.19 The Curing of Slabs.

### 3.4.3.3 Testing of Concrete Slabs

#### A. Testing Machine

Concrete slabs are tested by a flexural testing machine (ALFA) in the laboratory of the College of Engineering / University of Misan, as shown in Figure 3.20. The capacity of the device is 6000 kN with dimensions (5 meters long × 0.8 meters wide), and the device contains a hydraulic jack with an electronic control panel.

Figure 3.20 The Flexural Test Machine.

**B. LVDT**

A linear variable differential transformer (LVDT) was used to measure the deflection of all slabs in the mid-span area, which recorded the reading automatically as shown in Figure 3.21.

Figure 3.21 The Position of LVDT on the Slab.

### C. Strain Gages

One strain gauge with a length of 30 mm was used for each concrete slab; the location is in the middle of the slab as shown in Figure 3.22. The concrete area on which the strain gauge is placed is cleaned, then a base layer is placed for leveling the surface and left for 24 hours. Then the strain gauge is fixed to the concrete surface with a special adhesive, and then the strain gauge wires are connected to the Data Logger device, as shown in Figure 3.23.


Figure 3.22 The Strain Gauge Location for All Slabs.


Figure 3.23 Paste Gauges on The Concrete Slabs.

**D. Slab Test Method**

The testing of Slabs is done by using a universal testing machine at Misan University College of Engineering, as seen in Figure 3.24. To show crack growth, all slabs were cleaned and colored white. The machine applied a concentrated load to the structural member via a steel loading roll over a thin rubber strip, achieving uniform contact between the load and the slab. Then the device (LVDT) is installed in the middle of the slab from the bottom to measure the deflection. After completing the adjustment procedures, the hydraulic device is operated, and the load is applied in successive increments of the slab from the top under the influence of flexion until the final failure load is reached. The laptop records and saves the readings of deflection, load, and strain at each applied phase, as well as observes the failure and cracking pattern for the slab. Once the final failure of the slab is reached, the device stops loading.

Figure 3.24 Flexural Test of Slabs.

# CHAPTER FOUR: TEST RESULTS AND DISCUSSION

## 4.1 General

In this chapter, the results and discussion of fresh and hardened concrete are presented. The slump result test of fresh concrete is mentioned here. While for hardened concrete some test results are presented in this chapter, such as compression, splitting, flexural strength, and modulus of elasticity tests. In addition, ultrasonic pulse velocity, absorption, and density tests. Eight mix designs are presented here: seven mixes with partial replacement of natural sand with PET reinforced with polypropylene fibers, and one mix is the reference. Also, the test results of concrete slabs are presented, and the structural behavior results of these slabs are evaluated for each replacement ratio of PET waste containing fibers. 16 concrete slabs, divided into 8 reinforced concrete slabs reinforced with steel bars and 8 other slabs without steel bars. The test results on the slab include knowing the ultimate failure load of the slab, ultimate deflection, strain, failure mode, stiffness, ductility index, and absorption energy with graphs for each group and evaluating their results for each replacement ratio.

## 4.2 Tested Specimens' Results

The test results of the concrete samples used in this study were divided into two parts. The first part includes the presentation of the results of the mechanical and physical tests on the concrete samples containing PET waste as sand replacement and reinforced with polypropylene fibers, and the second part includes the study of the structural behavior of concrete slabs with simple support under the effect of bending. 208 concrete samples of all concrete mixtures were used for the purpose of testing the mechanical and physical properties of the concrete used in this study. These concrete samples consist of 72 standard cubes with dimensions of (150×150×150) mm, 48 concrete prisms with dimensions of (100×100×500) mm, 72 cylinders with dimensions of (200×100) mm, and 16 cylinders with dimensions of (300×150) mm. (16) One-way rectangular concrete slabs with dimensions of (1500×500×80) mm, two slabs for each ratio, containing PET waste as a substitute for sand in different ratios and reinforced with polypropylene fibers, divided into 8 concrete slabs with steel bars and 8 slabs without steel bars.

### 4.2.1 Part (1): Results of Tests of Mechanical and Physical of Concrete Specimens

This section presents and discusses the results of tests on samples of fresh and hardened concrete containing different proportions of polyethylene terephthalate waste as a substitute for sand and reinforced with polypropylene fibers. The mechanical properties of the hardened concrete samples are tested at the ages of 7, 28, and 90 days for each replacement ratio. These tests include:

1-Slump test (workability of fresh concrete)

2-Mechanical properties tests for hardened concrete

2-1 Compressive resistance

2-2 Flexural resistance

2-3 Split tensile resistance

2-4 Modulus of elasticity

3-Physical properties tests for hardened concrete

3-1 Dry Density

3-2 Absorption

3-3 Ultrasonic pulse velocity test

#### 4.2.1.1 Workability (Slump Test)

Slump was promptly recorded after mixing to guarantee that mixtures with a water-cement ratio of 0.4. According to Figure 4.1 and Table 4.1, the results showed that the workability of the concrete declines with increasing percentages of PET waste in the mixture. When compared to the reference mix, the 50% PET replacement rate yielded a more difficult concrete workability of 40 mm, which is 75.3% less than the slump of the reference mixture. While specimens that contain PET waste as sand replacement for ratios (0%, 5%, 10%, 15%, 20%, 30%) and reinforcement with polypropylene fibers, which achieved a decrease of 7.4%, 11.1%, 19.8%, 29%, 47.5%, and 58%, respectively, when compared to the value of the reference ratio. The workability of concrete is reduced because PET waste particles have a greater surface area compared to sand particles. This higher surface area allows for the saturation of a considerable quantity of water on their surface, resulting in a decrease in the workability of the concrete. Another reason the workability is reduced when the PET increases is that the particles from PET bottles have sharp and irregular edges, which increases their surface area. Increasing the water-to-cement ratio is one possible solution to this issue; however, it affects concrete's performance and is hence not recommended, or the addition of superplasticizers, which enhanced the mixture's workability and were used in this investigation.

Table 4.1 Result of Slump for Concrete Specimens Containing PET Waste with Fibers.

| PET/ SAND % | Slump (mm) | Variation in slump % | Workability classification | Limit of EN 206 [44] |
|---|---|---|---|---|
| 0%PET+0%PP(R) | 162 | 0 | High | >160mm |
| 0%PET+1.5%PP | 150 | -7.4 | Medium | 100-150mm |
| 5%PET+1.5%PP | 144 | -11.1 | Medium | 100-150mm |
| 10%PET+1.5%PP | 130 | -19.8 | Medium | 100-150mm |
| 15%PET+1.5%PP | 115 | -29 | Medium | 100-150mm |
| 20%PET+1.5%PP | 85 | -47.5 | Low | 50-90mm |
| 30%PET+1.5%PP | 68 | -58 | Low | 50-90mm |
| 50%PET+1.5%PP | 40 | -75.3 | Very Low | <50mm |

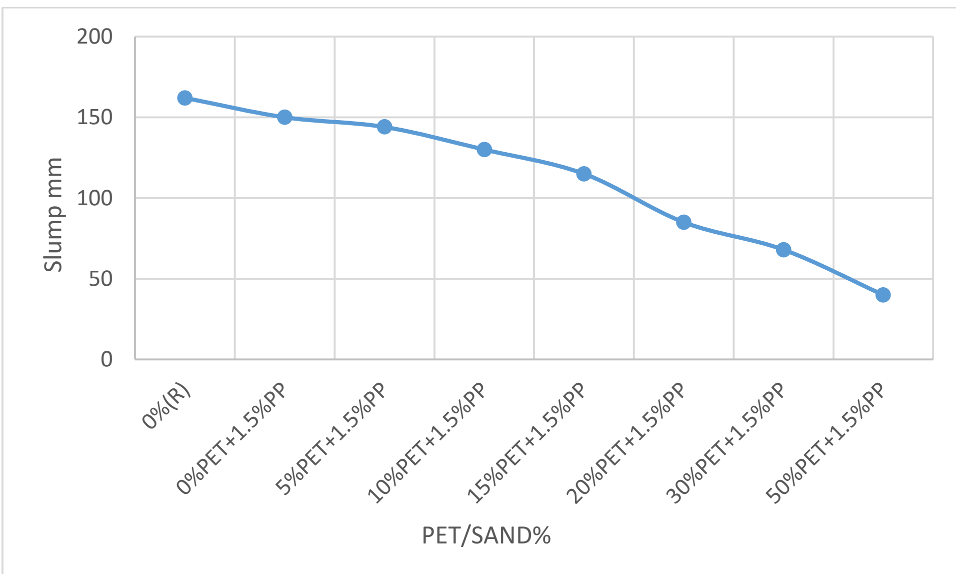



Figure 4.1 Results Curve for Mixtures Containing PET Waste with Fibers.

#### 4.2.1.2 Results of Mechanical Properties

##### 4.2.1.2.1 Compression Strength Results

Concrete specimens reinforced with polypropylene fiber and containing PET waste as a sand substitute were tested for compressive strength at 7, 28 and 90 days of age. The findings are shown in Table 4.2 and Figure 4.2. Evidence of an improvement in compressive strength relative to the reference mixture of concrete cubes was found at 7, 28, and 90 days of concrete age in varying proportions for specimens containing PET, namely (5%PET+1.5%PP) and (10%PET+1.5%PP), respectively.

Results after 7 days: Showed that compressive strength improved with sand replacement ratios up to 10% over the reference ratio (0% PET). There is a 39.22% improvement in the specimen's compressive strength (10% PET+1.5% PP). While specimens that contain PET waste as sand replacement for ratios (15%, 5%, 0%, 20%, 30%, 50%) and reinforcement with polypropylene fibers, which achieved a rise of (27.45%, 21.29%, 15.41%, 13.73%, -7.28%, -35.85%) respectively, when compared to the value of the reference ratio.

At 28 days of age: There was a discernible shift in the compression strength curve; however, it was less pronounced than the shift at 7 days before when contrasted with the reference cube. The compressive strength of the specimen (10%PET+1.5%PP) increased by 29.06% more than that of the reference cube. While specimens that contain PET waste as sand replacement for ratios (15%, 5%, 20%, 0%, 30%, 50%) and reinforcement with polypropylene fibers achieved a rise of 23.4%, 19.21%, 14.29%, 6.4%, -10.59%, and -37.68%, respectively, when compared to the value of the reference ratio.

Results after 90 days: Showed that compressive strength improved with sand replacement ratios up to 10% over the reference ratio (0% PET). There is a 38.44% improvement in the specimen's compressive strength (10% PET+1.5% PP). While specimens that contain PET waste as sand replacement for ratios (0%, 5%, 15%, 20%, 30%, 50%) and reinforcement with polypropylene fibers achieved a rise of (1.94%, 19.65%, 26.35%, 14.90%, -29.59%, -39.31%), respectively, when compared to the value of the reference ratio.

Because plastic particles may more effectively fill some of the holes in concrete with a low plastic percentage, boosting the specimen's compressive strength (10%PET+1.5%PP) is possible. However, there are a number of variables that might influence the decrease in compressive strength that occurs when the replacement PET percentage goes over 10%. These include the fact that PET particles have a poor affinity for cement paste, as well as the fact that PET trash is both larger and more irregularly shaped than sand particles.

The specimens containing PET particles as sand replacement cracked without smashing or crushing at the failure phase, with the reason being the ductility produced by PET particles and polypropylene fibers, which reduces cracking and absorbs energy. In contrast, the specimen containing the reference percentage of cube failed suddenly with smashing when it reached the failure stress (Figure 4.3).

Table 4.2 Results of Compression Strength for Concrete Specimens Containing PET Waste with Fibers.

| PET/ SAND % | Average compressive strength fcu (MPa) | | | Variation in compressive strength % (28 days) |
|---|---|---|---|---|
| | 7 days | 28 days | 90 days | |
| 0% PET+0%PP(R) | 35.7 | 40.6 | 46.3 | --- |
| 0%PET+1.5%PP | 41.2 | 43.2 | 47.2 | 6.40 |
| 5%PET+1.5%PP | 43.3 | 48.4 | 55.4 | 19.21 |
| 10%PET+1.5%PP | 49.7 | 52.4 | 64.1 | 29.06 |
| 15%PET+1.5%PP | 45.5 | 50.1 | 58.5 | 23.40 |
| 20%PET+1.5%PP | 40.6 | 46.4 | 53.2 | 14.29 |
| 30%PET+1.5%PP | 33.1 | 36.3 | 32.6 | -10.59 |
| 50%PET+1.5%PP | 22.9 | 25.3 | 28.1 | -37.68 |

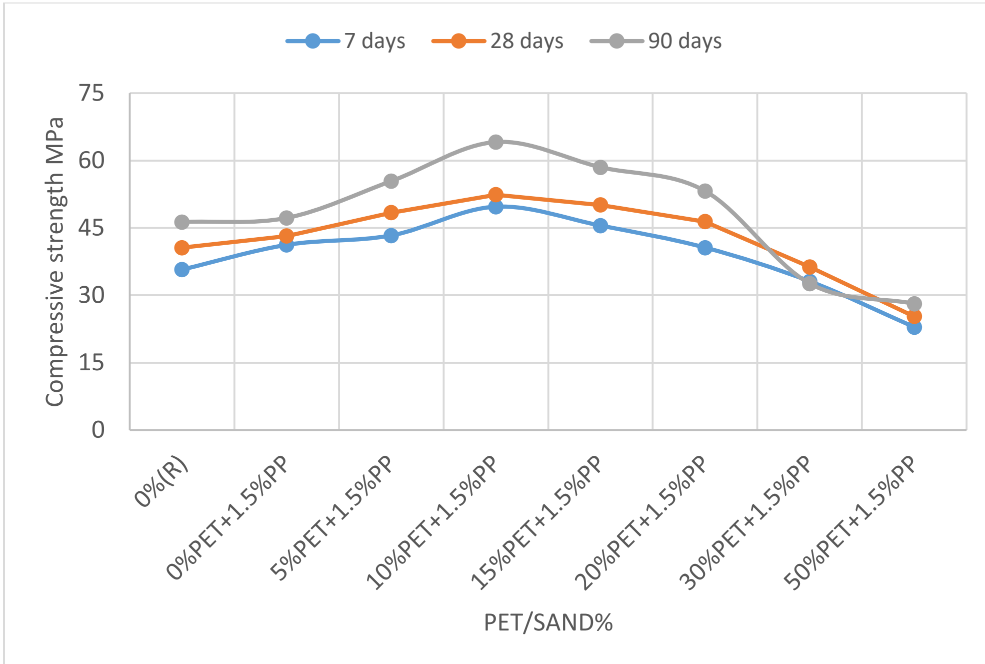



Figure 4.2 Results Compressive Strength Curve for Mixtures Containing PET Waste with Fibers.


Figure 4.3 Mode Failure of Compressive Specimens.

#### 4.2.1.2.2 Splitting Tensile Strength Results

Table 4.3 and Figure 4.4 show the results of the splitting tensile strength test at 7, 28 and 90 days for the reference specimen and concrete specimens that used PET waste as sand replacement and were reinforced with polypropylene fiber further. When compared to the reference specimens, the findings demonstrated that the concrete's splitting tensile strength was increased when PET was used as a sand substitute in the range of 5%–15% with polypropylene fiber.

At 7 days: The reference specimen achieved the split tensile strength of 2.1 MPa. When PET waste was used as sand replacement, we noticed an increase in tensile strength, where the specimen (10%PET+1.5%PP) achieved the highest tensile strength of 3 MPa, an increase of about 42.86% higher than the reference specimen, while the other specimens that contain PET waste for the ratios (15%, 5%, 20%, 0%, 30%, 50%) with polypropylene fibers are increased by (28.57% ,23.81% ,19.05%, 9.52%, -4.76%, -27.62%) greater than the reference specimen. whereas the replacement of 10% represented the ideal percentage.

At the age of 28 days: The increasing of tensile strength occurred in the same way. When the specimens that contain PET waste for the ratios (0%, 5%, 10%, 15%, 20%, 30%, 50%) with polypropylene fibers are increased by (4.17%, 20.83%, 37.5%, 29.17%, 16.67%, -4.17%, -20.83%), respectively, greater than the reference specimen.

At the age of 90 days: The increasing of tensile strength occurred in the same way. When the specimens that contain PET waste for the ratios (0%, 5%, 10%, 15%, 20%, 30%, and 50%) with polypropylene fibers are increased by 10.34%, 31.03%, 62.07%, 44.83%, 24.14%, -6.90%, and -27.59%, respectively, greater than the reference specimen.

PET particles are more ductile and sharper than sand particles, increasing splitting tensile stress. Samples substituted with 50% PET showed a decrease in splitting tension. This phenomenon may be caused by a huge number of particles forming a cohesive mass. This research employs PET garbage as a weight proportion of sand because PET particles are more numerous than sand at the same percentage. The flat surfaces of PET waste particles do not absorb water, reducing cement hydration.

The reference cylinder experiences a quick crushing and complete splitting in half, while the PET waste cylinder specimens exhibit no such separation. Instead, surface cracks appear and spread over the sample, as seen in Figure 4.5, suggesting that the PET waste contributed to the ductility of the material. However, when subjected to ultimate stress, PET specimens did not split in half, and their fracture patterns were more visible than those of the reference specimens prior to failure.

Table 4.3 Results of Splitting Tensile Strength for Concrete Specimens Containing PET Waste.

| PET/ SAND % | Average splitting tensile strength ft (MPa) | | | Variation in splitting tensile strength % (28 days) | fc ' MPa |
|---|---|---|---|---|---|
| | 7 days | 28 days | 90 days | | |
| 0 %PET+0%PP (R) | 2.1 | 2.4 | 2.9 | --- | 34.51 |
| 0%PET+1.5%PP | 2.3 | 2.5 | 3.2 | 4.17 | 36.72 |
| 5%PET+1.5%PP | 2.6 | 2.9 | 3.8 | 20.83 | 41.14 |
| 10%PET+1.5%PP | 3.0 | 3.3 | 4.7 | 37.5 | 44.54 |
| 15%PET+1.5%PP | 2.7 | 3.1 | 4.2 | 29.17 | 42.59 |
| 20%PET+1.5%PP | 2.5 | 2.8 | 3.6 | 16.67 | 39.44 |
| 30%PET+1.5%PP | 2 | 2.3 | 2.7 | -4.17 | 30.86 |
| 50%PET+1.5%PP | 1.52 | 1.9 | 2.1 | -20.83 | 21.51 |

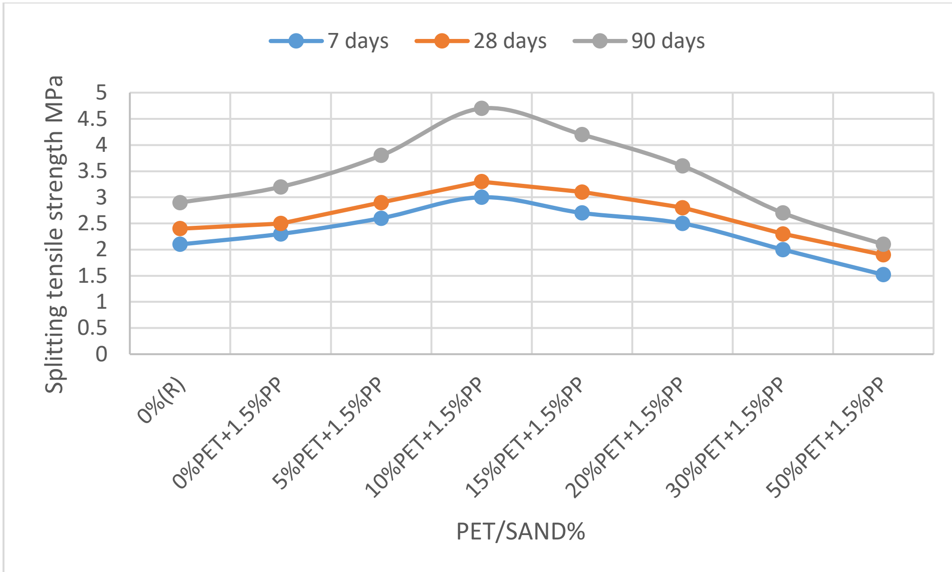



Figure 4.4 Results of Splitting Tensile Curve for Mixtures Containing PET Waste with Fibers.

| 0%(R) | 0%PET+1.5%PP | 5%PET+1.5%PP | 10%PET+1.5%PP |
|---|---|---|---|

| 15%PET+1.5%PP | 20%PET+1.5%PP | 30%PET+1.5%PP | 50%PET+1.5%PP |
|---|---|---|---|

Figure 4.5 Mode Failure of Splitting Tensile Specimens.

#### 4.2.1.2.3 Flexural Strength

At 7, 28 and 90 days of age, the reference specimen and concrete specimens reinforced with polypropylene fiber and containing PET waste as sand replacement were tested for flexural strength, as indicated in Table 4.4 and Figure 4.6. Six 500*100*100 mm prism samples were tested for flexural strength for each ratio of PET waste substitution ac. Two samples were taken to assess the strength of the concrete after seven days, two after twenty-eight days, and two after ninety days. When compared to the reference specimens, the flexural strength of the concrete was shown to be increased when 5%–15% of the sand was replaced.

At the age of 7 days: The specimens that contain PET waste ratios in a range of (5-20%) with polypropylene fibers achieved an increase in flexural strength with a variation of (24.32%, 16.22%), whereas the specimen (10%PET+1.5%) represented the highest value of flexural strength by 37.84%, while the percentage 50% gave results that were approached from the reference percentage.

At the age of 28 days: In comparison to the reference samples, the results showed the specimens that contain PET waste ratios ranging from 5% to 20% with polypropylene fibers led to an increase in flexural strength with an increment of 22.5% to 12.5%. For the specimen (50%PET+1.5%PP), the flexural strength showed a slight decrease from the reference concrete by 17.5 %. The specimen (10%PET+1.5%PP) obtained the highest flexural strength with an increase of 37.5% when compared to the reference concrete.

At the age of 90 days: In comparison to the reference samples, the results showed the specimens that contain PET waste ratios ranging from 5% to 20% with polypropylene fibers led to an increase in flexural strength with an increment of 31.82% to 11.36%. For the specimen (50%PET+1.5%PP), the flexural strength showed a slight decrease from the reference concrete by 15.91 %. The specimen

(10%PET+1.5%PP) obtained the highest flexural strength with an increase of 43.18% when compared to the reference specimen. Adding a modest amount of PET waste to concrete mixtures may increase flexural strength and make the concrete more flexible before failure compared to sand particles. The use of PET waste in quantities above 10% reduced the modulus of rupture due to a weak transition region between PET granules and cement paste, resulting in water collection around the particles.

Figure 4.7 clearly illustrates the failure manner by comparing the reference specimen, which split in half when subjected to the failure load, with the 10% PET specimen, which collapsed without any abrupt cracking or crumbling. It refers to the fact that PET particles may enhance concrete's flexural behavior, which in turn affects slabs' flexural behavior by decreasing fracture width and protecting reinforcing bars, and adding the polypropylene fibers also reduces the crack and absorbs energy.

Table 4.4 Results of Flexural Strength for Concrete Specimens Containing PET Waste with Fibers.

| PET/ SAND % | Average flexural strength fr (MPa) | | | Variation in flexural strength % (28 days) | fc ' MPa | $fr=0.62\sqrt{fc'}$ |
|---|---|---|---|---|---|---|
| | 7 days | 28 days | 90 days | | | |
| 0 %PET+0%PP(R) | 3.7 | 4.0 | 4.4 | --- | 34.51 | 3.64 |
| 0%PET+1.5%PP | 4.3 | 4.6 | 5.2 | 15 | 36.72 | 3.76 |
| 5%PET+1.5%PP | 4.6 | 4.9 | 5.8 | 22.5 | 41.14 | 3.98 |
| 10%PET+1.5%PP | 5.1 | 5.5 | 6.3 | 37.5 | 44.54 | 4.14 |
| 15%PET+1.5%PP | 4.8 | 5.0 | 5.6 | 25 | 42.59 | 4.05 |
| 20%PET+1.5%PP | 4.3 | 4.5 | 4.9 | 12.5 | 39.44 | 3.89 |
| 30%PET+1.5%PP | 3.6 | 3.8 | 4.2 | -5 | 30.86 | 3.44 |
| 50%PET+1.5%PP | 3.1 | 3.3 | 3.7 | -17.5 | 21.51 | 2.88 |

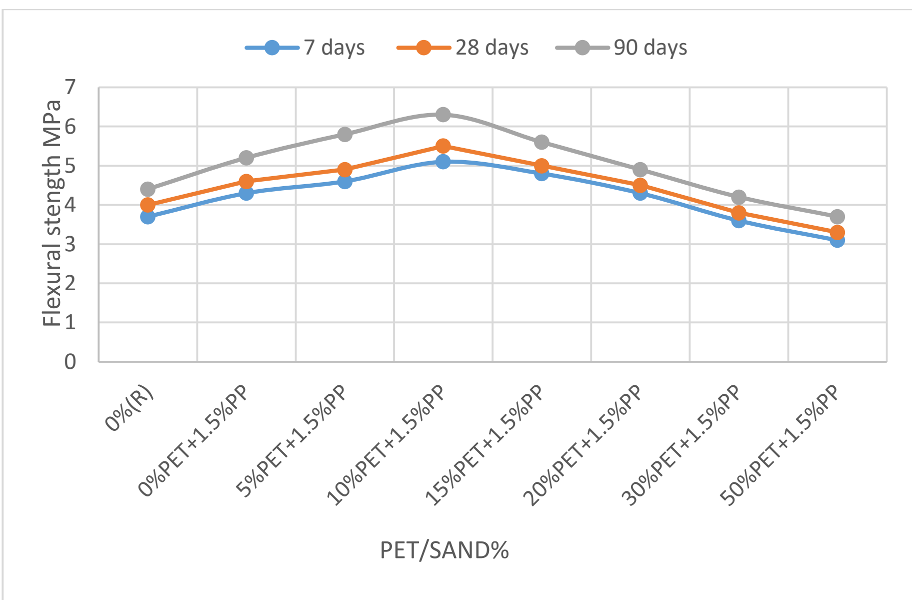
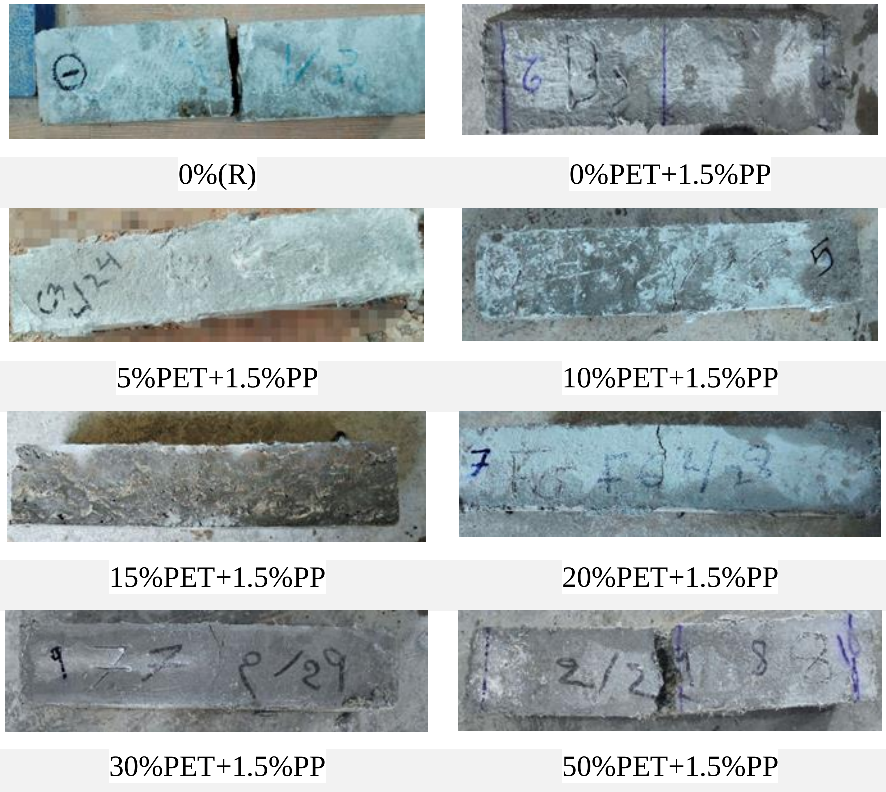



Figure 4.6 Results of Flexural Strength Curve for mixtures Containing PET Waste with Fibers.



0%(R) | 0%PET+1.5%PP
5%PET+1.5%PP | 10%PET+1.5%PP
15%PET+1.5%PP | 20%PET+1.5%PP
30%PET+1.5%PP | 50%PET+1.5%PP

Figure 4.7 Mode Failure of Flexural Specimens.

#### 4.2.1.2.4 Modulus of Elasticity

The modulus of elasticity may be determined by measuring the stress-strain curve in accordance with ASTM-C 469-02 [41].

Figure 4.8 and Table 4.5 display the results of the elastic modulus. The modulus of elasticity decreases dramatically with an increasing ratio of recycled PET plastic particles, as shown by the results and relationships. To start, the highest ever recorded value of modulus of elasticity was 30.5117 GPa, which was attained by the cylinder that did not include any waste (reference ratio) of polyethylene terephthalate (PET) or fiber. Then The modulus of elasticity of the specimen (0%PET+1.5%PP) that contained just fiber was 28.2945 GPa with a decrease of -7.27% when compared to the reference sample. In addition, when the proportion of

PET particles in the concrete mixture increases, the elastic modulus values progressively drop with increasing strain values. The concrete specimens containing PET waste for ratios (5%, 10%, 15%, 20%, 30%, 50%) and reinforced with polypropylene fibers record a specific value of 27.0163 GPa, 24.2103 GPa, 21.6722 GPa, 19.8120 GPa, 17.0345 GPa and 14.3442 GPa with a change of -11.46%, -20.65%, -28.97%, -35.06%, -44.17% and -52.99% respectively. The results from the laboratory demonstrated that strain and modulus of elasticity have an inverse relationship, which is in line with the law of modulus and validates the findings. Also, the concrete modulus was entirely altered by the PET particles, which had a lower elastic modulus and greater ductility than sand particles.

Table 4.5 Results Test of Modulus of Elasticity for Concrete Specimens.

| PET/SAND% | Modulus of elasticity values (GPa) | Variation % |
|---|---|---|
| 0%(R) | 30.5117 | --- |
| 0%PET+1.5%PP | 28.2945 | -7.27 |
| 5%PET+1.5%PP | 27.0163 | -11.46 |
| 10%PET+1.5%PP | 24.2103 | -20.65 |
| 15%PET+1.5%PP | 21.6722 | -28.97 |
| 20%PET+1.5%PP | 19.8120 | -35.06 |
| 30%PET+1.5%PP | 17.0345 | -44.17 |
| 50%PET+1.5%PP | 14.3442 | -52.99 |

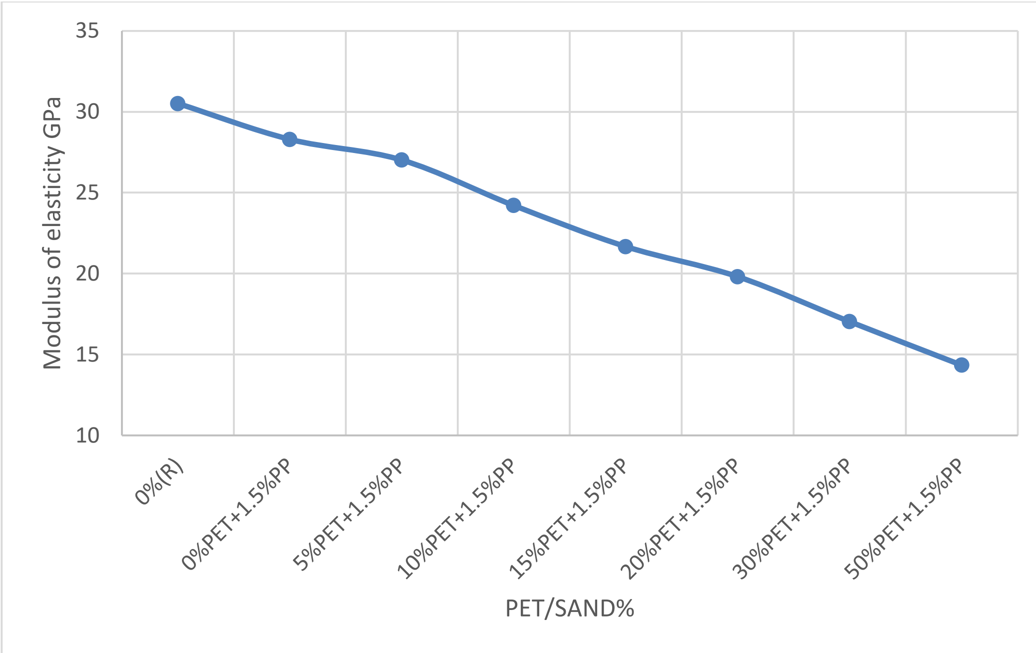



Figure 4.8 Results of Modulus of Elasticity Curve for Mixtures Containing PET Waste with Fibers.

#### 4.2.1.3 Results of Physical Properties

##### 4.2.1.3.1 Dry Density

The cube specimens containing PET waste for ratios (0%, 5%, 10%, 15%, 20%, 30%, 50%) and reinforced with polypropylene fibers in addition to the reference mix were used to measure dry density measurement before compression strength testing. Simultaneously with the compression test, the dry density was determined at 7, 28 and 90 days of age. You can see in Table 4.6 and Figure 4.9 that the density drops as the ratio of PET particles to concrete increases. At the age of 28 days, the density of reference specimens is 2372.81 kg/m$^3$, then it slightly decreased when the replacement ratio increased. The specimen (0% PET+ 1.5% PP) had a recorded density of 2360.79 kg/m$^3$ with a decrease of 0.50% compared to reference specimens. On the other hand, the increasing of PET replacement percentage to 50%, where the specimen (50%PET +1.5%PP) achieved a density of 1912.30 kg/m$^3$ with a decreasing of 19.4% compared to the reference mix, and the other replacement ratios of PET waste (5%, 10%, 15%, 20%, 30%) and reinforced with PP fiber record a decreasing of about 0.8%, 3.88%, 4.05%, 4.20%, and 4.96%), respectively. The major reason concrete density is dropping is because PET particles have a low density of 1380 kg/m$^3$. The creation of lightweight concrete is aided by the decrease in density.

Table 4.6 Results Test of Density for Concrete Specimens.

| PET/ SAND % | Density ɣ (kg/m$^3$) | | | Variation in density % (28 days) | *fc '* MPa | *fc'/ ɣ* |
|---|---|---|---|---|---|---|
| | 7 days | 28 days | 90 days | | | |
| 0%PET+0%PP(R) | 2376.89 | 2372.81 | 2369.23 | --- | 34.51 | 14.5 |
| 0%PET+1.5%PP | 2380.23 | 2360.79 | 2335.12 | -0.51 | 36.72 | 15.6 |
| 5%PET +1.5%PP | 2366.52 | 2353.78 | 2322.76 | -0.80 | 41.14 | 17.5 |
| 10%PET+1.5%PP | 2343.25 | 2280.85 | 2245.52 | -3.88 | 44.45 | 19.5 |
| 15%PET+1.5%PP | 2317.93 | 2276.74 | 2227.58 | -4.05 | 42.59 | 18.7 |
| 20%PET+1.5%PP | 2280.30 | 2273.19 | 2251.40 | -4.20 | 39.44 | 17.4 |
| 30%PET+1.5%PP | 2116.15 | 2255.11 | 2225.16 | -4.96 | 30.86 | 13.7 |
| 50%PET+1.5%PP | 1886.22 | 1912.30 | 1615.84 | -19.41 | 21.51 | 11.2 |

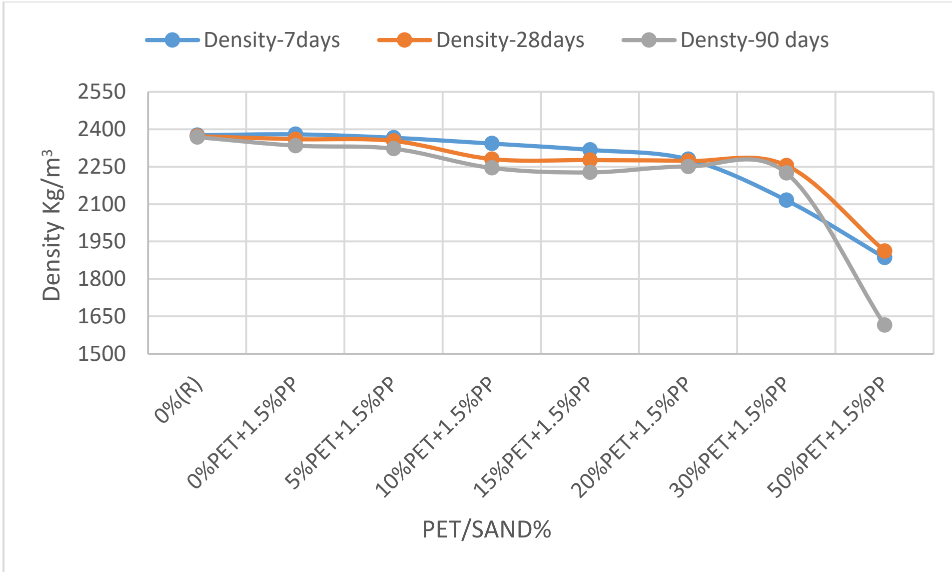



Figure 4.9 Results of Density Curve for Mixtures Containing PET Waste with Fibers.

#### 4.2.1.3.2 Absorption Test

For the absorption test, a total of eight concrete cubes were used, with one cube assigned to each percentage of PET particles. In accordance with ASTM C642 [87], the cubes were first oven-dried for 72 hours to get their dry weight and then submerged in water for 24 hours to obtain their wet weight. A look at Figure 4.10 and Table 4.7 displays the outcomes. As the amount of PET waste/sand increased, the absorption ratio also increased. With an absorption ratio of 1.55%, the reference cube is recorded. The concrete specimens containing PET waste for ratios (0%, 5%, 10%, 15%, 20%, 30%, 50%) and reinforced with polypropylene fibers had an absorption ratio of 1.59%, 1.68%, 1.79%, 2.11%, 2.37%, 2.79%, and 3.41% greater than the reference mixture by 2.58%, 8.39%, 15.48%, 36.13%, 52.90%, 80%, and 120%, respectively. As contrasted to sand, aggregate made from PET waste has more irregularly shaped, sharply edged, and highly surfaced particles, which create more spaces between them. When the PET waste dries and fills with water, the pores dilate, increasing the absorption.

Table 4.7 Results Test of Water absorption for Concrete Specimens.

| PET/ SAND% | Dry weight (D.W) kg | Wet weight (W.W) kg | W.W-D. W kg | Absorption ratio % | Variation % |
|---|---|---|---|---|---|
| 0%PET+0%PP(R) | 7.944 | 8.067 | 0.123 | 1.55 | ---- |
| 0%PET+1.5%PP | 7.945 | 8.071 | 0.126 | 1.59 | 2.58 |
| 5%PET+1.5%PP | 7.926 | 8.059 | 0.133 | 1.68 | 8.39 |
| 10%PET+1.5%PP | 7.805 | 7.945 | 0.14 | 1.79 | 15.48 |
| 15%PET+1.5%PP | 7.765 | 7.929 | 0.164 | 2.11 | 36.13 |
| 20%PET+1.5%PP | 7.713 | 7.896 | 0.183 | 2.37 | 52.90 |
| 30%PET+1.5%PP | 7.121 | 7.320 | 0.199 | 2.79 | 80 |
| 50%PET+1.5%PP | 6.034 | 6.240 | 0.206 | 3.41 | 120 |

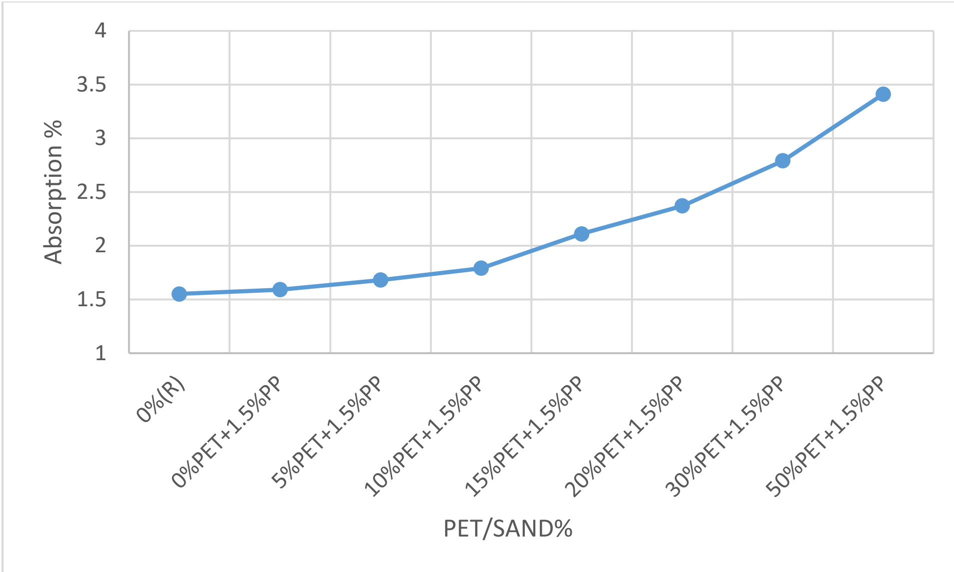



Figure 4.10 Results of Water Absorption Curve for Mixtures Containing PET Waste with Fibers.

**4.2.1.3.3 Ultrasonic Pulse Velocity (UPV) Results**

Ultrasonic pulse velocity test results for concrete specimens (cubes) containing PET waste in ratios (0% ,5%, 10%, 15%, 20%, 30%, 50%) and reinforced with polypropylene fiber in addition to the reference specimen are shown in Figure 4.11 and Table 4.8. A three cubes was evaluated for every percentage of PET waste. All tests were conducted in a linear fashion. According to BS 1881 Part 116 [88], this test is done at 28 and 90 days.

At 28 days: Due to PET's very low velocity characteristics, the findings demonstrated that the pulse velocity gradually decreases as the fraction of PET particles rises. Reference specimens recorded a pulse velocity estimated at 4.660 Km/s, and the other concrete specimens containing PET waste for ratios (0%, 5%, 10%, 15%, 20%, 30%, 50%) with fibers recorded a pulse velocity of (4.651, 4.598, 4.487, 4.205, 4.012, 3.692, 3.371) Km/s, namely less than the reference mixture by (-0.19%, -1.33%, -3.71%, -9.76%, -13.91%, -20.77%, and -27.66%), respectively.

At 90 days: The reference specimens recorded a pulse velocity estimated at 6.402 Km/s, and the other concrete specimens containing PET waste for ratios (0%, 5%, 10%, 15%, 20%, 30%, 50%) with fibers recorded a pulse velocity of (6.311, 6.308, 6.056, 5.847, 5.486, 5.310, 4.921) Km/s, namely less than the reference mixture by (-1.42%, -1.47%, -5.40%, -8.67%, -14.31%, -17.06%, and -23.13%), respectively.

As the amount of PET waste in concrete increases, both the density and the pulse velocity drop. For example, at 28 days, compared to the reference specimens, the density decreases by 19.41% and the pulse velocity decreases by 27.66% after using 50% PET waste. Therefore, it may be concluded that PET waste particles have lower.

Table 4.8 Results Test of Ultrasonic Pulse Velocity for Concrete Specimens.

| PET/ SAND % | Readings of ultrasonic velocity (Km/s) | | Variation % in UPV at 28 days | Quality of concrete according to the BS 1881[43] limits Standard at 28 days |
|---|---|---|---|---|
| | at 28 days | at 90 days | | |
| 0%(R) | 4.660 | 6.402 | --- | Very good |
| 0%PET+1.5%PP | 4.651 | 6.311 | -0.19 | Very good |
| 5%PET+1.5%PP | 4.598 | 6.308 | -1.33 | Very good |
| 10%PET+1.5%PP | 4.487 | 6.056 | -3.71 | Very good |
| 15%PET+1.5%PP | 4.205 | 5.847 | -9.76 | Very good |
| 20%PET+1.5%PP | 4.012 | 5.486 | -13.91 | Very good |
| 30%PET+1.5%PP | 3.692 | 5.310 | -20.77 | Note good |
| 50%PET+1.5%PP | 3.371 | 4.921 | -27.66 | Note good |

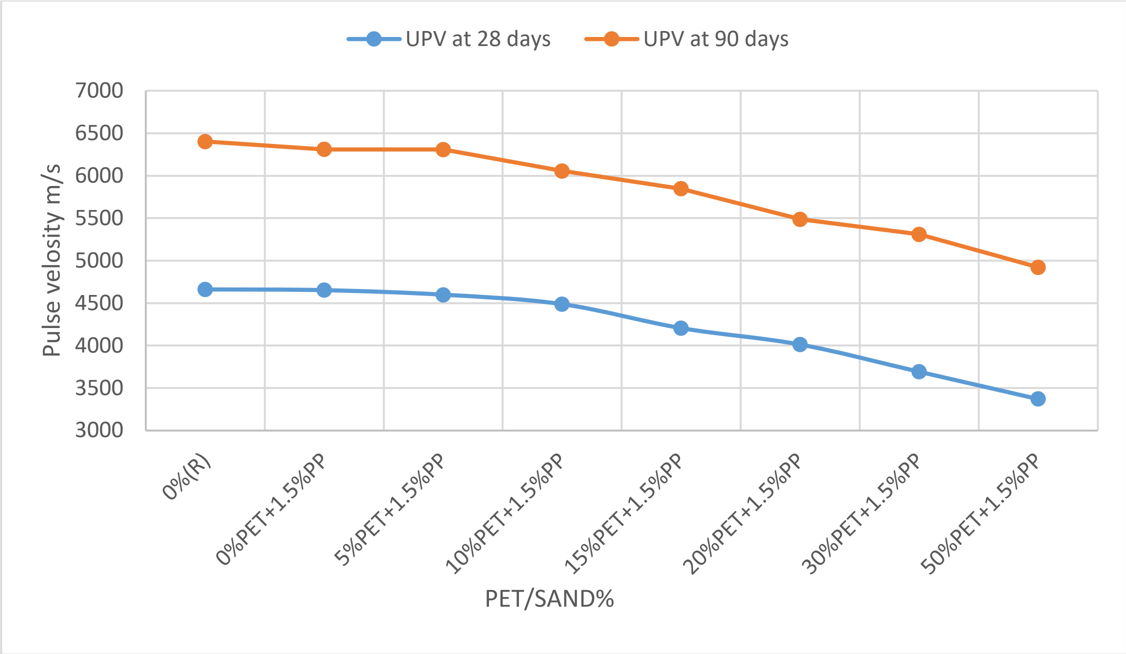



Figure 4.11 Results of Ultrasonic Pulse Velocity Curve for Mixtures Containing PET waste with Fibers.

### 4.2.2 Part Two: Flexural Behavior of Fiber Reinforced Concrete Slabs Contained PET Waste as Sand Replacement

The flexural behavior of concrete slabs is inspected by:

- Ultimate load
- Deflection at mid span
- Flexural Compression Strain
- Ductility index
- Stiffness
- Energy absorption
- Crack pattern

As shown in Figure 4.12, fourteen specimens (two specimens for each percentage of PET particle replacement and contained 1.5% of polypropylene fibers) and two for reference percentage were tested, and then the total number for slabs is sixteen divided into eight reinforced with steel bars and the other eight without reinforcement. Based on the crack path development for each load increment, the mid-span deflection and the crack pattern are determined.

Figure 4.12 Concrete Slab Specimens used for all PET /SAND Percentage.

### 4.2.2.1 Slab Ultimate Load

The ultimate loads for all concrete slabs containing polypropylene fibers and different ratios of PET waste particles are recorded and presented in Table 4.9. All slabs are homogeneous sections, and some slabs have steel reinforcement and others haven't steel reinforcement.

Table 4.9 Results of Ultimate Load for Slabs Specimens.

| Slab I. D. | *Pu* Kn | *Pu/Pu* % (reference slab) | Ultimate load variation % |
|---|---|---|---|
| S0%0%R | 40.3 | 100.0 | --- |
| S0%PF1.5%R | 42 | 104.2 | 4.22 |
| S5%PF1.5%R | 46 | 114.1 | 14.14 |
| S10%PF1.5%R | 51 | 126.6 | 26.55 |
| S15%PF1.5%R | 45 | 111.7 | 11.66 |
| S20%PF1.5%R | 40 | 99.3 | -0.74 |
| S30%PF1.5%R | 38 | 94.3 | -5.71 |
| S50%PF1.5%R | 17 | 42.2 | -57.82 |
| -------------- | ----- | ----- | ------- |
| S0%0%U | 15 | 100.0 | --- |
| S0%PF1.5%U | 19 | 126.67 | 26.67 |
| S5%PF1.5%U | 21 | 140 | 40 |
| S10%PF1.5%U | 23 | 153.33 | 53.33 |
| S15%PF1.5%U | 18 | 120 | 20 |
| S20%PF1.5%U | 16 | 106.67 | 6.57 |
| S30%PF1.5%U | 13 | 86.67 | -13.33 |
| S50%PF1.5%U | 10 | 66.67 | -33.33 |

The results of reinforced slabs show that the ultimate failure load of the reference slab S0%0%R (without PET and fibers) is 40.3 kN. When compared to the reference slab, slab S0%PF1.5%%R exhibited a 4.22% increase in ultimate failure load, reaching 42KN. A concrete slab with a 5% PET plastic waste to sand ratio (S5%PF1.5%R) achieved an ultimate failure load of 46 KN, which is 14.14% more than the reference slab. The slab concrete that contains 10% PET waste (S10%PF1.5%R) has a greater ultimate load of 51 KN, an increase of 26.55% compared to the reference slab. Slab S15%PF1.5%R, which replaced 15% of the sand with PET waste, had an ultimate failure load of 45 KN increase by 11.66% when compared to the reference samples. However, specimens S20%PF1.5%R and S30%PF1.5%R showed a decline in ultimate strength when compared to the reference slab; the former had a failure load of 40 KN and the latter of 38 KN, a decline of -0.74% and -5.71%, respectively. Then the slab (S50%PF1.5%R) achieved a severe decline in ultimate failure load (17KN), which decreased 57.82% when compared to the reference slab. Figure 4.13 shows the relationship between reinforcement slab maximum failure load and PET waste replacement ratio.

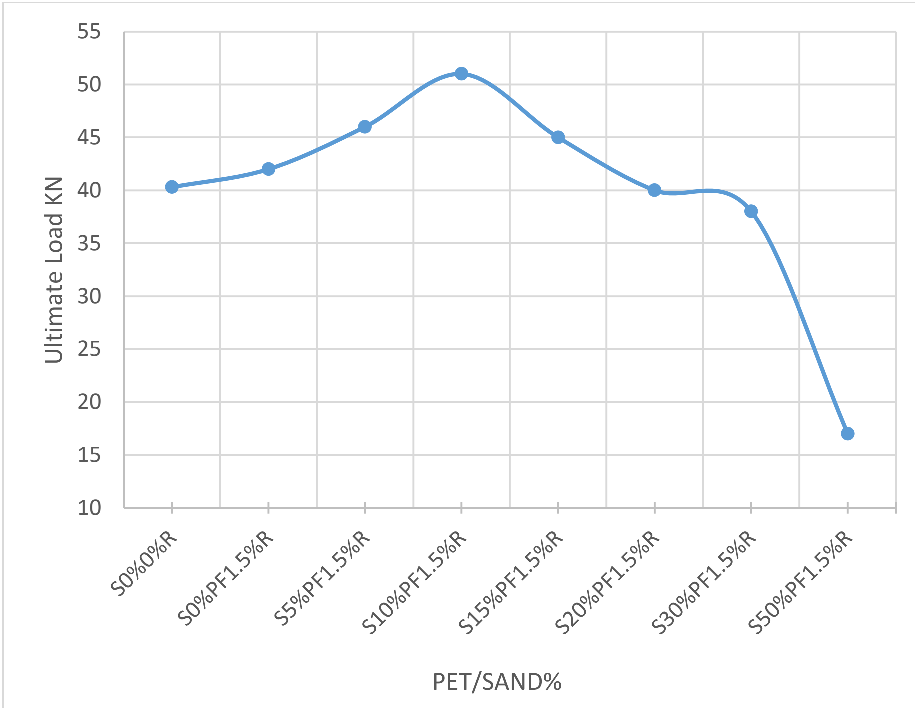



Figure 4.13 The Curve of Ultimate Load for Slabs Reinforced with Steel Bars.

The maximum failure load of un-reinforcement concrete is shown in Figure 4.14. The results showed that the slab (S10%PF1.5%U) achieved the highest value of the maximum failure load compared to all of the slabs containing polypropylene fibers and PET replacement ratios (0%, 5%, 15%, 20%, 30%, 50%), with a change of 26.67%, 40%, 20%, 6.57%, -13.33%, and -33.33%, respectively.

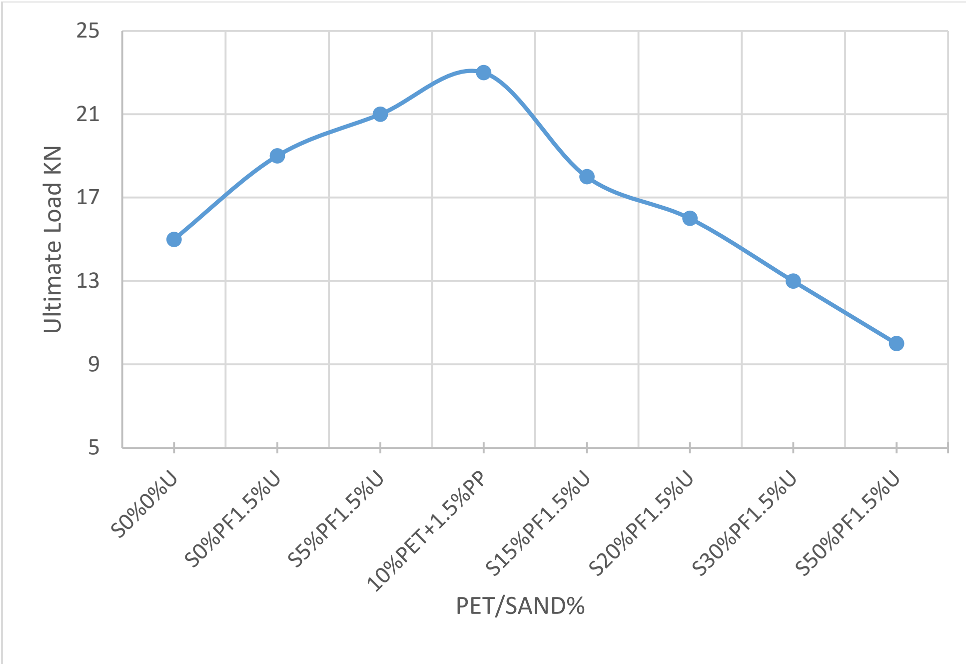



Figure 4.14 The Curve of Ultimate Load for Slabs without Reinforced Steel Bars.

### 4.2.2.2 Load-Deflections Behavior

Table 4.10 presents the deflection of all concrete slabs containing PET waste as sand replacement and contain polypropylene fibers.

Figure 4.15 displays a mid-span load deflection curve, which shows the maximum deflection of all concrete slabs. As the percentage of PET waste in the concrete slabs rises, the maximum deflection also rises in the range of 5–30%, according to the data. The lowest maximum deflection measured by the reference slab S0%0%R was 15.3 mm. In contrast, the concrete slabs S0%PF1.5%R, S5%PF1.5%R, S10%PF1.5%R, S15%PF1.5%R, and S20%PF1.5%R achieved maximum deflections of 17.28, 19.56, 21.75, 23.72, and 25.65 mm, respectively. These slabs were 12.94%, 27.84%, 42.16%, 55.03%, and 67.65% greater than the reference specimen. With a 77.97% increase over the reference slab, slab S30%PF1.5%R reached the maximum deflection of 27.23 mm. when the replacement ratio 50% slab (S50%PF1.5%R) achieved a slight increase in maximum deflection of 16.32, which increased by 6.67% compared to the reference slab.

Table 4.10 Results of Maximum Deflection for Slabs Specimens.

| Slab I. D. | *Pu* KN | Maximum deflection Δu (mm) | Δu/Δu % (reference slab) | Variation in deflection% |
|---|---|---|---|---|
| S0%0%R | 40.3 | 15.3 | 100 | --- |
| S0%PF1.5%R | 42 | 17.28 | 112.94 | 12.94 |
| S5%PF1.5%R | 46 | 19.56 | 127.84 | 27.84 |
| S10%PF1.5%R | 51 | 21.75 | 142.16 | 42.16 |
| S15%PF1.5%R | 45 | 23.72 | 155.03 | 55.03 |
| S20%PF1.5%R | 40 | 25.65 | 167.65 | 67.65 |
| S30%PF1.5%R | 38 | 27.23 | 177.97 | 77.97 |
| S50%PF1.5%R | 17 | 16.32 | 106.67 | 6.67 |
| ---------- | ----- | ------ | ----- | ----- |
| S0%0%U | 15 | 13.02 | 100 | --- |
| S0%PF1.5%U | 19 | 14.18 | 108.91 | 8.91 |
| S5%PF1.5%U | 21 | 14.74 | 113.21 | 13.21 |
| S10%PF1.5%U | 23 | 16.1 | 123.66 | 23.66 |
| S15%PF1.5%U | 18 | 17.55 | 134.79 | 34.79 |
| S20%PF1.5%U | 16 | 18.36 | 141.01 | 41.01 |
| S30%PF1.5%U | 13 | 16.28 | 125.04 | 25.04 |
| S50%PF1.5%U | 10 | 9.17 | 70.43 | -29.57 |

The presence of PET waste has a favorable influence on the behavior of concrete slabs, as seen in Figure 4.15, which shifts to another, more flexible behavior in Figure 4.16, as shown in the maximum deflection path behavior. Based on the relationship between the ultimate failure load and maximum deflection, sample S10%PF1.5%R is considered optimal. As an early warning system before failure, it also shows that the fraction time is becoming longer. A critical property of concrete is its capacity to reduce the effects of dynamic and impulsive stresses in addition to seismic activity.

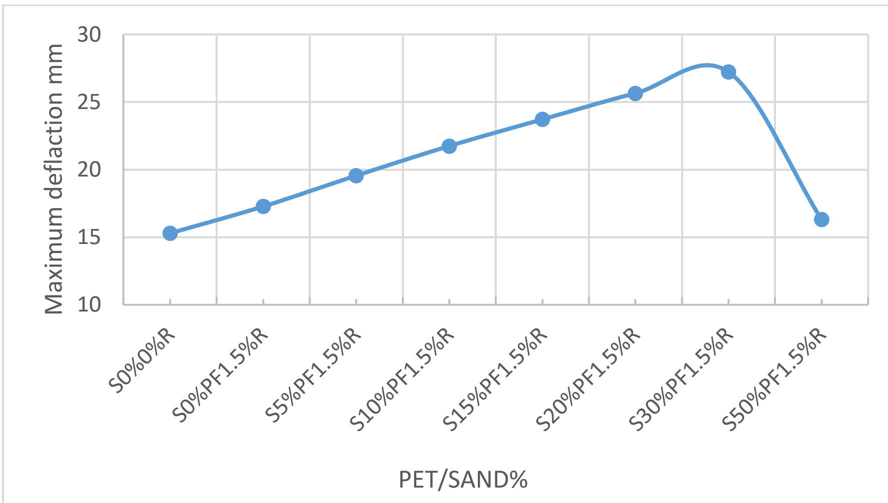



Figure 4.15 The Maximum Deflection for Slabs Reinforced with Steel Bars.

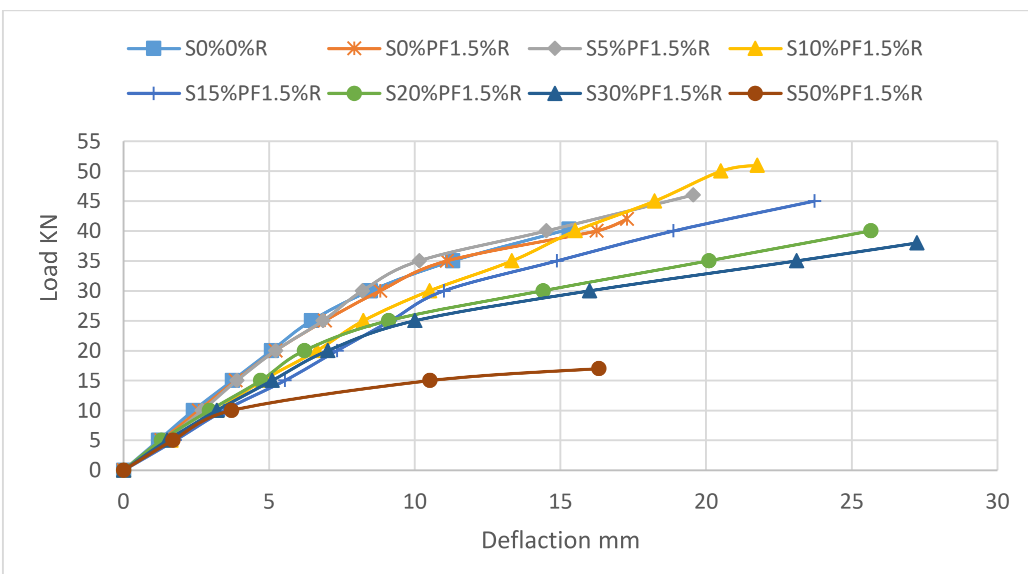



Figure 4.16 The Load To Deflection Relation for Concrete Slabs Reinforced With Steel Bars.

The maximum deflection of un-reinforcement concrete is shown in Figure 4.17. The results showed that the slab (S20%PF1.5%U) achieved the highest value of the maximum deflection compared to all of the slabs containing polypropylene fibers and PET replacement ratios (0%, 5%, 10%, 15%, 20%, 30%, 50%) with a change of 8.91%, 13.21%, 23.66%, 34.79%, 41.01%, 25.04%, and -29.57%, respectively. Figure 4.18. The load-to-deflection relationship for un-reinforced concrete slabs.

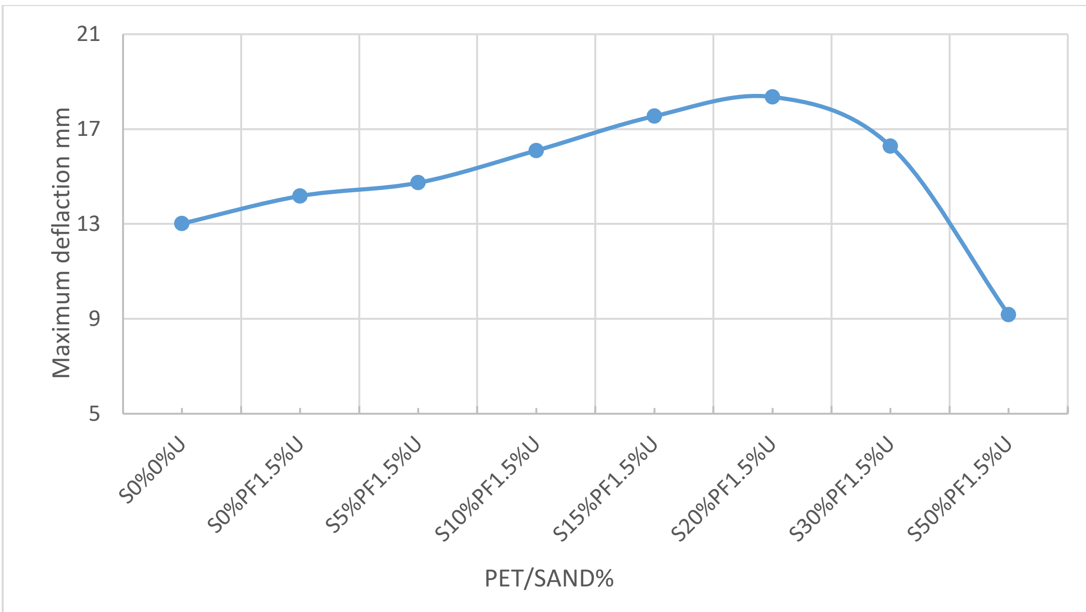



Figure 4.17 The Maximum Deflection for Concrete Slabs Un-reinforced with Steel Bars.

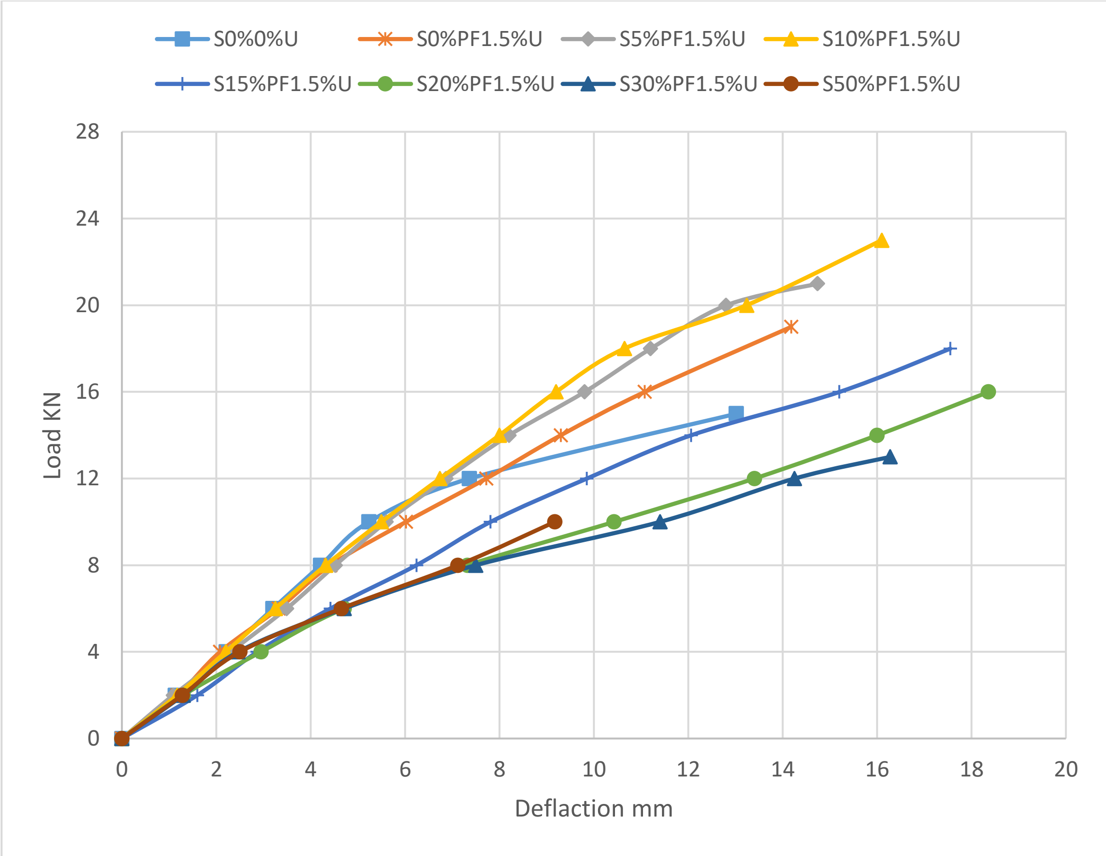



Figure 4.18 The Load To Deflection Relation for Concrete Slabs Un-reinforced With Steel Bars.

### 4.2.2.3 Flexural Compression Strain at ultimate Load

The results of readings flexural compression strain at ultimate load for concrete slabs are shown in Table 4.11.

Table 4.11 Results of Compression Strain for Slabs Specimens.

| Slab I.D. | Compression Strain | Variation in Compression Strain % |
|---|---|---|
| S0%0%R | 0.002639 | --- |
| S0%PF1.5%R | 0.002805 | 6.29 |
| S5%PF1.5%R | 0.003065 | 16.14 |
| S10%PF1.5%R | 0.0031 | 17.47 |
| S15%PF1.5%R | 0.003155 | 19.55 |
| S20%PF1.5%R | 0.003284 | 24.44 |
| S30%PF1.5%R | 0.003305 | 25.24 |
| S50%PF1.5%R | 0.0021 | -20.42 |
| --------- | --------- | ------ |
| S0%0%U | 0.00162 | --- |
| S0%PF1.5%U | 0.001735 | 7.10 |
| S5%PF1.5%U | 0.001852 | 14.32 |
| S10%PF1.5%U | 0.001914 | 18.15 |
| S15%PF1.5%U | 0.002018 | 24.57 |
| S20%PF1.5%U | 0.002265 | 39.81 |
| S30%PF1.5%U | 0.001786 | 10.25 |
| S50%PF1.5%U | 0.001123 | -30.68 |

According to the flexural strain measurements, compression strain in reinforced concrete slabs increases as the percentage of PET waste rises in range (5%–30%). Figure 4.19 shows strain curves, which further demonstrate that reference specimen S0%0%R had compression strains of 0.002639. Slabs S0%PF1.5%R, S5%PF1.5%R, S10%PF1.5%R, S15%PF1.5%R, S20%PF1.5%R, and S30%PF1.5%R that record strains of 0.002805, 0.003065, 0.0031, 0.003155, 0.003284, and 0.003305, respectively, with increments of 6.29%, 16.14%, 17.47%, 19.55%, 24.44%, and 25.24, respectively, compared with the reference slab. Then the slab (S50%PF1.5%R) achieved decline in strain 0.0021, which decreased 20.42% compared to the reference slab. The flexural strain should not go over 0.0035, and all of the strain measurements were within that range. Figure 4.20 shows a load-strain curve for each specimen, which contrasts the brittleness of the reference concrete slabs with that of the specimens treated with PET particles

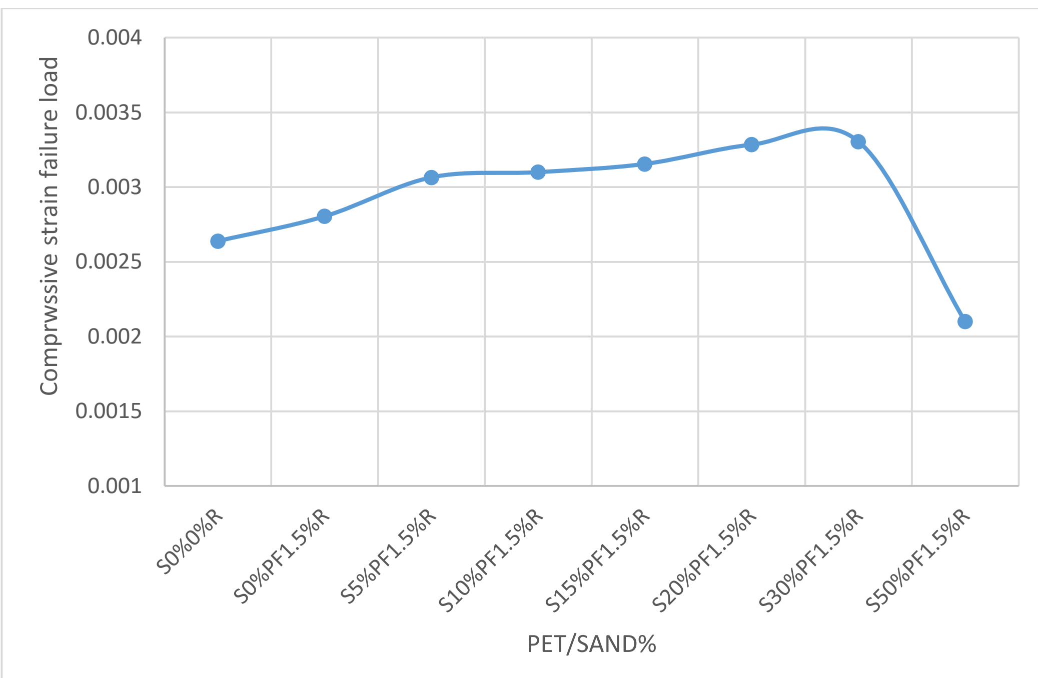



Figure 4.19 The Strain at Failure Load for Concrete Slabs Reinforced With Steel Bars.

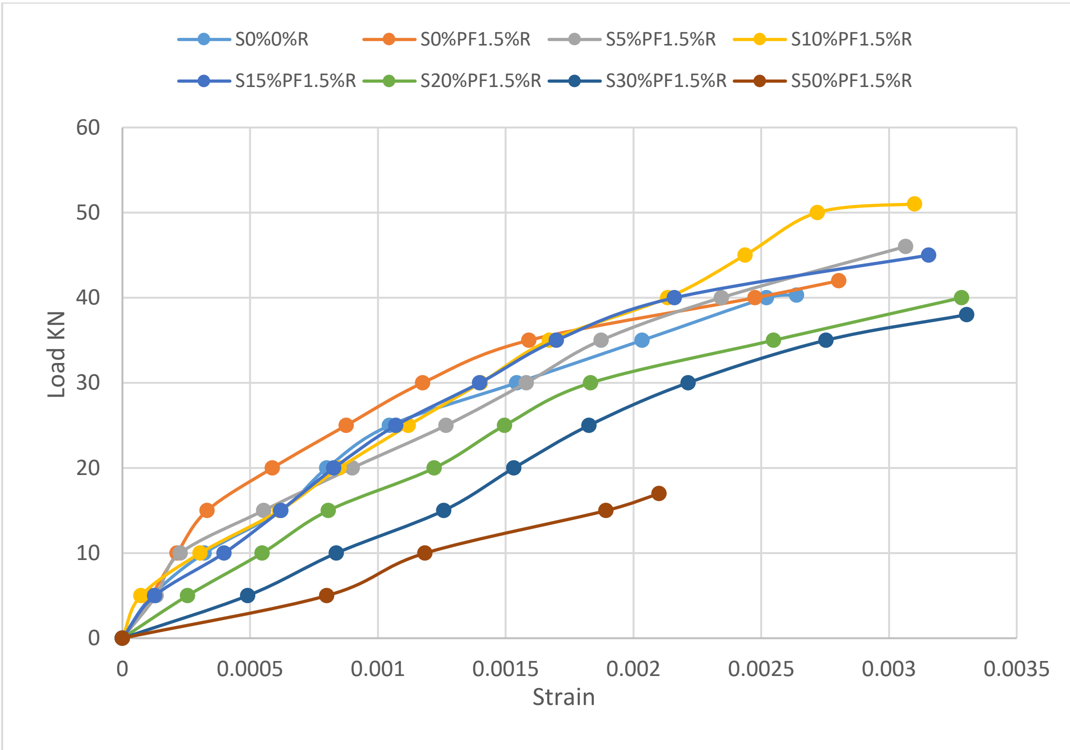



Figure 4.20 The Load to Strain for Concrete Slabs Reinforcement with Steel Bars.

The results of the unreinforced slabs showed that the slab (S20PF1.5%U) achieved the highest value of the strain compared to all slabs containing polypropylene fibers and replacement ratios of PET (0%, 5%, 10%, 15%, 20%, 30%, 50%), with an increase of about (7.10%, 14.32%, 18.15%, 24.57%, 39.81%, 10.25%, and -30.68%), respectively, as shown in Figure 4.21. Also, Figure 4.22 shows the load-strain curves for each un-reinforcement slab containing polypropylene fibers and different ratios of PET waste particles.

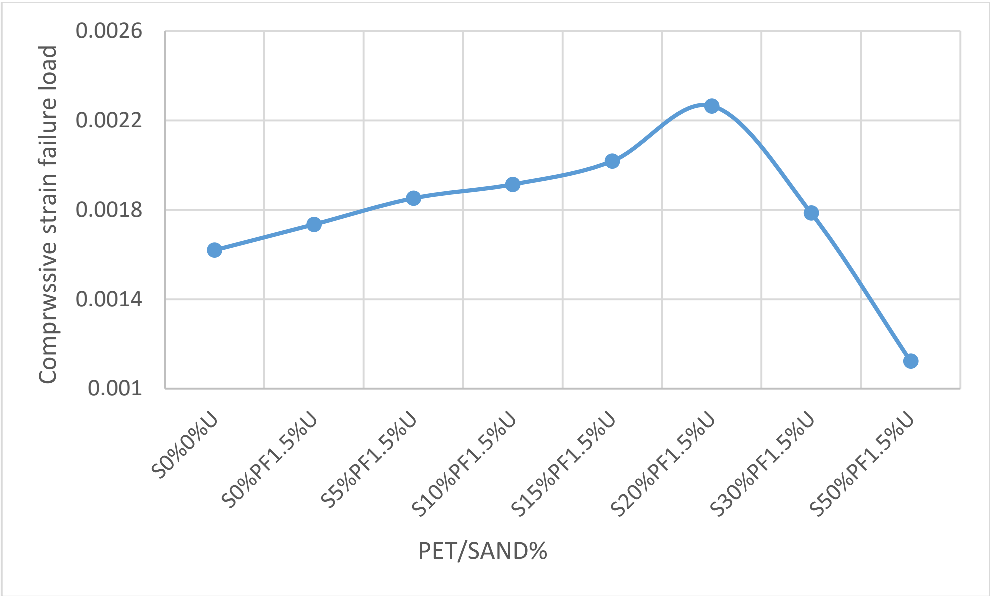



Figure 4.21 The Strain at Failure load for Slabs Concrete Un-reinforced With Steel Bars.

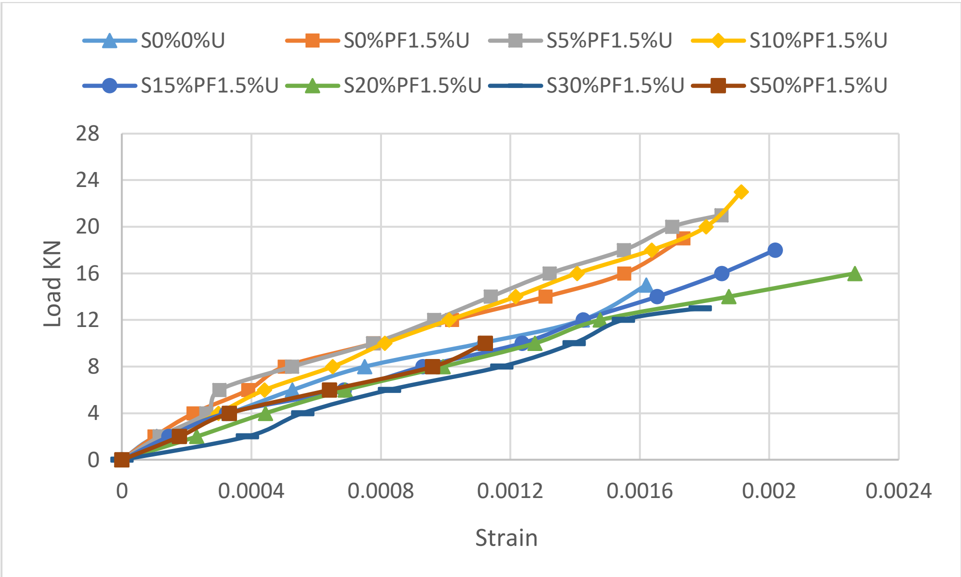



Figure 4.22 The Load to Strain for Concrete Slabs with Un-reinforcement Steel Bars.

### 4.2.2.4 Ductility index

The ductility index μ may be found by contrasting the load-deflection curve, which is determined by the ratio of the ultimate deflection Δu to the yield deflection Δy. Table 4.12 presents the ductility index of all concrete slabs containing PET waste as sand replacement and contain polypropylene fibers.

Table 4.12 The Results of Ductility Index for Slabs Specimens.

| Slab I.D. | Maximum Deflection Δu(mm) | Yield Deflection Δy (mm) | Ductility Index D.I | Variation in Ductility % |
|---|---|---|---|---|
| S0%0%R | 15.3 | 7.7 | 1.99 | ---- |
| S0%PF1.5%R | 17.28 | 8.4 | 2.06 | 3.52 |
| S5%PF1.5%R | 19.56 | 9.4 | 2.08 | 4.52 |
| S10%PF1.5%R | 21.75 | 10 | 2.18 | 9.55 |
| S15%PF1.5%R | 23.72 | 10.8 | 2.20 | 10.55 |
| S20%PF1.5%R | 25.65 | 8.8 | 2.91 | 46.23 |
| S30%PF1.5%R | 27.23 | 8.6 | 3.17 | 59.30 |
| S50%PF1.5%R | 16.32 | 3.99 | 4.08 | 105.03 |

In comparison to the control samples, the ductility increases were compatible with the final deflection increase. The ductility index of the concrete slabs increased as the percentage of PET waste increased. Slabs S0%PF1.5%R, S5%PF1.5%R, S10%PF1.5%R, S15%PF1.5%R, S20%PF1.5%R, and S30%PF1.5%R had ductility indices of 2.06, 2.08, 2.18, 2.20, 2.91, and 3.17, respectively. Relative to the reference slab, which had the lowest ductility index of 1.99, the corresponding increase ratios were 3.52%, 4.52%, 9.55%, 10.55%, 46.23%, and 59.30%. Then the slab (S50%PF1.5%R) whose replacement ratio was 50%, achieved a rise in ductility of 4.08, which increased 105.03% when compared to the reference slab. The results are shown in Figure 4.23.

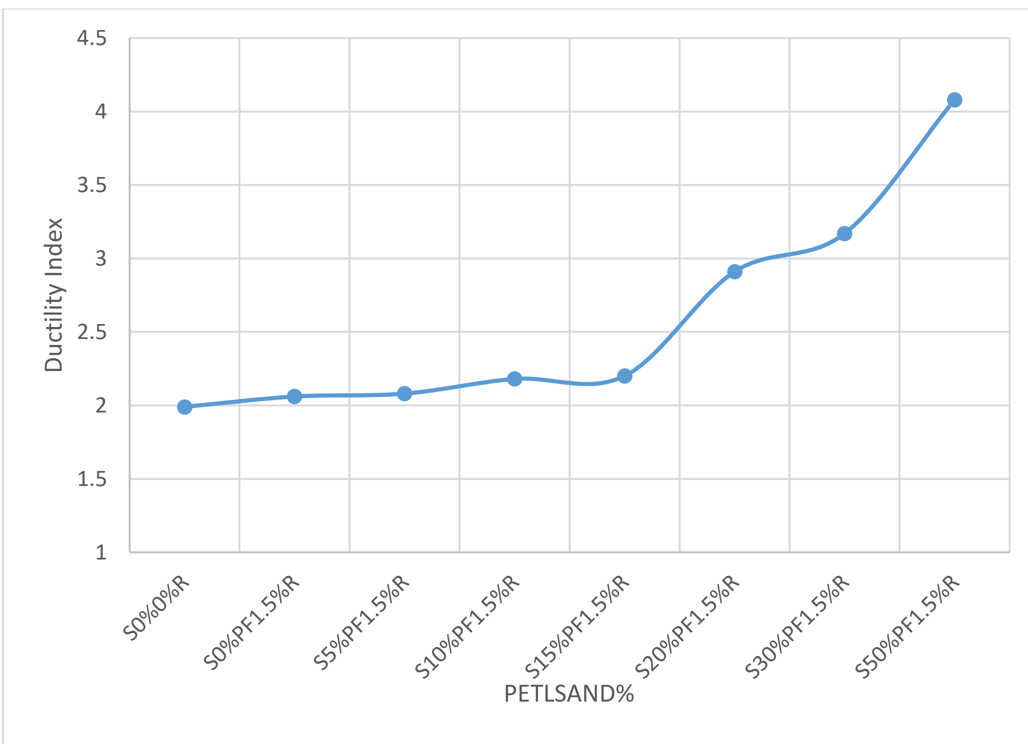



Figure 4.23 The Ductility Index for Concrete Slabs Reinforced with Steel Bars.

### 4.2.2.5 Stiffness

The initial stiffness and secant stiffness may be obtained from the load-deflection curve. To get the initial stiffness, divide the yield load (PY) by the deflection at yield load (Δy). Additionally, divide the final applied load (Pu) by the ultimate deflection (Δu) to get the secant stiffness. The stiffness is computed in accordance with the work of T. Sullivan et al. [45]. The equations that follow:

$$\text{Initial stiffness} = \frac{PY}{\Delta y} \qquad 4.1$$

$$\text{Secant stiffness} = \frac{Pu}{\Delta u} \qquad 4.2$$

The results are in Table 4.13. According to the results, the initial stiffness of the reference concrete slab S0%0%R or slabs with a low PET content S0%PF1.5%R and S5%PF1.5%R were similarly close, measuring 3.90, 3.75, and 3.67 KN/mm, respectively. The initial stiffness of slabs, S10%PF1.5%R, S15%PF1.5%R, and S20%PF1.5%R, was 3.0, 2.79, and 2.73 KN/mm, respectively, and these slabs showed decreases of 23.08%, 28.46%, and 30% when compared to the reference slab. Slab S30%PF1.5%R achieved the lowest initial stiffness of 2.67 KN/mm with a decrease of 31.54% compared to the reference slab. Then the slab (S50%PF1.5%R) achieved initial stiffness of 3.1KN/mm, which was less than 20.51 compared to the reference slab. As can be seen in Figure 4.24, the initial stiffness reduces as the amount of PET waste increases in range (5%-30%).

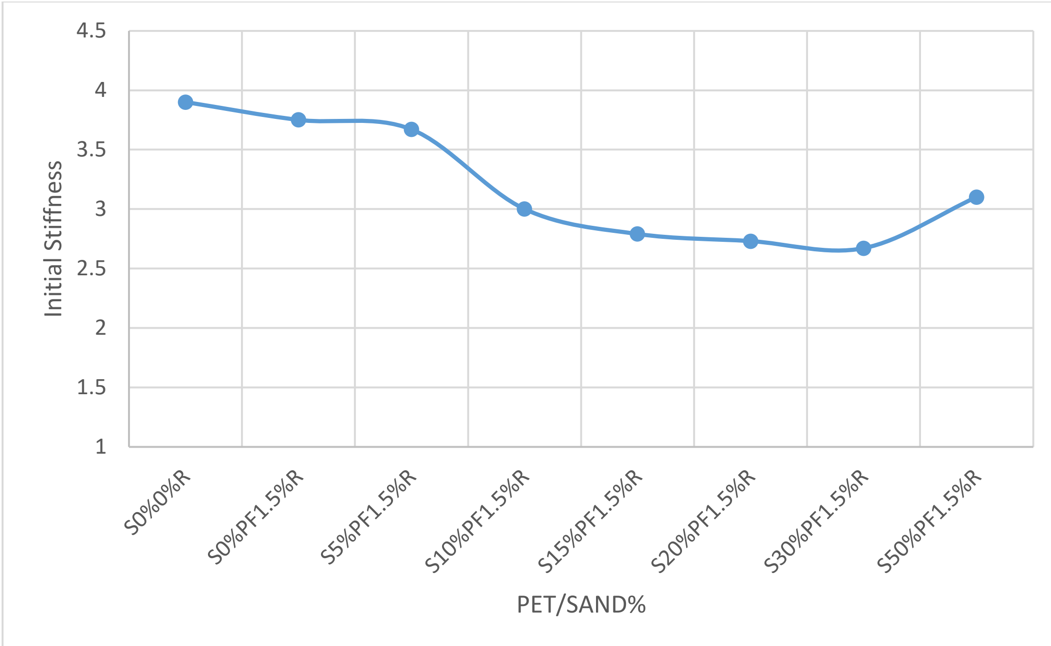



Figure 4.24 The Initial Stiffness for Concrete Slabs Reinforced with Steel Bars.

Secant stiffness reduces when the percentage of PET waste in concrete slabs increases, as shown in Figure 2.25. The reference slab recorded secant stiffness of 2.63 KN/mm, while concrete slabs S0%PF1.5%R, S5%PF1.5%R, S10%PF1.5%R, S15%PF1.5%R, S20%PF1.5%R, S30%PF1.5%R and S50%PF1.5%R had secant stiffness of 2.43, 2.35, 2.34, 1.9, 1.56, 1.40, and 1.04 KN/mm, respectively. This stiffness was 7.60%, 10.65%, 11.03%, 27.76%, 40.68%, 46.77%, and 60.46% lower than the reference slab. There is an inverse connection between deflection and stiffness in slabs, which is consistent with this result.

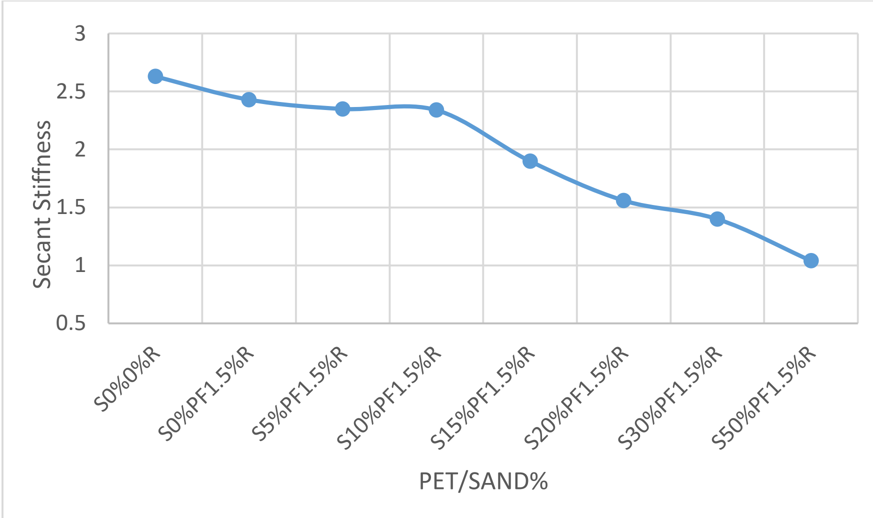



Figure 4.25 The Secant Stiffness for Concrete Slabs Reinforced with Steel Bars.

The results of the unreinforced slabs showed that the reference slab (S0%0%U) achieved the highest value of the initial stiffness compared to all slabs containing polypropylene fibers and replacement ratios of PET (0%, 5%, 10%, 15%, 20%, 30%, 50%) with a decrease of about (3.11%, 10.36%, 11.92%, 32.64%, 35.23%, 10.88%, and 23.32%), respectively, as shown in Figure 4.26.

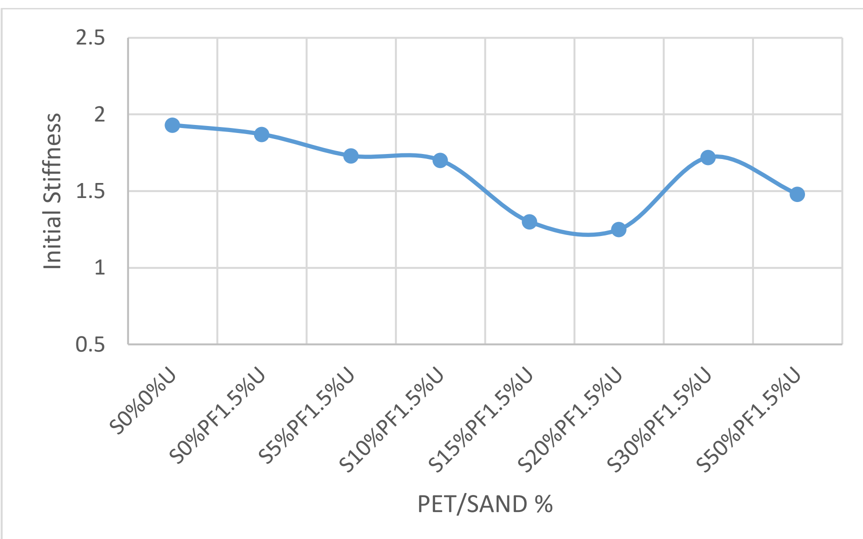



Figure 4.26 The Initial Stiffness for Concrete Slabs Un-reinforced with Steel Bars.

Table 4.13 The Results of Initial and Secant Stiffness for all Concrete Slabs.

| Slab I.D. | Initial stiffness kN/mm | Variation in initial stiffness % | Secant stiffness kN/mm | Variation in secant stiffness % |
|---|---|---|---|---|
| S0%0%R | 3.90 | --- | 2.63 | --- |
| S0%PF1.5%R | 3.75 | -3.85 | 2.43 | -7.60 |
| S5%PF1.5%R | 3.67 | -5.90 | 2.35 | -10.65 |
| S10%PF1.5%R | 3.0 | -23.08 | 2.34 | -11.03 |
| S15%PF1.5%R | 2.79 | -28.46 | 1.90 | -27.76 |
| S20%PF1.5%R | 2.73 | -30 | 1.56 | -40.68 |
| S30%PF1.5%R | 2.67 | -31.54 | 1.40 | -46.77 |
| S50%PF1.5%R | 3.1 | -20.51 | 1.04 | -60.46 |
| ---- | ---- | ---- | ---- | ----- |
| S0%0%U | 1.93 | --- | 1.15 | --- |
| S0%PF1.5%U | 1.87 | -3.11 | 1.34 | 16.52 |
| S5%PF1.5%U | 1.73 | -10.36 | 1.42 | 23.48 |
| S10%PF1.5%U | 1.70 | -11.92 | 1.43 | 24.35 |
| S15%PF1.5%U | 1.3 | -32.64 | 1.03 | -10.43 |
| S20%PF1.5%U | 1.25 | -35.23 | 0.87 | -24.35 |
| S30%PF1.5%U | 1.72 | -10.88 | 0.80 | -30.43 |
| S50%PF1.5%U | 1.48 | -23.32 | 1.09 | -5.22 |

The secant stiffness of the reference slab started with a value of 1.15, and the slabs S0%PF1.5%U, S5%PF1.5%U, and S10%PF1.5%U achieved increments of 16.52%, 23.48%, and 24.35%, respectively, but slabs S15%PF1.5%U, S20%PF1.5%U, S30%PF1.5%U, and S50%PF1.5%U achieved a decrease of -10.43%, -24.35%, -30.43%, and -5.22% compared to the reference slab, as shown in Figure 4.27.

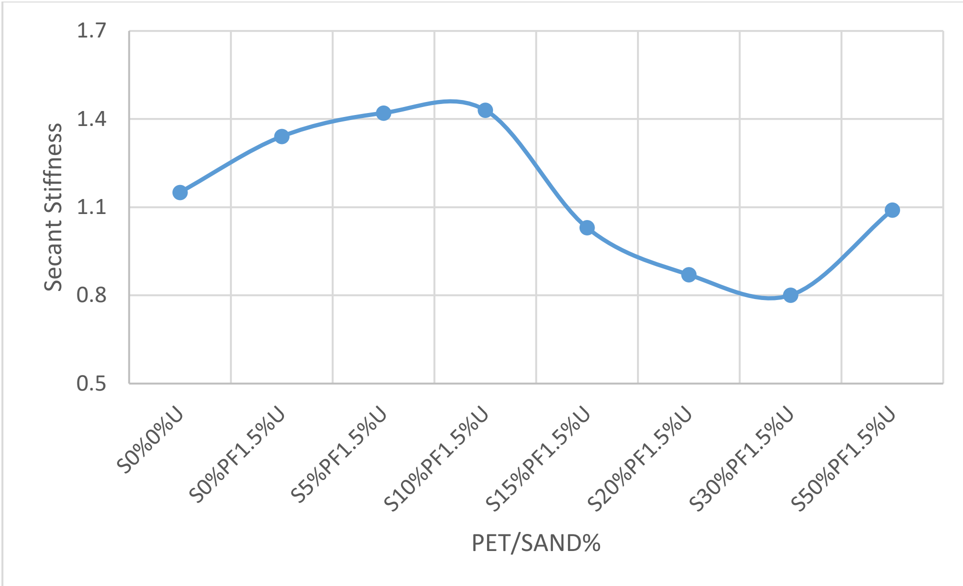



Figure 4.27 The Secant Stiffness Curve for Concrete Slabs Un-reinforced with Steel Bars.

### 4.2.2.6 Energy Absorption

The absorption energy, or toughness, is the area under the load-deflection curve. The results of absorption energy for all slabs containing polypropylene fibers and different percentages of PET waste as sand replacement reinforcement with steel bars, as well as those without steel bars, are in Table 4.18.

Energy absorption was determined by finding the area under the load-deflection curve. Figure 4.28 displays the results of the energy absorption. An increase of PET waste particles in concrete slabs significantly increases energy absorption in the range (5%–30%). The reference slab recorded an energy absorption of 381.15 kN.mm. While concrete slabs S0%PF1.5%R, S5%PF1.5%R, S10%PF1.5%R, S15%PF1.5%R, S20%PF1.5%R, and S30%PF1.5%R had energy absorptions of 452.79, 571.11, 626.73, 648.0, 665.48, and 687.45 KN.mm, respectively. These absorptions were 18.80%, 49.84%, 64.43%, 70.01%, 74.60%, and 80.36% larger than the reference slab. whereas the slab (S50%PF1.5%R) achieved a severe decline in energy absorption of 197.35 KN.mm which decreased 48.22% compared to the reference slab. This action exemplifies the fact that recycled PET has a markedly beneficial influence on the ability of reinforced concrete slabs to absorb energy.

Table 4.14 The Results of Energy Absorption for all Concrete Slabs

| Slab I.D. | Energy Absorption kN.mm | Variation in Energy Absorption % |
|---|---|---|
| S0%0%R | 381.15 | --- |
| S0%PF1.5%R | 452.79 | 18.80 |
| S5%PF1.5%R | 571.11 | 49.84 |
| S10%PF1.5%R | 626.73 | 64.43 |
| S15%PF1.5%R | 648.0 | 70.01 |
| S20%PF1.5%R | 665.48 | 74.60 |
| S30%PF1.5%R | 687.45 | 80.36 |
| S50%PF1.5%R | 197.35 | -48.22 |
| ---- | ---- | ----- |
| S0%0%U | 125.41 | --- |
| S0%PF1.5%U | 152.37 | 21.50 |
| S5%PF1.5%U | 176.83 | 41.00 |
| S10%PF1.5%U | 210.99 | 68.24 |
| S15%PF1.5%U | 178.25 | 42.13 |
| S20%PF1.5%U | 163.18 | 30.12 |
| S30%PF1.5%U | 127.39 | 1.58 |
| S50%PF1.5%U | 51.43 | -58.99 |

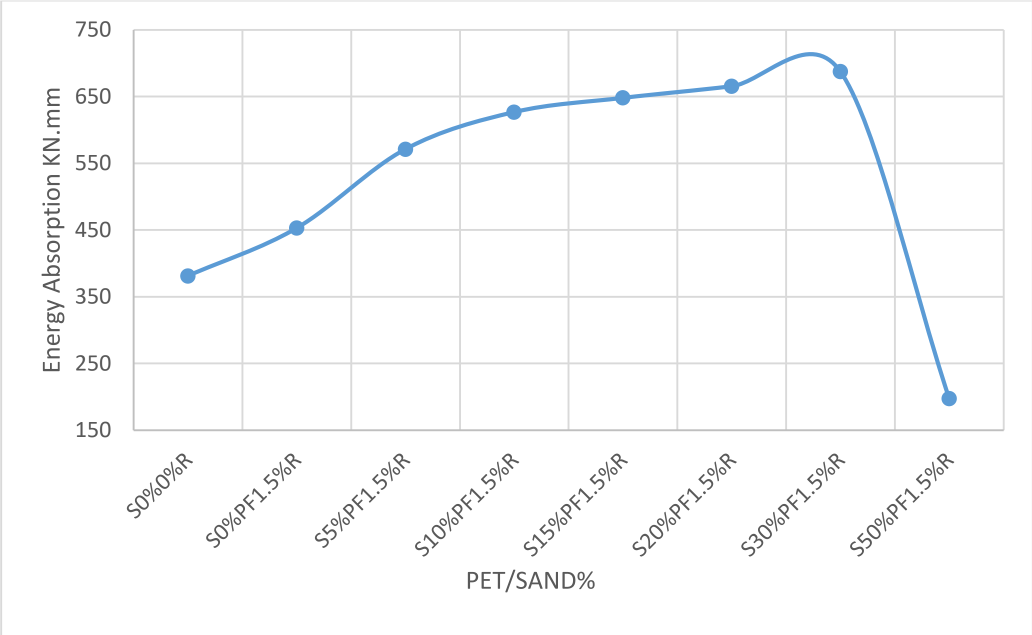



Figure 4.28 The Energy Absorption Curve for Concrete Slabs Reinforced with Steel Bars.

Figure 4.29 shows the absorption path is convergent for slabs without steel bars. The absorption of the reference slab started with a value of 125.41 and gradually increased as PET percentages increased. The slabs S0%PF1.5%U, S5%PF1.5%U, S10%PF1.5%U, S15%PF1.5%U, S20%PF1.5%U, and S30%PF1.5%U achieved increments of 21.50%, 41.00%, 68.24%, 42.13%, 30.12%, and 1.58%, respectively, but slab S50%PF1.5%U achieved a decrease of -58.99% compared to the reference slab.

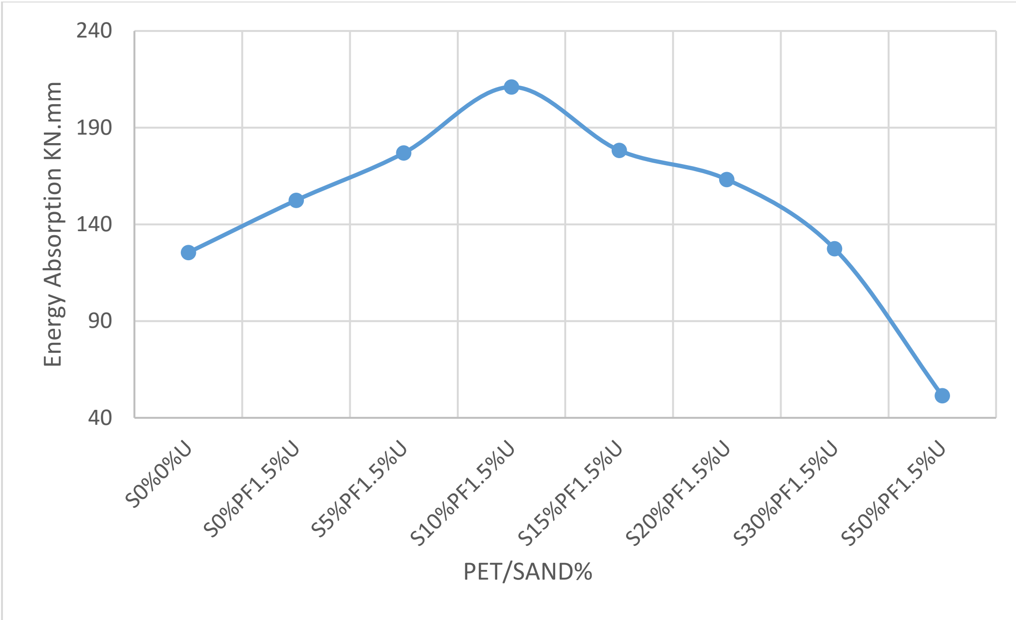



Figure 4.29 The Energy Absorption Curve for Concrete Slabs Un-reinforced with Steel Bars.

### 4.2.2.7 Cracking

Cracks occur in concrete when the applied tensile stress is greater than the tensile stress of the reinforced concrete slab. The following items are used to check for cracks in all concrete slab specimens:

1. First cracking load (Pcr)

2. Cracks pattern

#### 4.2.2.7.1 First Cracking Load (Pcr)

The initial cracking loads for every concrete slab were documented, as shown in Figure 4.30 and Table 4.15. As the percentage of PET waste in concrete slabs rises in range (5%–15%), the findings reveal a progressive increase in the load at which the first fracture arises. The reference slab showed the first crack at a load of 14KN, while slabs S0%PF1.5%R, S5%PF1.5%R, S10%PF1.5%R, and S15%PF1.5%R showed the first crack at loads of 15, 20, 35, and 38 KN, respectively, and these slabs showed increases of 7.14%, 42.86%, 150%, and 171.43% when compared to the reference slab. However, specimens S20%PF1.5%R showed a slight increase in the first crack at a load of 16 KN, which was more than 14.29% when compared to the reference slab. Then the slabs S30%PF1.5%R and S50%PF1.5%R achieved decline in the first crake at loads of 12 and 10 KN, which decreased by 14.29% and 28.57% when compared to the reference slab.

Table 4.15 The Results of First Crack for Slabs Reinforced with Steel Bars.

| Slab I.D. | Pcr (KN) | Pu (KN) | Pcr/Pu % | Variation in Pcr % |
|---|---|---|---|---|
| S0%0%R | 14 | 40.3 | 34.74 | --- |
| S0%PF1.5%R | 15 | 42 | 35.71 | 7.14 |
| S5%PF1.5%R | 20 | 46 | 43.48 | 42.86 |
| S10%PF1.5%R | 35 | 51 | 68.63 | 150 |
| S15%PF1.5%R | 38 | 45 | 84.44 | 171.43 |
| S20%PF1.5%R | 16 | 40 | 40 | 14.29 |
| S30%PF1.5%R | 12 | 38 | 31.58 | -14.29 |
| S50%PF1.5%R | 10 | 17 | 58.82 | -28.57 |

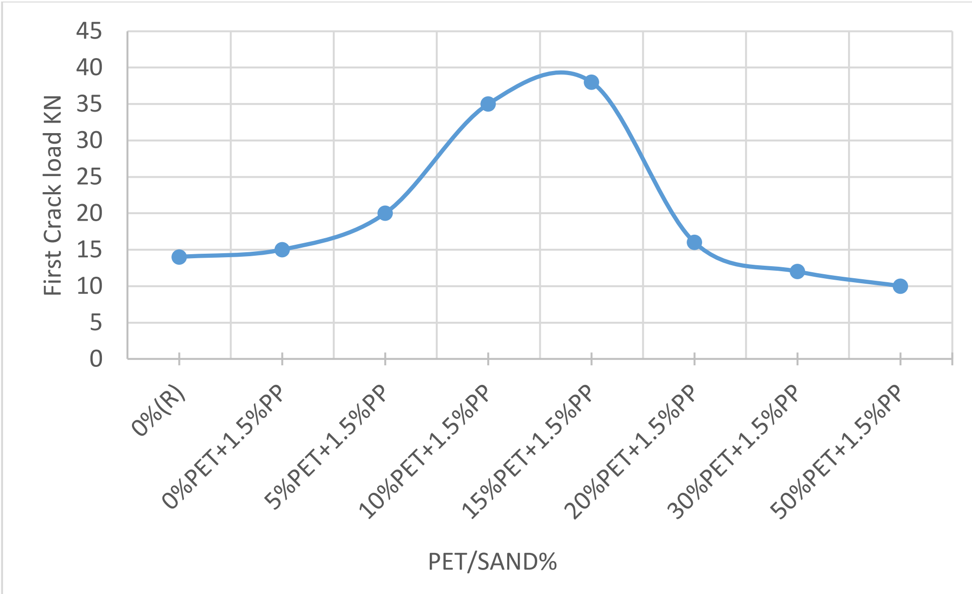



Figure 4.30 The First Crack Curve for Concrete Slabs Reinforced with Steel Bars.

#### 4.2.2.7.2 Cracks Pattern

Slab fracture patterns were unpredictable, showing up in a variety of forms and lengths. For slabs containing varying percentages of PET plastic waste, fractures often emerged in the tension zone mid-span and spread until they met the compression zone. The cracking pattern of reinforcement slabs is seen in Figure 4.32.

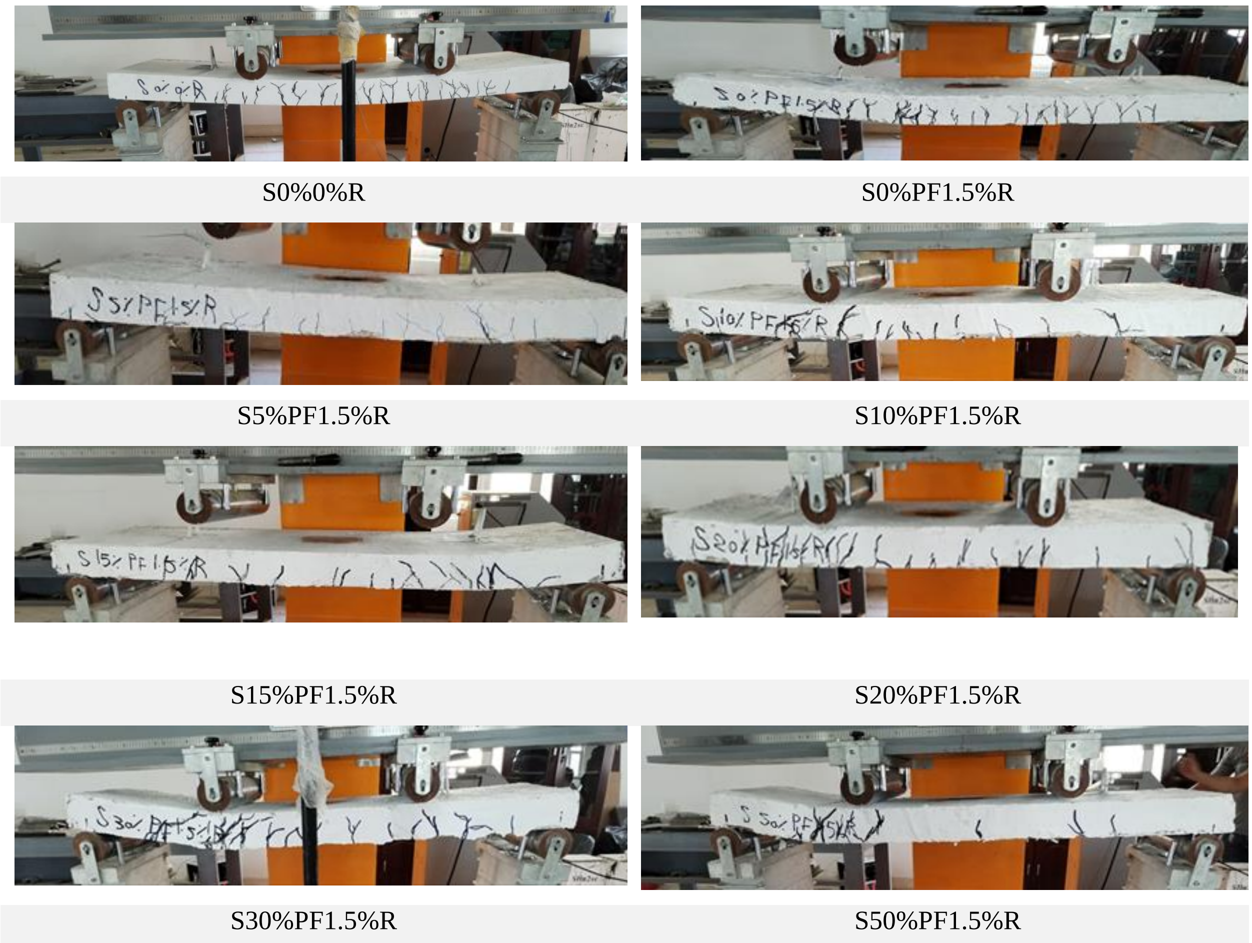
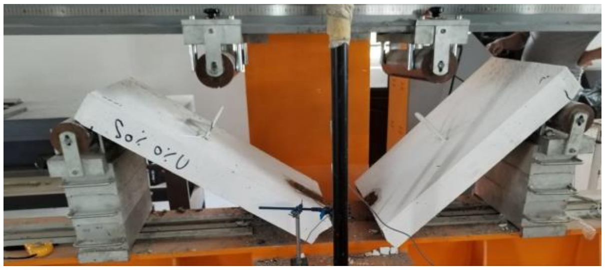



Figure 4.31 The Crack Pattern for Concrete Slabs Reinforced with Steel Bars.

There are no early cracks for slabs when we test specimens without steel bars. This is because no apparent cracks occur before finally failure. Along with that, there was no discernible deflection warning before these slabs abruptly failed. Slabs that were reinforced with polypropylene fibers and used PET waste as a substitute for sand failed slowly but suddenly; cracking began in the tension zone and progressed straight to the compression zone. In terms of the fracture pattern, in the control samples without PET waste, the slabs failed due to a single crack around the middle of the span. For slabs containing low percentages of PET waste up to 20%, the specimens failed by one fracture under a point of one of the applied loads, but for slabs containing high percentages of PET waste, namely 30% and 50%, the specimens failed by two cracks at sites of load application, as seen in Figure 4.32.



S0%0%U S0%PF1.5%U

S5%PF1.5%U S10%PF1.5%U

S15%PF1.5%U S20%PF1.5%U

S30%PF1.5%U S50%PF1.5%U

Figure 4.32 The Crack Pattern For Concrete Slabs Un-reinforced with Steel Bars.

# CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

## 5.1 General

This chapter presents important results from the experimental testing of concrete that uses PET waste as sand replacement. There are three parts to the conclusions:

1. Physical and Mechanical Properties of Fiber Reinforced Concrete Incorporating PET Waste as Sand Replacement.

2. Flexural Investigation of Fibrous Concrete Slabs Incorporating PET Wastes as sand Replacement.

3. Structural behavior of concrete slabs incorporating PET waste as sand replacement and reinforced with polypropylene fibers.

## 5.2 Conclusions

### 5.2.1 Physical and Mechanical Properties

1. An increasing amount of PET waste reduces the workability of concrete mixtures. The reference mix had the best workability, while recording the mixtures containing PET waste as sand replacement for the ratios (0%, 5%, 10%, 15%, 20%, 30%, and 50%) and reinforced with polypropylene fibers, a

decrease in the workability by about 7.4%, 11.1%, 19.8%, 29%, 47.5%, 58%, and 75.3% compared to the reference mixture, respectively.

2. The compressive strength, splitting tensile strength, and flexural strength increase with the increase of PET waste content until the replacement ratio of 10% is reinforced with polypropylene fibers. So the specimen with 10% PET and 1.5% polypropylene fiber achieved compressive, tensile, and flexural strengths greater than the reference specimen by 29.06%, 37.5%, and 37.5%, respectively. while the specimen with 50% PET and 1.5% polypropylene fiber showed reduction in compressive, tensile, and flexural strength by 37.68%, 20.83% and 17.5%, respectively, compared with reference specimens.

3. The elastic modulus decreased when the ratio of replaced PET increased. When compared to the reference specimens, the specimen containing 50 % PET and 1.5 % polypropylene fiber showed a reduction of 52.99 % in Young's modulus

4. There was an increase in absorption and a decrease in concrete density and ultrasonic pulse velocity when the proportion of PET was increased. The reference sample showed higher density, pulse velocity, and a lower absorption rate. Since the pulse velocities fall with decreasing densities, the void space grows, and the absorption rate rises, the findings are consistent. For example, the concrete sample with 50% PET and 1.5% polypropylene fiber showed a 120% increase in absorption and a -19.41% decrease in density compared to the reference sample.

### 5.2.2 Flexural Investigation of Fibrous concrete slabs incorporating PET Wastes as sand replacement.

1. The ultimate load at failure for all reinforced slabs rises as the PET percentage in the slabs increases up to 10%. Slabs S0%PF1.5%R, S5%PF1.5%R, S10%PF1.5%R, and S15%PF1.5%R all had their failure loads raised relative to the reference specimens by 4.22%, 14.14%, 26.55%, and 11.66%, respectively. In contrast, slabs S20%PF1.5%R, S30%PF1.5%R, and S50%PF1.5%R had their failure load reduced by 0.74%, 5.71%, and 57.82%.

2. When comparing the findings to the reference specimen, the slab with 30% of PET particles (S30%PF1.5%R) had the greatest deflection index increases of 77.97%, and the slab with 50% PET (S50%PF1.5%R) had the ductility index increments of 105.03%.

3. Compression strain at failure load rose with increasing percentage of PET particles in concrete slabs, whereas energy absorption increased dramatically, according to the results. The energy absorption and strain increments generated by the specimen (S30%PF1.5%R) were 80.36% and 25.24% larger, respectively, than those produced by the reference slab.

4. Concrete slabs with a higher PET content have lower secant stiffness and initial stiffness. When compared to the reference slab, the slab (S50%PF1.5%R) had a lower secant stiffness of 60.46%% then the slab (S30%PF1.5%R) had a lower initial stiffness of 31.54%.

5. The first fracture load capacity rose with the percentage of PET in the concrete slab in range (5%-15%), reaching a maximum of 171.43% for slab S15%PF1.5%R compared to the reference slab.

### 5.2.3 Structural behavior of concrete slabs incorporating PET waste as sand replacement and reinforced with polypropylene fibers

1. Increasing the amount of PET in reinforced slabs from 0% to 10% raises the ultimate load at failure for all of them. Failure loads were increased by 26.67%, 40%, 53.33%, 20%, and 6.57% compared to the reference specimens for slabs S0%PF1.5%U, S5%PF1.5%U, S10%PF1.5%U, S15%PF1.5%U, and S20%PF1.5%U, respectively. On the other hand, the failure load of slabs S30%PF1.5%U and S50%PF1.5%U was lowered by 13.33% and 33.33%, respectively.

2. The results showed that the slab containing 20% PET particles (S20%PF1.5%U) had the maximum deflection increase of 41.01%.

3. Also, the findings showed that the slab containing 20% PET particles (S20%PF1.5%U) had the maximum strain increase of 39.81%, and the slab containing 10% PET (S10%PF1.5%U) had the highest energy absorption increment of 68.24% when compared to the reference specimen.

4. Slabs of concrete with a greater percentage of PET exhibit reduced initial stiffness. The reference slab had the highest initial stiffness of 1.93. Then, the

secant stiffness increased when the PET increased for a range of 5%-10%, so the slab (S10%PF1.5%U) was increased by 24.35% compared to the reference slabs.

## 5.3 Recommendations

The recommendations below are suggestions for future studies and research:

1. The positive impact of PET waste on concrete's physical and mechanical properties and slabs' structural behavior suggests further investigation into the reinforcing behavior of other structural components, such as beams and fiber-reinforced hollow slabs, in the presence of flexural and punching shear loads.

2. Because PET increases concrete's ductility, it's important to investigate how the different quantities of PET added with steel fibers affect the manufacture of high- or ultra-strength concrete, looking at the results from many angles.

3. Investigate the use of hybrid reinforced concrete beams with high PET content as sand substitute in a tension zone.

4. Investigate the behavior of concrete slabs reinforced with PET bars to resist the effects of shrinkage and thermal stresses.

# REFERENCES


[1] G.O. Bamigboye, K. Tarverdi, A. Umoren, D.E. Bassey, U. Okorie, J. Adediran "Evaluation of eco-friendly concrete having waste PET as fine aggregates" Cleaner Materials. 2021 Dec 15;2:100026.

[2] N.F. Abas, O.O. Taiwo "Utilization of pet wastes aggregate in building construction—A review" Int. J. Recent Technol. Eng. 2020;9:656-63.

[3] S. Chavan, P. Rao" Utilization of Waste PET bottle fibers in concrete as an Innovation in Building Materials—[A Review Paper]" Int. J. Eng. Res. 2016;5(1):304-7.

[4] N.V. Heredia. Incorporation of waste polyethylene terephthalate (PET) into concrete using statistical mixture design (Doctoral dissertation, Memorial University of Newfoundland).

[5] C. Doğan, I. Demir "Polymer fibers and effects on the properties of concrete" Gümüşhane Üniversitesi Fen Bilimleri Dergisi. 2021;11(2):438-51.

[6] Z.Z. Ismail, and AL-Hashmi E.A. "Use of waste plastic in the concrete mixture as aggregate replacement "Journal of Waste Management, Elsevier, Vol.28, PP.2041-2047, 2007.

[7] E. Rahmani, M. Dehestani, M.H. Beygi, H. Allahyari, I.M. Nikbin, On the mechanical properties of concrete containing waste PET particles. Construction and Building Materials. 2013 Oct 1;47:1302-8.

[8] P.G. Prabhui, C.A. Kumar, R. Pandiyaraj, P. Rajesh, and L.S. Kumar , Study on the utilization of waste PET bottle fiber in concrete "Journal of International Journal of Research in Engineering & Technology, IMPACT,Vol.2, PP.233-240, 2014.

[9] A. Khanna, S. Singla, Y. Jain, Investigation of the Mechanical Properties of Concrete by Replacing Fine Aggregates Partially with Pulverized Waste Plastic Bottle Fibers. International Journal of Emerging Technology and Advanced Engineering, 5 (6), 128. 2015;134.

[10] I. Almeshal et al., Eco-friendly concrete containing recycled plastic as partial replacement for sand. Journal of Materials Research and Technology, 2020. 9(3): p. 4631-4643.

[11] A.O. Dawood, A.-K. Hayder, and R.S. Falih, Physical and mechanical properties of concrete containing PET wastes as a partial replacement for fine aggregates. Case Studies in Construction Materials, 2021. 14: p. e00482.

[12] R.S. Falih, A.O. Dawood, and A.-K. Hayder, Structural Behavior of Reinforced Concrete Beams Containing Pet Waste Particles as Sand Replacement. Civil and Environmental Engineering, 2022. 18(1): p. 209-220.

[13] G. Tapkire, S. Parihar, P. Patil, H.R. Kumavat, Recycled plastic used in concrete paver block. International journal of research in engineering and technology. 2014 Jun 25;3(21):33-5.

[14] P.S. Patil, J.R. Mali, G.V. Tapkire,H.R. Kumavat, Innovative techniques of waste plastic used in concrete mixture. International Journal of Research in Engineering and Technology. 2014 Jun 3;3(9):29-32.

[15] M.J. Islam, M.S. Meherier, A.R. Islam, Effects of waste PET as coarse aggregate on the fresh and harden properties of concrete. Construction and Building materials. 2016 Oct 30;125:946-51.

[16] S.B. Kim, N.H. Yi, H.Y. Kim., J.H.J. Kim, and Y.C. Song, Material and structural performance evaluation of recycled PET fiber reinforced concrete. Journal of cement & Concrete Composites, Elsevier, Vol.32, PP.232-240,2010.

[17] L.A.P.D Oliveira and P. João, Castro-Gomes “Physical and mechanical behavior of recycled PET fiber reinforced mortar “Journal of Construction and Building Materials, Elsevier, Vol.25, PP.1712-1717,2011.

[18] T. Subramani and A.F. Rahman, An Experimental Study on The Properties of PET Fiber Reinforced Concrete” International Journal of Application or Innovation in Engineering & Management, IJAIEM,Vol.6,2017.

[19] N.K. Bui, T. Satomi, H. Takahashi, Recycling woven plastic sack waste and PET bottle waste as fiber in recycled aggregate concrete: An experimental study. Waste management. 2018 Aug 1;78:79-93.

[20] A. Ismail Al-Hadithi, M. Ahmed Abbas, The effects of adding waste plastic fibers on the mechanical properties and shear strength of reinforced concrete beams. Iraqi Journal of Civil Engineering. 2018 Jun 1;12(1):110-24.

[21] H.M. Adnan, A.O. Dawood, Strength behavior of reinforced concrete beam using re-cycle of PET wastes as synthetic fibers. Case Studies in Construction Materials. 2020 Dec 1;13:e00367.

[22] D. Foti, Use of recycled waste pet bottles fibers for the reinforcement of concrete. Composite Structures. 2013 Feb 1;96:396-404.

[23] M.L.A Kumar, Ramana Reddy Dr.I.V., and Sasidhar Dr.C.” Experimental Investigations on The Flexural Strength of PET Reinforced Concrete “International Journal of Emerging Technology and Advanced Engineering, IJETAE, Vol.4, 2014.

[24] D. Foti and F. Paparella , Impact behavior of structural elements in concrete reinforced with PET grids “Journal of Mechanics Research Communications, Elsevier, Vol.57, PP.57-66, 2014.

[25] A.O. Dawood, H.M. Adnan, Experimental investigation of using PET wastes as tension bars in reinforced concrete beams. Journal of University of Babylon for Engineering Sciences. 2019 Feb 11;27(1):247-61.

[26] M. RAS, Effect of polypropylene fibers on the mechanical properties of normal concrete. JES. Journal of Engineering Sciences. 2006 Jul 1;34(4):1049-59.

[27] K. Ramujee, Strength properties of polypropylene fiber reinforced concrete. International journal of innovative research in science, engineering and technology. 2013 Aug;2(8):3409-13.

[28] M. Kumar, Sri Priya Er Vinodh, An Experimental Study on Mechanical Properties of Concrete by Using Polypropylene Fibers." International Journal of scientific research and management (IJSRM) 3.10 (2015): 3614-3619.

[29] D.S. Dharan, A. Lal, Study the effect of polypropylene fiber in concrete. International Research Journal of Engineering and Technology. 2016 Jun 6;3(6):616-9.

[30] A. Nayak, V. Karthik, M.L. Likhit, K.K. Abhishek, D. Chandran, & H. Pailoor, Experimental study on hardened properties of concrete by using polypropylene fibre as additive.

[31] IQS 5/1984 "Portland cement Central Organization for Standardization and Quality Control Iraq" (in Arabic).

[32] IQS 45-(1984), Aggregates from Natural Sources for Concrete and Building Construction. Central Organization for Standardization and Quality Control-COSQC. Baghdad-Iraq, 1984.

[33] ASTMC494/C494M-17, "Standard Specification for Chemical Admixtures for Concrete," ASTM Int. West Conshohocken, PA, no. January, pp. 1–10, 2017.

[34] ASTM A615/A615M-13, "Standard Specification of Deformed and Plain Carbon Steel Bars for Concrete Reinforcement", (ASTM A615M-13), ASTM International West Conshohocken. (2013).

[35] Zhu, M. F., & Yang, H. H. (2006). Handbook of fiber chemistry. 3rd ed. New York: CRC Press. p. 139–260.

[36] Madhavi, T. C., Raju, L. S., & Mathur, D. (2014). Polypropylene fiber reinforced concrete-a review. *International journal of emerging technology and advanced engineering*, *4*(4), 114-118.

[37] ASTMC143, "Standard Test Method for Slump of Hydraulic-Cement Concrete 1," 2000, doi: 10.1520/C0143_C0143M-12.

[38] BS1881/PART116(1989), Method for Determination of Compressive Strength of Concrete Cubes. British Standards Institution. London, 1989.

[39] ASTMC78/C78M-18, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)ASTM International. USA," vol. 04.02, pp. 1–3, 2002.

[40] A. Drews, "Standard Test Method for Split Tensile Strength-ASTM C 496-04," Man. Hydrocarb. Anal. 6th Ed., pp. 545-545–3, 2008, doi: 10.1520/C0496.

[41] ASTM C469 standard, "Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression", journal: Annual book of ASTM Standards, volume :(4), pages:(469), (2002).

[42] ASTMC642, "Standard test method for density, absorption, and voids in hardened concrete," C642-13, 2013.

[43] British Standard Institute, "BSI 1881- PART 116(1983). Method for Determination of Compressive Strength of Concrete Cubes,Testing Concrete," Constr. Stand., vol. 2, no. 2, p. BS 1881-108, 1983.

[44] European- Standard, "EN 206-1 Concrete - Part 1: Specification, performance, production and conformity," Eurocode, vol. 3, pp. 1–72, 2000.

[45] T. J. Sullivan, G. M. Calvi, and M. J. N. Priestley, "Initial stiffness versus secant stiffness in displacement based design (Paper No. 2888)," 13th World Conf. Earthq. Eng., vol. 65, no. 2888, pp. 581–626, 2004.

# APPENDIX

## Flexural reinforcement

All slabs were designed according to ACI318-14 Code. The steps of analysis of the reference slab as follows:

From the design of the slab in Figure 3.18

Check one way slab $=\frac{1500}{500}=3>2$ ∴ Design one way slab

Check the simply support $=\frac{1450}{20}=72.5mm$

$\because \rho = \frac{As}{bd}$

$$d = h - cover - \frac{db}{2}$$

Let concrete cover = 20 mm.

So, d =55 mm , S=150mm

$As = 1000\frac{A_b}{S} = 473.33mm^2$ ,Where $A_b = 71mm^2$

$\therefore \rho = \frac{473.33}{1000*55} = 8.606*10^{-3}$

$\rho min = \frac{1.4}{fy} = 3.382*10^{-3}$

$\rho max = \rho 0.005$ For tension controlled section

$\beta 1 = 0.85 - 0.005\frac{f`c-28}{7} > 0.65$ for f`c > 28 MPa

$\because \rho 0.005 = 0.85\,\beta 1 * \frac{f`c}{fy} * \frac{\varepsilon u}{\varepsilon u + 0.005} = 20.2*10^{-3}$ ,Then $\varepsilon_u = 0.003$

∵ concrete strength f`c equal to 32 MPa and yield strength of reinforcement equals 414 MPa

∴ $\beta 1 = 0.82$

∴ $\rho_{0.005} = 20.2*10^{-3}$

∵ ρmax <ρ< ρmin ∴ OK. So, ϕ=0.90

∴$\phi Mn = \phi Asfy(d - \frac{a}{2})$

$a = \frac{Asfy}{0.85*f`c*b}$ =7.2

$\phi Mn = 0.9 * 473.33 * 414(55 - \frac{7.2}{2})$ =9.06 KN.m

$Mu = \frac{W_u L^2}{8}$ , L=1.45mm

$Mu=0.26W_u$

$Mu = \phi Mn$

$0.26W_u=9.06$

$W_u=34.85$KN/m

Wu= $1.2W_d + 1.6W_L$

Wu = 1.2 $W_d$+1.6$W_L$= 1.2 * density * volume+1.6 $W_L$

34.85=1.2 (2.5*0.08) +1.6 $W_L$

$W_L$=21.63 KN/m

Check spacing

$S = \min\{1000\frac{A_b}{A_s}, 3t, 450\}$

S=min {150, 450, 450}

S=150mm

$$No. of\ bars = \frac{473.33}{71} = 6.6\ \cong 6$$

So,6Ø10 in short direction @290mm

4Ø10 in short direction @150mm

# الخلاصة


تتناول هذه الدراسة تأثير استخدام نفايات البولي إيثيلين تيريفثاليت (PET) كبديل جزئي للركام الناعم في الخلطات الخرسانية. وتهدف إلى تقييم الخصائص الميكانيكية والفيزيائية للخرسانة الليفية، إلى جانب دراسة تأثيرها على سلوك الانحناء للبلاطات الخرسانية الليفية، سواء أكانت مزودة بتسليح فولاذي أم غير مسلحة. الجزء الأول من الدراسة يركز على استبدال جزء من الرمل بنفايات PET ودراسة تأثيره على الخصائص الميكانيكية والفيزيائية للخرسانة. حيث تم استخدام سبع نسب استبدال مختلفة في هذه الدراسة: 0%، 5%، 10%، 15%، 20%، 30%، و50%، مع إضافة 1.5% من ألياف البولي بروبيلين كنسبة ثابتة من حجم الخرسانية. كما أُعدّت خلطة مرجعية للمقارنة. أُجريت الاختبارات الميكانيكية عند أعمار 7 و28 و90 يومًا، وركزت على مقاومة الانضغاط، مقاومة الشد الانشطاري، مقاومة الانحناء، ومعامل المرونة. وشملت الاختبارات الفيزيائية قياس الكثافة، معدل امتصاص الماء، وسرعة النبضات فوق الصوتية. أظهرت النتائج أن نسب الاستبدال بين 5% و10% حسّنت الخصائص الميكانيكية للخرسانة بشكل ملحوظ. إذ ارتفعت مقاومة الانضغاط بنسبة 19.21% إلى 29.06%، ومقاومة الشد الانشطاري بنسبة 20.83% إلى 37.5%، ومقاومة الانحناء بنسبة 22.5% إلى 37.5% مقارنة بالخلطة المرجعية. وتم تحديد النسبة المثلى للاستبدال عند 10%. ومع ذلك، لوحظ انخفاض في الخصائص الميكانيكية (مقاومة الانضغاط، الشد الانشطاري، والانحناء) عند تجاوز نسبة استبدال 15%. كما انخفض معامل المرونة، الكثافة، وسرعة النبضات فوق الصوتية، بينما ازداد معدل امتصاص الماء مع زيادة محتوى PET.

الجزء الثاني من الدراسة يتناول تأثير استبدال الرمل بنفايات PET على سلوك الانحناء للبلاطات الخرسانية الليفية. تم إعداد أربعة عشر بلاطة بأبعاد 1500 × 500 × 80 ملم، وقُسّمت إلى مجموعتين: المجموعة الأولى ضمّت سبعة بلاطات مسلحة بالفولاذ، بينما اشتملت المجموعة الثانية على سبعة بلاطات غير مسلحة. لكل نسبة استبدالPET ، تم إعداد بلاطتين بالإضافة إلى بلاطتين مرجعيين. تم اختبار البلاطات لقياس الحمل الأقصى للفشل، الهطول النهائي، امتصاص الطاقة، الصلابة، مؤشر الليونة، والانفعال. كما تم دراسة التشققات والتي تشمل الشق الأول ونمط التصدع. أظهرت النتائج أن زيادة محتوى PET في البلاطات المسلحة بالفولاذ أدى إلى تحسين ملحوظ في عدة خصائص. ارتفع الحمل الأقصى للفشل بنسبة 4.22% إلى 26.55%، والهطول النهائي بنسبة 12.94% إلى 77.97%، ومؤشر الليونة بنسبة 3.52% إلى 105.03%، والانفعال بنسبة 6.29% إلى 25.24%، وامتصاص الطاقة بنسبة 18.80% إلى 80.36%. كما ارتفع حمل الشق الاول بنسبة 7.14% إلى 171.43%. ومع ذلك، لوحظ انخفاض في الصلابة الابتدائية بنسبة 3.85% إلى 31.54%،

والصلابة الثانوية بنسبة 7.60% إلى 60.46%. أما البلاطات الغير المسلحة، فقد أظهرت أيضًا تحسنًا في الأداء. ارتفع الحمل الأقصى للفشل بنسبة 26.67% إلى 53.33%، والهطول النهائي بنسبة 8.91% إلى 41.01%، والانفعال بنسبة 7.10% إلى 39.81%، وامتصاص الطاقة بنسبة 21.50% إلى 68.24%.

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة ميسان / كلية الهندسة

قسم الهندسة المدنية

# تصرف الانحناء للبلاطات الخرسانية المسلحة أحادية الاتجاه والمعززة بالألياف المتضمنة نفايات (PET) البلاستيكية كبديل مستدام للرمل

من قبل

زهراء احمد صبار

بكالوريوس هندسة مدني 2020

رسالة
مقدمة الى كلية الهندسة في جامعة ميسان
كجزء من متطلبات الحصول على درجة الماجستير في علوم الهندسة المدنية / الانشاءات

جمادى الآخرة 1446 هـ

بأشراف
الاستاذ الدكتور: عباس عودة داود