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Civil Engineering Department

PET WASTES CONCRETE PROPERTIES AND ITS EFFECTIVENESS ON STRUCTURAL BEHAVIOR OF REINFORCED CONCRETE BEAMS

A THESIS
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(STRUCTURES)

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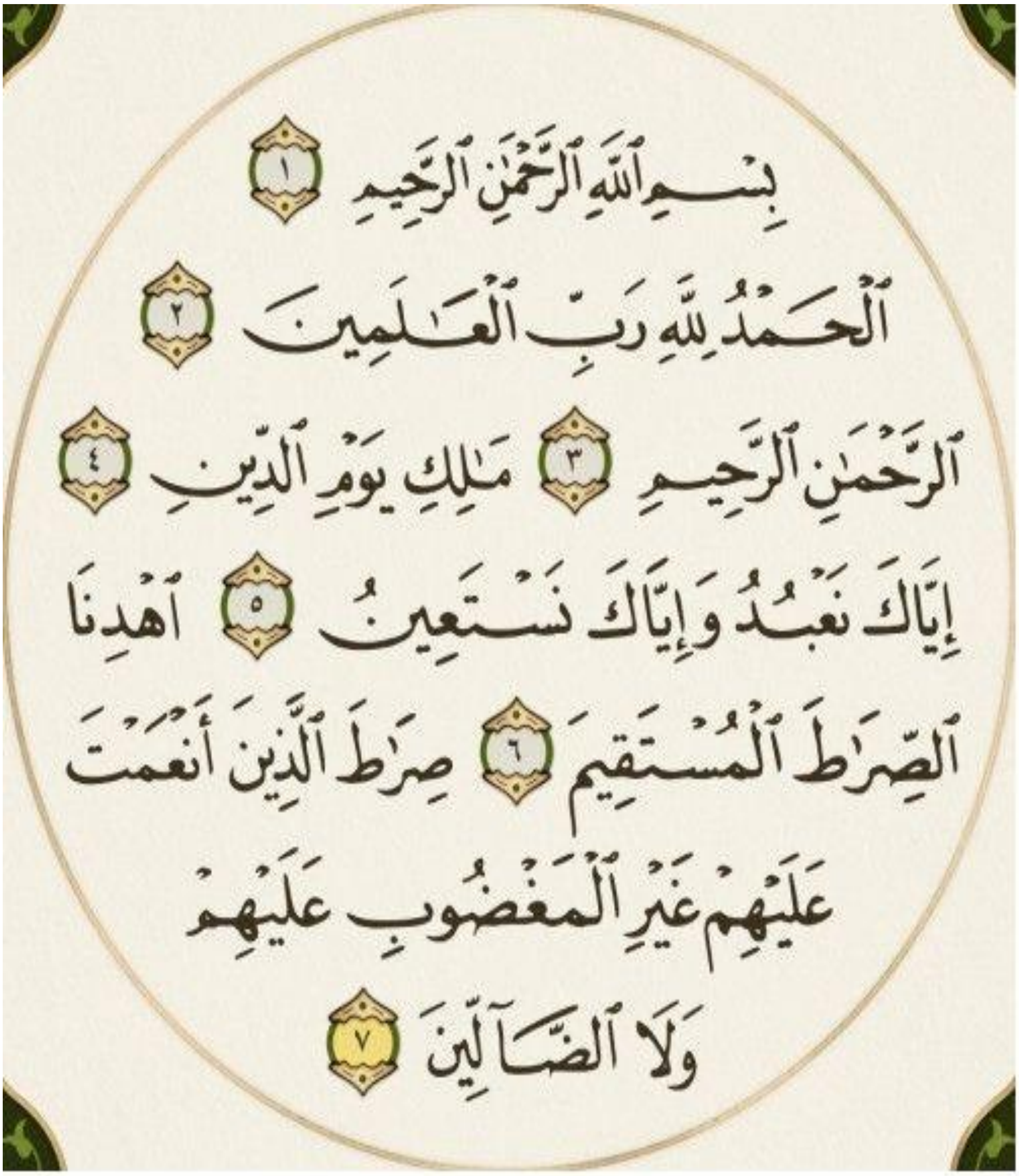

سورة الفاتحة -الايات (١-٧)

DEDICATION

To *those who left life and left in our hearts the beautiful effect,* **my uncles, Sheikh Rishm, Hajj Hashem, Hajj Hussein.** *may God have mercy on them.*

To *the dedication and sincerity instance, my role model, and my ideal in life.....* **My beloved father***.*

To *the one who gave her happiness and comfort to my happiness.* **My honorable mother***.*

To *the symbol of sincerity, loyalty and companion path.....* **My dear wife.**

To *The pleasures of life ......***my children**

To *everyone who called me well*

To **my Colleagues** *for their help practically*

I offer you that humble work

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ABSTRUCT

In this study, the influence of using polyethylene terephthalate (PET) wastes as a partial replacement of natural sand is investigated to study the mechanical and physical properties of concrete beside its impact on the structural behavior of semi-full scale beams. The present study was divided into three parts. First part deal with the effect of partial replacement of sand with PET waste on the mechanical and physical properties of concrete, where six replacement percentage were used in this study 5% ,7.5% ,10% ,12.5% ,15% , and 20%. Mechanical tests at ages of 7, 14, and 28 days for compression, splitting, flexure, modulus of elasticity, and toughness, as well as physical tests for density, volumetric change, plastic shrinkage, ultrasonic velocity and absorption, in addition, shear strength are performed within this part. Results showed that the specimens containing partial substitution ratios ranging within 5%–12.5% displayed 26.8%–43.64%, 18.6%–26.9%, and 18.1%–30.2% increments in the compressive, tensile, and flexural strengths, respectively, compared with the reference specimens. The optimum replacement percentage of PET is 7.5% and mechanical properties decrease when the PET content exceeds 15%. The findings also revealed an increase in toughness and decrease in modulus of elasticity, shear strength, shrinkage with increasing the PET content in the concrete generally.

Second part deal with the effect of using PET waste as a partial substitute for fine aggregate on the structural behavior of reinforced concrete beams. Six 150 * 300 * 2300 mm concrete beams with similar steel reinforcement (one beam for each PET percentage) in addition to the reference concrete beam were investigated. Beams tested via ultimate load failure, ultimate deflection, energy absorption, stiffness, ductility index, and compression strain. Cracks investigation which including first crack load and crack

pattern, then compare it with the reference beams to evaluate the effect of PET waste on its structural behavior. The results showed that the increasing of PET waste content in the concrete beams led to increasing in the ultimate failure load, ultimate deflection, ductility index, strain, and energy absorption at a rate ranging within 0%–4%, 23.2%–93.7%, 12.13%–93%, 432%–1139%, and 51%–275%, respectively. While a reduction in the initial and secant stiffness at a rates ranging within 5%-38% and 19.2%–46.4%, respectively, was shown.

Third part deals with the effect of using PET bottle waste as reinforcement bars in concrete beams. Waste of PET bottles has been reshaped as a long strips which used to forming PET bars. The tighten PET bars are used as alternative to the steel bars in the tensile area. Five concrete beams with dimensions (150*200*1400) mm are used in this part.Two of them are controllers beams with and witout tension steel reinforcement.The other three beams are reinforced with three different forms of tighten PET bars. PET bars achieved an ultimate failure load of up to 25% of the failure load for specimens containing steel bars.

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List of Abbreviations and Symbols

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British standard
PVC	Polyvinyl chloride
fcu	Cube Compressive Strength in MPa
fr	Modulus of rupture in MPa
fy	Yield strength for steel
PET	Polyethylene Terephthalate
PP	Polypropylene
SP	Superplasticizer
w/c	Water to cement ratio
P/S	PET/Sand
Ab	Absorption
S	Slump
V	Shear
V.C	Volumetric change
P.S	Plastic shrinkage
E	Modulus of elasticity
T	Energy absorption (Toughness)
A.ε	Axial strain
D.I	Ductility index
C.ε	Compressive strain
I.S	Initial stiffness
S.S	Secant stiffness
C.L	Crack length

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CHAPTER ONE
INTRODUCTION

Chapter One

Introduction

1.1 General

The population in the 21st century reached more than seven billion people, which requires many buildings and housing constructions all over the world [1]. This leads to increase the demand for concrete. The annual production of concrete in the world exceeds 11.6 billion tons annually, and expects to increase by 2050 to 18 billion tons annually [2]. Thus, the materials that constitute concrete may experience decline or depletion. Therefore, studies on the use of sustainable alternative materials as partial or full alternatives to some components of concrete have been conducted. One of the crucial considerations is the ratio of the additives to concrete and their influence on the concrete properties. Different materials can be added to concrete in order to changing its engineering properties.

On the other hand the increase in population capacity was accompanied by a tremendous increase in the amount of solid waste. Some of these wastes degrade over time; others are not degradable, which pose the greatest danger to the environmental and ecological system, as they increase pollution. The challenge for most governments lies in how to treat these wastes, as there are many ways to deal with them in order to get rid of environmental damage. Polyethylene terephthalates (PET) are considered one of the most widespread non-degradable solid wastes in the world, due to the increasing global demand for the production of fibers and PET bottles for packaging drinking water and soft drinks. The rapid expansion of the PET bottle industry has increased growth in global PET consumption. The important of using different shapes of PET waste in concrete has been a modern trend of studies for a large number of researchers because of its great environmental benefit represented by ridding the environment of pollution and improving the behavior and properties of concrete in all its uses, in addition to the possibility of using it as a sustainable future alternative to some components of concrete that may be a decline in the future or the depletion of its sources because of the increasing demand for concrete in the future.

1.2 Sustainability

Sustainability means “meeting the needs of the present without compromising the ability of the future generations to meet their own need. For more than 200 years, concrete has been accepted for its long-lasting and dependable nature. In addition to durability and dependability, concrete also has superior energy performance, is flexible in design, is affordable, and is relatively environmentally friendly. It can be expected that concrete will be needed to increase industrialization and urbanization while protecting the environment. To do this, the concrete industry should consider recycling industrial by-products and waste safely and economically. When industrial by-products or some wastes replace concrete components, the environmental impact improves along with the energy efficiency and durability of concrete [3].

1.3 Green Concrete

Green concrete is defined as a concrete which uses waste material as at least one of its components, or its production process does not lead to environmental destruction [4]. It should also have high performance and life cycle sustainability. In other words, green concrete is an environment friendly concrete. Green concrete improves the three pillars of sustainability: environmental, economic, and social impacts. The key factors that are used to identify whether the concrete is green are : amount of portland cement replacement materials, manufacturing process and methods, performance and life cycle sustainability impacts. Green concrete should follow reduce, reuse and recycle technique or any two process in the concrete technology. The three major objective behind green concept in concrete is to reduce green house gas emission (carbon dioxide emission from cement industry); to reduce the use of natural resources such as limestone, shale, clay, natural river sand, natural rocks that are being consume for the development of human mankind that are not given back to the earth; and the use of waste materials in concrete that results in the air, land and water pollution. This objective behind green concrete will result in the sustainable development without destruction natural resources [5].

1.4 Solid Waste Management

Solid waste is the useless, unwanted and discarded material resulting from day to day activities in the community. Solid waste management may be defined as the discipline associated with the control of generation, storage, collection, transfer, processing and disposal of solid waste [6].

One of the main goals of sustainable solid waste management is to maximize the ability of its recycling and reusing. The most common waste materials are metal and plastic which are available in enormous quantities in the world [5].

1.4.1 Solid Plastic Waste

In the 1860s, Plastic production was invented for the first time but in the 1920s it was developed for industry. In the 1940s, it became one of the fastest growing global industries. Between 1950 and 2012, with the gradual replacement of materials such as metal and glass with plastic, production growth worldwide increased between the 1970s and 2012. The average annual rate of plastic growth increased from 1.7 million tons to nearly 300 million tons in 2015 [7]. The global annual production in 2017 reached about 393 million tons [8]. Percent of plastic that ranged from 22% to 43%

represents a wasted resource worldwide. It takes up valuable place, when it is disposed of in landfills, and spoils societies and the environment by cause pollution, in addition to, environmental damage to marine ecosystems by plastics. It is indicated that if current production continues and waste is poorly managed 12 billion metric tons will enter landfills or the environment by 2050 [9]. The environmental and social benefits of plastic must be balanced against the problems represented by its durability and amazing size worldwide as waste stream.

1.4.2 PET Plastic Waste

PET (also abbreviated PETE) is short for polyethylene terephthalate. PET is first synthesized in North America in the mid-1940s by DuPont chemists searching for new synthetic fibers. In the early 1970s, the technology was developed for blow-stretch molding PET into bottles. The PET bottle was patented in 1973 [10]. PET is a clear, lightweight plastic and strong, that is most used for packaging beverages and foods, especially soft drinks, juices and water as shown in Fig. (1-1).

Fig. (1-1): Kinds of pet plastic products

PET typical properties included:

- Strength in thermoplastic, high hardness and stiffness.

- High abrasion resistance and low friction.
- High stability in dimensions.
- The range of service temperature is from -40°C to 100°C.
- It is white in the semi-crystalline state and transparent in the amorphous state (glass clear).
- Physiologically acceptable.
- At room temperature resistant to water, neutral and acidic salts, dilute acids, ethers, alcohol, fats, oils, aliphatic and aromatic hydrocarbons.
- Not resistant to alkalis, phenols, superheated steam, esters, chlorinated hydrocarbons and oxidizing acids.
- Stress cracking resistant [12].

The average global consumption of PET bottles is about 20 million tons, with an annual is increased of 12%-15%. At the same time, recycling rate of PET bottles is low at just 29.3% [12]. PET consumption dominated the production of beverage containers, which equals 79% of total world production in 2017[13] as shown in Fig. (1-2).

1.4 .3 Recycled PET Waste

Resource energy is the energy that remains in the raw material and can be used after the recycling process. Almost 40% of PET energy used is as a result of 'resource energy. PET is one of the most recycled plastics worldwide, and it is completely recyclable. PET's high strength that compared to its light weight is a key to its energy efficiency [9]. Products commonly made from recycled PET include jars, and new PET bottles, clothing, carpet, rope, industrial strapping, automotive parts, sleeping bags and fiberfill for winter jackets, construction materials, and protective packaging.

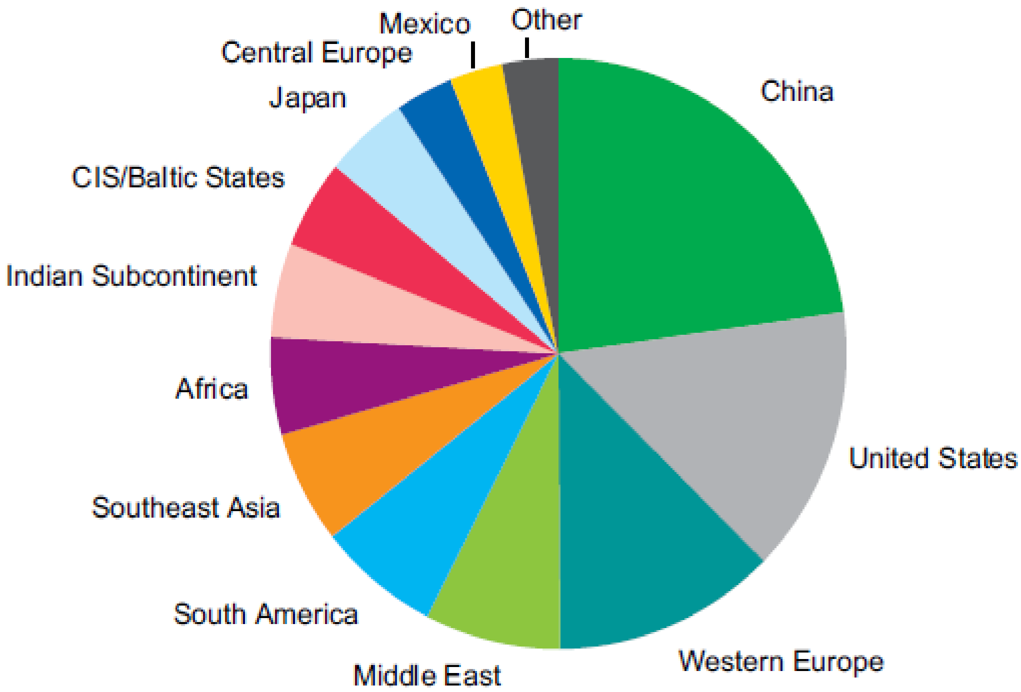


Fig. (1-2): World consomption of PET solid-state resines 2017 [13]

1.4.4 Locally Plastic Waste

The prosperity of the process of producing water and soft drinks bottled with plastic bottles are significantly in Iraq, especially during the last decade. In addition to the huge quantities imported across borders, accompanied by an improvement in the living reality of the Iraqi individual has doubled the daily consumption of these products, in addition to consumption in the various occasions and government institutions (which represent very large quantities). The state of the environment in Iraq report 2017[14] is indicated the amount of solid waste generated per person per day is estimated at 0.3 kg / person / day and in some area it is reached 1 kg / person / day that are depending on the standard of living. There are no accurate statistics on the amount of PET solid waste annually or the annual increase in it. The government factories for the recycling are very few and non-existent in most regions with compared to the enormous volume of solid waste.

This study focused on the recycling of plastic PET bottle waste, which represents the highest percentage of plastic solid waste and its reuse in reinforced concrete, in order to reduce the impact of these wastes on environment and improve the construction properties, there by obtaining great double benefit. Fig. (1-3) shows a local collection station of PET waste.

Fig. (1-3): PET bottles wastes collection point

1.4.5 Recycle PET Waste in Construction Fields

Recycling waste means the process of treating scrap or waste and making use of its potential to produce useful materials that are sometimes completely different from their original state. The recycling of PET waste in the construction field includes using it in the form of building materials as a partial substitute for fine or coarse aggregate, or as fibers added to concrete, it is considered one technique to reduce impact of this waste on the environment reducing the disposal cost. Several studies have been reviewed about recycling of plastic PET waste in different forms, in concrete mixture or structural fields[15-33].

1.5 Research Objectives

The current study focuses on using polyethylene terephthalate (PET) waste (bottles of water, soft drinks and juices exclusively) with two different forms, The first one as a fine aggregate within concrete mix and concrete beams, and the second as a reinforcement bars in concrete beams. The addition of PET waste to the concrete achieves two main benefits. The first benefit represented by providing a sustainable economical material that can partially replace other concrete components and the second one is an environmental benefit represented by solving some of the solid waste problems. The objectives of scientific research have been focused on the following:

1. Evaluate the effect of added PET particles on physical and mechanical properties of concrete mix, and find out the optimum percentage of plastic PET waste that is used as partial replacement of sand in concrete.
2. Investigate a new form of PET bottle wastes to be use as reinforcement bars through cutting PET bottle in to long continuous strips to obtain a low cost bars have a great resistance to corrosion.

1.6 Thesis Layout

The research includes five chapters and as follows:

- The first chapter provides an overview of population growth and its relationship to the production of concrete and the amount of disposal waste. Also explanation of the benefits of sustainability, green concrete, and an overview of solid plastic waste management, especially PET waste and some of its global statistics. In addition, recycle PET waste in constructions field.

- The second chapter includes a results review of the previous studies and the effect of the various PET waste forms on the properties and behavior of concrete mixtures.
- In the third chapter, the materials specifications, details of samples, equipment, mixing ratios, and tests used in the research were presented.
- In the fourth chapter, results and relationships of the work are presented and discussed.
- Chapter five explains the important conclusions from the study results, as well as some recommendations and proposals that document this study and ways of achieving them the scientific benefit of future studies.

CHAPTER TWO

LITERATURE REVIEW

Chapter two

Literature Review

2.1 General

In the past few decades, researches and studies are conducted were aimed to studying the behavior of concrete samples after combining them with recycled materials. Different materials with different forms of particles and fibers are used. One of the most common materials in recycled concrete researches is polyethylene terephthalate wastes (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. The focus will be on recycling of PET waste in the concrete in two ways, the first way is using PET waste as a partially replacement of one of the components of the concrete mixture, while the other one is deal with the use of PET waste as reinforcement in reinforced concrete beams.

2.2 Type of Recycled PET Wastes

The researches related to this field dealt with the use of PET waste in various forms, which summarized in four types briefly.

2.2.1 Using PET Waste as a Fiber

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:-

In 2007 Ochi et al. [15], used PET recycled fiber produced from PET bottles. The length of PET fiber was 30 mm. The weight mixing ratio 1: 3: 2.4 (cement, fine aggregate, coarse aggregate) and the maximum size of coarse aggregates was 15 mm. Three w/c ratios of 55 %, 60%, and 65%, with four PET fibers percentages of 0%, 0.5%, 1.0%, and 1.5 % by volume were used. The results showed that the bending strength and toughness increased when the PET fibers percentage increase on one side, and with a decreasing of water to cement ratio on the other side. Also, concluded that 1.5% is the optimum fibers percentage, especially with the ratio of water to the cement of 55%.

In 2010, Kim et al. [16], used recycled PET fibers from waste PET bottles in concrete mixtures to study of the basic properties of materials, concrete resistance and drying shrinkage, in addition to study 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 was of 4.1% and 10.1% respectively. Coarse aggregate (crushed gravel) maximum size was 25 mm and river sand fine aggregate, were 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 Fig. (2-1). 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 increase. The maximum deflection at mid-span was larger than the specimens without fibers by approximately 400%.

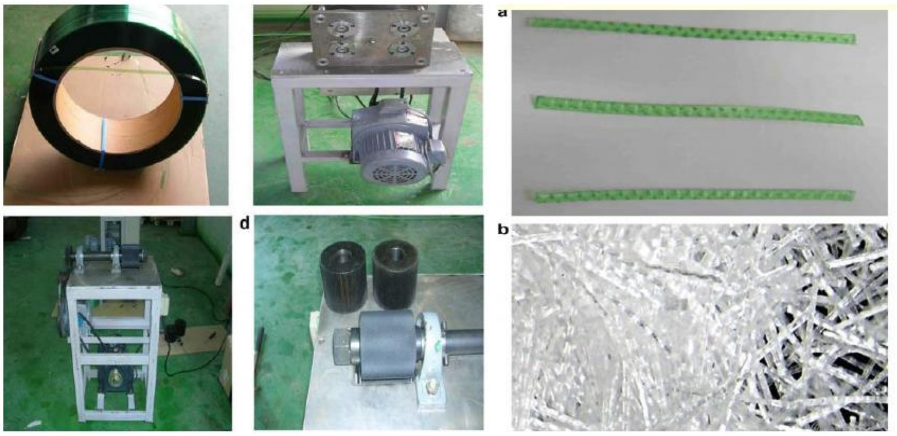


Fig. (2-1): Manufacturing system of recycled PET fibers and geometry of the recycled PET fibers and PP fiber [16]

In 2011 Luiz A. Pereira de Oliveira and Joao P. Castro-Gomes [17], used different volumetric PET fibers percentages of 0%, 0.5%, 1.0%, and 1.5% with dimensions, thickness of 0.5 mm, width of 2 mm, and length of 35 mm as shown in Fig. [2-2 (a)]. The mix proportions were of 1:1:6 by volume and compared with the reference mix of 1:3 cement mortar compositions. They showed that incorporating PET fibers into the reference mixture 1: 1: 6 led to increases in bending strength. Also, they find that the 1.5% volume of PET fiber was optimum and gave the mortar the best performance. Fig. [2-2(b)] shows a cube failure mode.

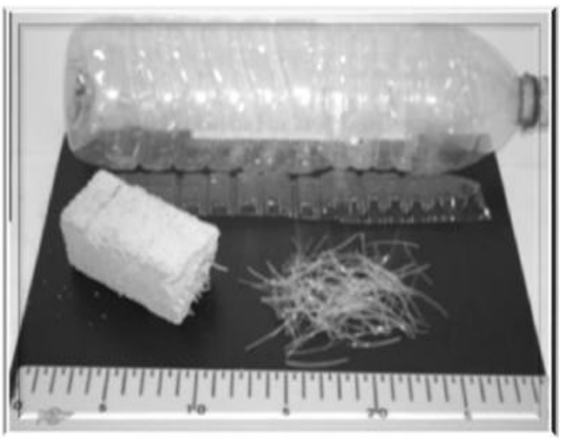
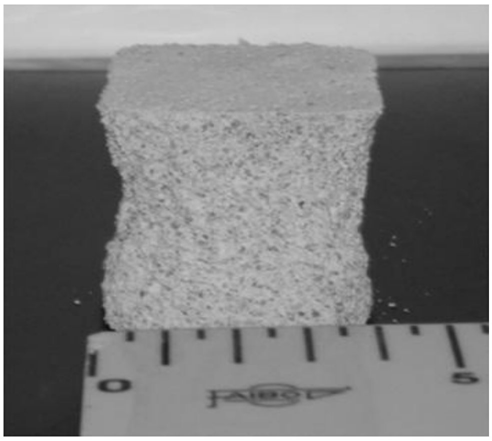
a  b 

Fig. (2-2): a- Polyethylene terephthalate (PET)recycled fibers, b- Typical failure of a mortar after compressive test [17]

In 2011 fraternal et al. [18], carried out two types of fiber, the first type is PET wast fibers and the second one is PP (polypropylene) wast fibers. Three different lengths of PET wast fibers and one length of PP wast fiber with diameters ranging from 0.12 mm up to 2.00 mm were reshaped in private factories as shown in Fig. [2-3(a)]. The percentage of fiber for all types is 1% fiber to the volume of mixing. Mixiture ratios are 1:2.7: 2.73 and w/c is 0.53. They found that concrete reinforcement with recycled PET fibers enhancing the compressive and tensile strengths, ductility of concrete and thermal resistance as compared to plain concrete. Fig. [2-3(b)] shows specimen failure mode.

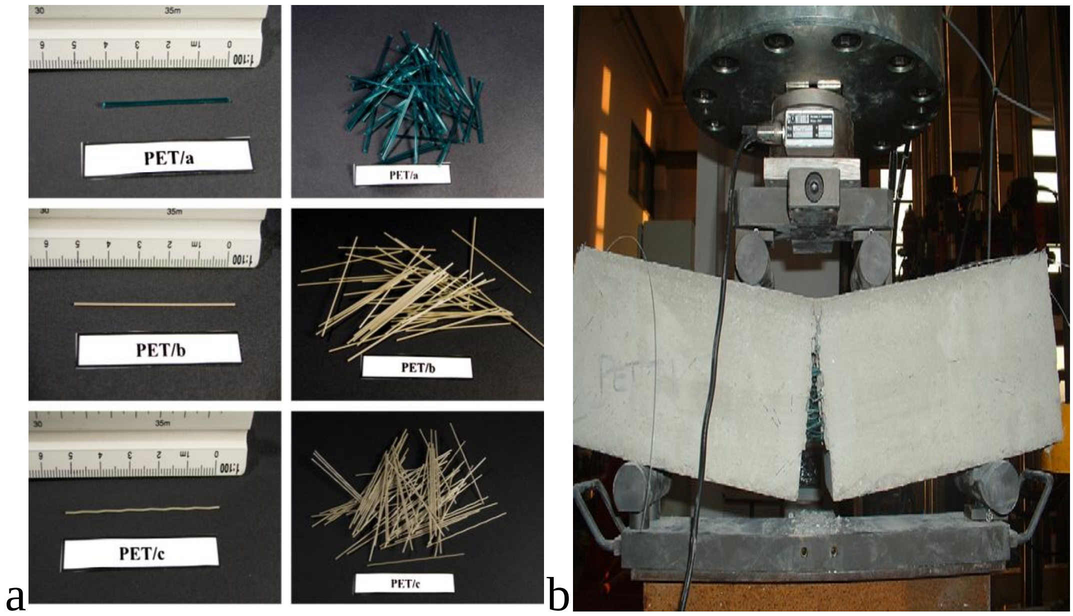


Fig. (2-3): a-Form of (PET) after cutting, b-Specimen failure mode [18].

In 2013 Cordoba et al. [19], carried out PET waste bottles flakes with three different lengths of 0.5, 1.5, and 3 mm, and 5 mm width (on average). Three volumetric percentages of 1.0%, 2.5%, and 5.0% from PET waste bottles flakes were used. The mixing ratio was 1: 2.17: 2.75 with a water/cement ratio of 0.485. The results are showed that particle PET with a length of 1.5 mm and a percentage of 2.5% have been highest compression strength, modulus of elasticity, and compressive strain, while PET particles, with a length of 3 mm had been lowest at a concentration of 5.0%.

In 2014 Fraternali, et al. [20], used two types of recycled PET waste fibers in concrete (PET / a and PET / b) in a seawater environment. The properties of the two PET waste fibers types were as shown in Table (2-1). The PET waste fibers content is 1 % by volume for both types. The mixing ratio was 1: 1.9: 1.56 as a (cement: sand: coarse aggregate) with w/c of 0.38 and fluidizing additive percent 0.8%. They reported that the seawater conditioning cause to loss of the ultimate ductility, in addition, it led to a decrease in the compression strength.

Table (2-1): Geometrical and mechanical properties of employed R-PET fibres [20]

Type of fibre	Specific gravity (kg/m3)	Profile	Diameter (mm)	Length (mm)	Tensile strength (MPa)	Ultimate strain (%)
PET/a	1340	Smooth	1.10	40	550	27
PET/b	1340	Crimped	0.70	52	274	19

In 2018 Khalid et al. [21] used polyethylene terephthalate wastes in reinforced concrete with two types as shown in Fig. (2-4). The first one is the form of non-irregularly shaped particles with dimensions ranging from 5 to 20 mm. The second is as PET fibers (RPET-5 and RPE-10) which that form of a ring with a width of (5 ±1) and (10 ±1) mm, respectively and cross-section diameters of 60 ± 5 mm. The water - cement ratio(w/c) was 0.55. They found that the compression strength of concrete beams containing RPET-10 was raised by 32.3% compared to the plain concrete beam. They also observed that the relative ductility of the reinforced concrete beam specimens with RPET fibers was comparable to that of regular reinforced concrete.

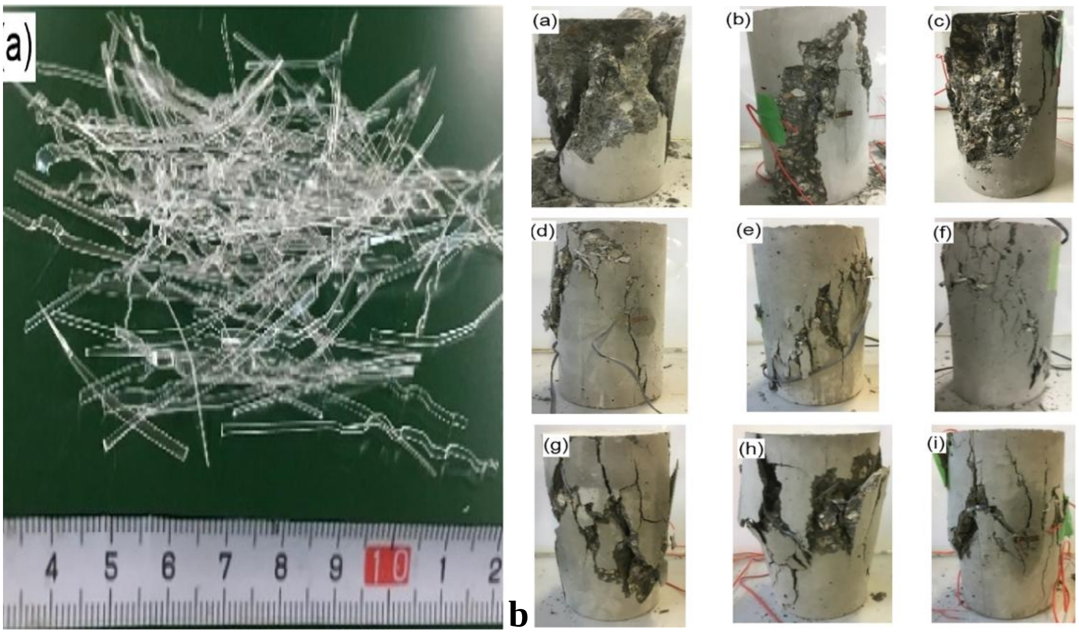
In 2018 Bui et al. [22], used PET bottle waste as fiber in recycled aggregate concrete. PET bottle was cut into 50–60 mm lengths and 2–3.5 mm widths as shown in Fig. [2-5(a)]. The mixing ratio was 1: 1.55: 2 (ce-

a- Ring shape PET fiber b- Irregularly shaped PET particles

Fig. (2-4): The PET waste fibers types [21]

nt, fine aggregate, and coarse aggregate) respectively, with silica fume of 21.4 kg for each cubic meter and w/c was 0.45. The percentage of PET fiber that used was 0.25%, 0.5%, and 0.75% by volume. They found that using PET fiber had been given better performed for mixture; also it enhanced the splitting tensile strength, compressive strength and shear strength. Fig. [2-5(b)] shows specimens failure mode.

a



b

Fig. (2-5): a- Recycled PET bottle fiber, b-Specimens failure mode [22]

In 2019 Al-Hadithi and Ahmed [23], used a 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 fibers length was 40mm, the average width of 4 mm and a thickness of 0.35 mm as shown in Fig.

[2-6(a)]. The mix proportions were 1: 1.62 : 2.55 by weight, the (w/c) and cement content was (0.448) and 430 kg/m^3, respectively.The maximum size of the gravel used was14 mm. The results showed that workability have been decreased when the percentage of PET fibers increase. Also, they observed that the increase in PET fibers percentage until 1% led to increasing in the compressive and shear strength of concrete. Also, they observed an increasing in energy and rising in the first crack load. Finally, they showed that increasing of PET fibers percentage until 1.25% led to increase splitting tensile strength. Fig. [2-6(b)] shows failure mode of reference specimen and 1.5% PET fibers specimens

a

b

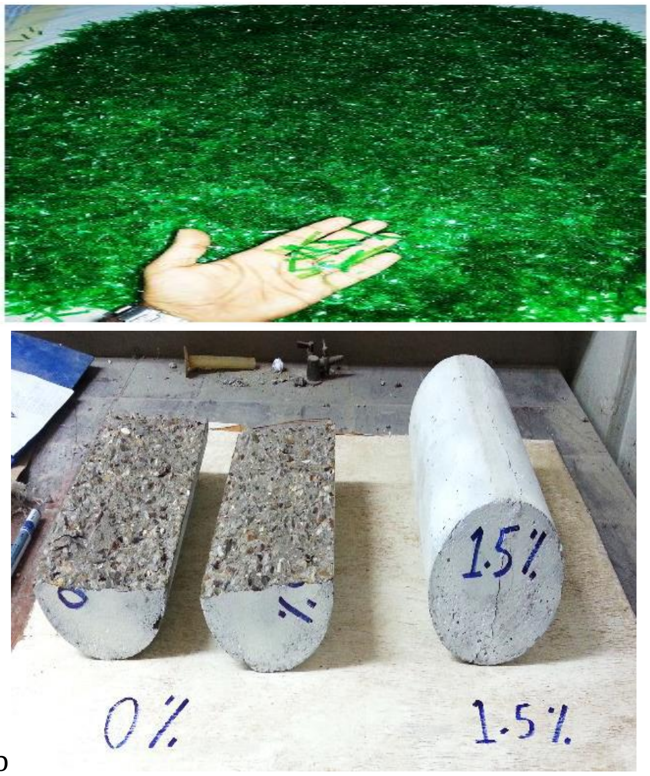


Fig. (2-6): a-The small fibers of soft drink bottles (PET), b- Failure mode of reference specimen and 1.5% PET fibers specimens [23]

In 2019 Adnan and Dawood [24], used PET waste fibers with two types of PET bottles, large and small. Two colors of large PET bottle white and green were cut by a special machine to random shape with maximum size of 25.4 mm as shown in Fig. (2-7), while the small PET bottle fibers were cut manually with dimensions of 40 mm length and 4mm width. The two types were used in concrete mixture with volumetric percentages of 1.5% and 3% and water to cement ratio of 0.41. They observed that the machine PET fiber show 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 is increased at a percentage 1.5% and decrease at percentage 3%.

Fig. (2-7): Types of used PET waste fibers [24]

2.2.2 Recycled PET Waste as a Fine Agregate

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

In 2005 Yun-Wang Choi et al. [25], used (PET) bottles waste as a partial replacement of fine aggregates in concrete mixture. Three water - cement ratios of 0.45, 0.49, and 0.53 were investigated. The replacement percentages of PET bottles aggregates were 0%, 25%, 50%, and 75% by volume of fine aggregate. The range size of PET bottles waste particles was 5–15mm. They observed a little change in the compressive strength of the samples when the replacement percentages were 25% and 50 %, and strength is reduced about 33% for the replacement percentage of 75% as compared to control specimen.

In 2008, Ismail et al. [26], presented PET bottle as a partial replacement of fine aggregate in the concrete mixture. PET bottle waste dimensions was 0.15-12 mm length and 0.15-4 mm width. In addition, to use of three percentages 0%, 10%, 15%, and 20% by weight of sand, as shown in Fig. (2-8). Mix proportion was (1cement: 1.88 sand: 2.68 gravel) by weight, with w/c was 0.53. The tests carried out at ages of 3, 7, 14 and 28 days for fresh and hardened concrete. They observed a sharply decreases in slump as a plastic waste percentage was increased. Also they observed that increasing the PET plastic waste led to reducing in flexural and compressive strength of concrete.

Fig. (2-8): PET bottle waste particles [26]

In 2009Albano et al. [27], used irregularly shaped PET particles with size ranging 2.6 - 11.4 mm. Three volumetric percentages of replacement were investigated 0%, 10%, and 20% as a sand partial replacement. Two w/c ratios of 0.50 and 0.60 were used. They found that using PET particles in plain concrete decreasing tensile and compressive strength, and elastic modulus specifically at 10% of PET contents. Cylinders failures Types were shown in Fig. (2-9).

a b c d

Fig. (2-9): Types of failures presented in the cylinders after compressive strength testing: (a) Longitudinal, (b) Cone, (c) Border, (d) Diagonal [27]

In 2010 Akcaozoglu et al. [28], carried out a shredded PET bottles waste as sand in light weight concrete. Two mortars samples groups were presented, one is containing PET wastes aggregates only and the second is consist of sand aggregates and PET wastes together. The PET/ cement ratio is of 0.50 used in the mixtures and the water to cement ratio (w/c) is of 0.45. The shredded PET granules size were between 0–4 mm which was the preparation of two mortar mixtures. Flexural,tensile, and compressive strength, water absorption measurements, shrinkage values, and dry and fresh unit weights of the specimens were tested. They found that the mixture that contain sand aggregates and PET together were possessed the value of compressive strength, flexural-tensile strength and unit weight larger than the mixtures containing PET aggregates only. Also, it was observed that mortars without sand recorded lower shrinkage values and water absorption ratios. Shredded waste PET particles are used in concrete to reduce earthquake risk on the building, and It can be useful in designing a seismic building.

In 2010 Frigione et al. [29], substituted fine aggregate (natural sand) partialy by un-washed PET bottleswaste (WPET) aggregates with percent of 5% from weight in concrete mixture. It is possessed a granulometry same as to that of the substituted sand. The coarse aggregate that used for reference concrete was crushed natural siliceous material with size 5–20 mm and specific gravity of 2.82, the fine aggregates was siliceous sand from fluvial deposits with size 0.1–5 mm. The PET bottles waste thickness was 1–1.5 mm, and grinded in a blade mill to the size of 0.1–5 mm. The mixtures composition content was from 300 to 400 kg/m^3 and water/cement ratio (from 0.45 to 0.55). They reported that the compressive strength and splitting tensile strength of WPET concrete were of 0.4%- 1.9% lower thanthe reference concretes but, a slightly higher ductility.

In 2013 Rahmani et al. [30], presented two sets of control samples contain PET bottle wast as a fine aggregate partial replacement in the concrete mixture with percentage 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 wast particles was 7 mm as shown in Fig. [2-10(a)]. This 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 wast as replacement of sand had been gave optimum compressive strength when w/c was 0.42 and replaced sand with 10% PET wastes particles produced compressive strength similar to reference samples without PET particles, but with low elastic modulus. This mean more ductile behavior. Also, they observed that the slump decreases as a plastic waste percentage increase. Fig.[2-10 (b)] shows prism failure mode.

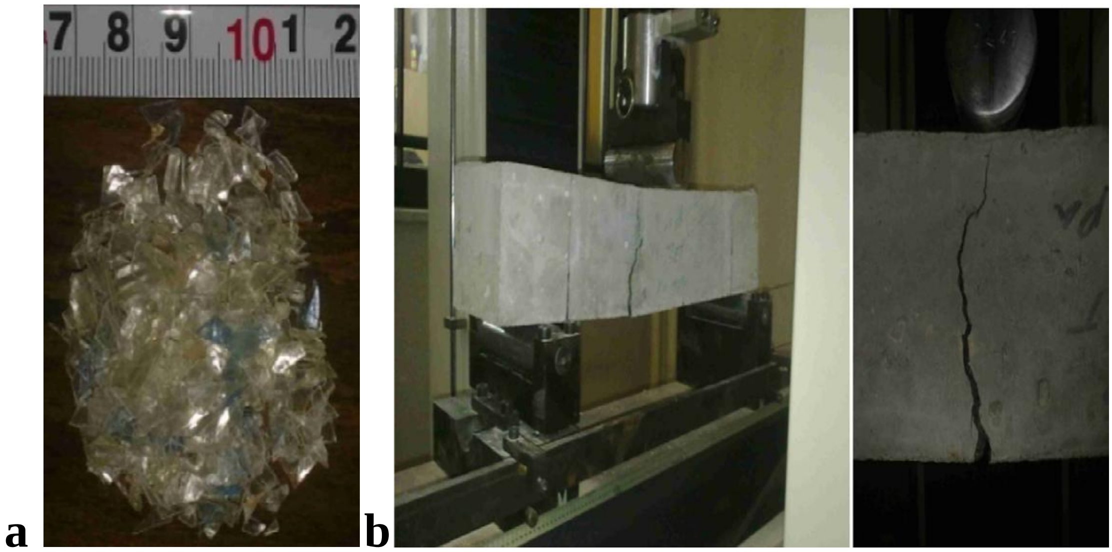


Fig. (2-10): a-Sample of plastic waste, b- Failure mode of specimens [30].

In 2014 Prabhu et al. [31], used PET bottle as a partial replacement of fine aggregate in form of fiber in the concrete mixture. The percentages of replacement were 0.5%, 1.0%, and 1.5% by volume. Three dimensions of fiber were used in this study 50*3 mm, 100* 3 mm, and 150*3 mm with mixing proportion of 1 : 1.48 : 2.54 and w/c of 0.45. Compressive and flexural strength tests were carried out at ages of 3, 7, and 28 days. They observed that the dimension of fiber 100*3 mm had been given higher strength and 1.0 % replacement of sand by volume fraction was the optimum percentage for both compressive and tensile strength.

In 2015 Khanna et al. [32], used PET waste plastic fibres as a partial replacement of fine aggregates in concrete mixture as shown in Fig. [2-11(a)]. The percentages of PET wast that used as a sand partial replacement were 10%, 20%, 30%, and 40% (by volume). Fly ash was used as partial replacment of cement with percentage 5%, 10% and 15% by weight. The water to cement ratio was 0.45. For each mix, Super plasticizer ratio was 0.01. They concluded that the compressive strength decrease with increasing of PET waste fibres amount and fly ash content. Also they concluded that maximum increasing in compressive strengthwas found when fly ash content 10% with a partial replacement of PET waste plastic fibres even up to 30% by volum. Fig.[2-11 (b)] shows cubes failure mode.

a  b 

Fig. (2-11): a-Waste plastic fibers, b- Cubes failure mode [32]

In 2016 Azhdarpour et al. [33], presented PET wast fragments as a fine aggregate partial replacement with percentages of 5%, 10%,15%, 20%, 25%, and 30%. Two different classes of plastic fragments were used.The First particle diameter of 2–4.9 mm (Pc) and the second one gradation fragment was finer with a diameter of 0.05 to 2 mm (Pf) as shown in Fig. [2-12(a)]. The water to cement ratio of 0.5 selected. They were found that adding PET wast decreases weight of concrete. Also observed that replacing 5% and 10% of fine aggregate with PET wasts particles increase the compressive strength up to 39% and 7.6% respectively, in addition, strengthen the flexural strength of concrete. Also they found that the substitution of more than 10% decreases flexural strength, but the substitution percentage 30% showed behavior like a creep in concrete. Fig.[2-12 (b)] shows a failure mode of prisms containing diferent PET percentages .

2.2.3 Recycled PET Waste as a Coarse Aggregate

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

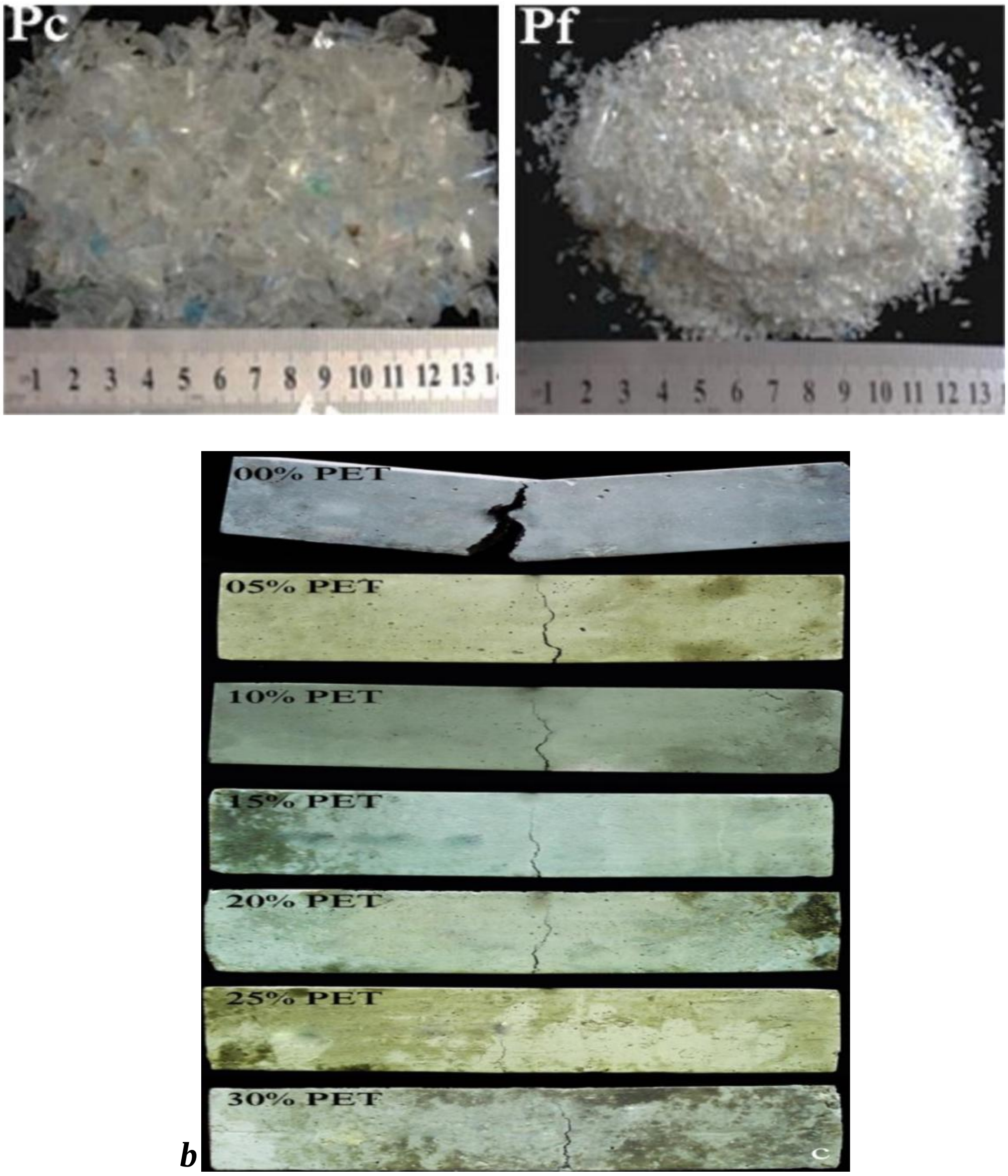


Fig. (2-12): a-Samples of waste bottles used in the mix design; Pc (coarse plastic particles) and Pf (fine plastic particles), b- Failure mode of prisms containing different PET percentages [33]

In 2014 Ganesh Tapkire et al. [34], 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 maximum size 10 mm. 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 can be used as a replacement for coarse aggregate in concrete without affecting on its properties was 20%.

In 2014 Patil et al. [35], used recycled plastic polyethylene terephthalate (PET) as coarse aggregate in the concrete mixture with percentage 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 days ages. They observed that when the PET plastic waste percentage increase, the compressive strength decreases. Also observed that using PET waste as a replacment of coarse aggregate up to percentge 20% gives resistance within the limits and when the replacment percentge was 10%, the results of compression resistance at 7 and 28 days were satisfied.

In 2016 Islam et al. [36]; made a comparison between PET wast 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 was used as coarse aggregates, while (PAC) PET wast was used as a volumetric coarse aggregates partial replacment with percentages of 0%, 20%, 30%, 40%, and 50% as shown in Fig. (2-13). Three water to cement ratios (w/c) of 0.42, 0.48, and 0.57 were used . They observed that PAC make high strength with replacment percentages up to 20 % so it can be useful in structural concrete especially with low w / c ratio and little amount of PAC concrete aggregate and the density for PAC were 4–10% reduction compare to the NAC.

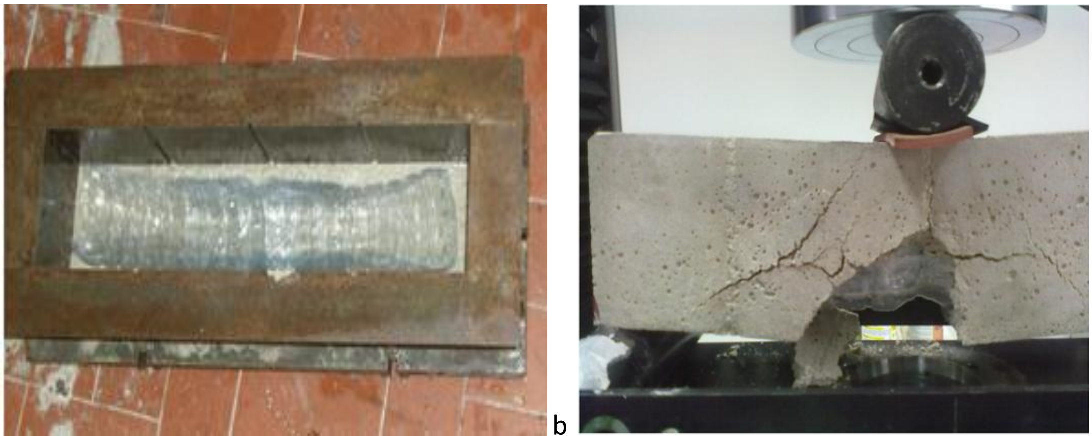
2.2.4 Recycled PET Waste as a Reiniforcement

There are a few researches in this field. This research is presented different method and formula for using of PET wastes as reinforcement of concrete beams. It will be reviewed some of researches and their findings as following:

Fig. (2-13): PET coarse aggregate [36]

In 2013 Foti et al. [37], used PET waste fibers as reinforcement of specimens that used in concrete beams as a rebar replacement. These PET fibers were produced by cutting the PET bottles into diffirent forms. Three forms of PET waste bottle were used as shown in Fig. (2-14). In the first one PET was in a circular fibers form with width 5 mm. A weight percentages of 0.5%, 0.75%, and 1.0% of concrete. Second form was using half bottle as a long strips of PET in a concrete beams arranged in a similar position to the rebar in concrete beams as shown in Fig. (2-15). The third type was a bottles strips with dimensions of 45 ×0.2×300 mm used in specimens as substitution of steel reinforcement. For tensile stress they were prepared 100×100×400 mm prisms reinforced with a large strips pruduced from cutting a 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 elements behavior while, for slab test they were used specimens of 800* 800*58 mm. The result was showed that the ideal percentage of circular PET waste fibers was 1.0%. Also, they found that the reinforcement forms of PET waste was successfully had been given high ductile behavior and concrete-PET adherence to the concrete slabs which is fundamental to inhibit complete failure.

(a) Circular PET fibers (b) Half bottle reinforcement (c) PET strips utilized in test 2.
Fig. (2-14): PET bottle waste samples [37]



a b
Fig. (2-15): Positioning of the half bottle reinforcement, b- Prism failure mode [37]

In 2014 Lopez et al. [38], used PET fiber that cutted by the special tool as shown in Fig. (2-16). Its dimensions were 4 and 0.34 mm width and thickness, respectively with two lengths, short length of 40 mm and continuous length of 600 mm. They were presented as reinforcement bar for concrete beam. Three percentages of recycled PET fiber 0.25%, 0.5%, and 1.00% by volume in addition to reference specimens were used. After four weeks, seven concrete beams with dimensions 100*150*600 mm were tested for flexural strength and the recycled PET fibers placed in the mold with 15 mm as a spacing between them as shown in Fig. (2-17). This study showed that the using of recycle PET fiber reinforced concrete with two types, short and continuous fibers were improved the ductile behavior, flexural strength and energy absorption capacity compared with specimens without fiber.

Fig. (2-16): Device used to obtain recycled PET fibers [38]

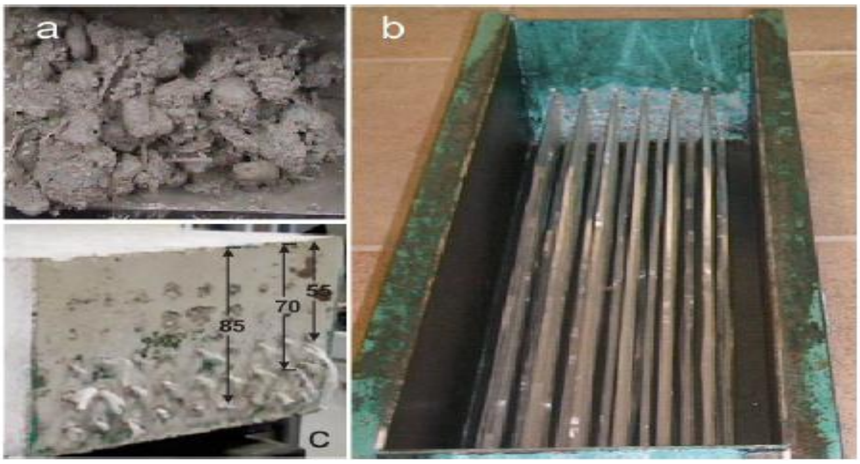


Fig. (2-17): a- Mold with short fibers. b- Mold with continuous fiber, c) The cross section. [38]

In 2014 Kumar et al. [39], used a PET waste fibers as reinforcement for concrete beams. Three types of recycled PET waste fiber reinforcement were used in this investigation.The first one was a hollow PET bar that prepared by a longitudinal cut of four bottles with length of 48 cm and the outer and inner diameter was 24 and 22.8 cm, respectively. The second type was PET long strips with dimensions of 8 cm length and 0.5 cm width were arranged by placing 11 of them one above the other to be a thickness of 6.6 cm. The last type was short PET strips similar to long strips with dimensions of 4 cm long, width of 0.4 cm and thickness of 0.6 mm.This type was arranged in seven detail of reinforcement.

Control specimens, concrete beams reinforced with rebar, concrete beams reinforced with one PET bar, concrete beam reinforced with two PET bars, concrete beam reinforced with steel and PET bars, concrete beams reinforced with steel and PET long strips and PET concrete with short strips as shown in Fig. (2-18). Seven concrete beams were tested at 28 days for flexural strength with dimensions 100*100*500 mm for these above reinforcement detail. The results showed that using different types of PET fiber reinforced concrete had better flexural strength, inhibiting early beam failure, also the type of beam that reinforced with steel and PET strips had been given a large increase in flexural strength compared to beams reinforced with rebar only.

Fig. (2-18): a) PET hollow bars,b) PET long strips as reinforcement along with steel, c) PET short strips, and d) Concrete with PET short strips filled in beam mold [39]

In 2014 , Foti et al. [40],used PET recycled bottle in long reinforcement discrete specimens as a substitution of steel bars by arranged it as a grid for slab. The cutting PET technique was started with removing the bottle neck,then cutting a 5 cm-wide strip longitudinally including the base of the bottle and ending on the opposite side. This way gave a strip with a length of about 60 cm. Four slabs with dimention of 800* 800* 58 mm have been prepared, two were non-reinforced concrete and other two with PET recycled bottle reinforced concrete grids as shown in Fig. (2-19). Impact load was tested for these slabs, the results showed that the reinforcement was successfully given very ductile behavior to the concrete slabs.

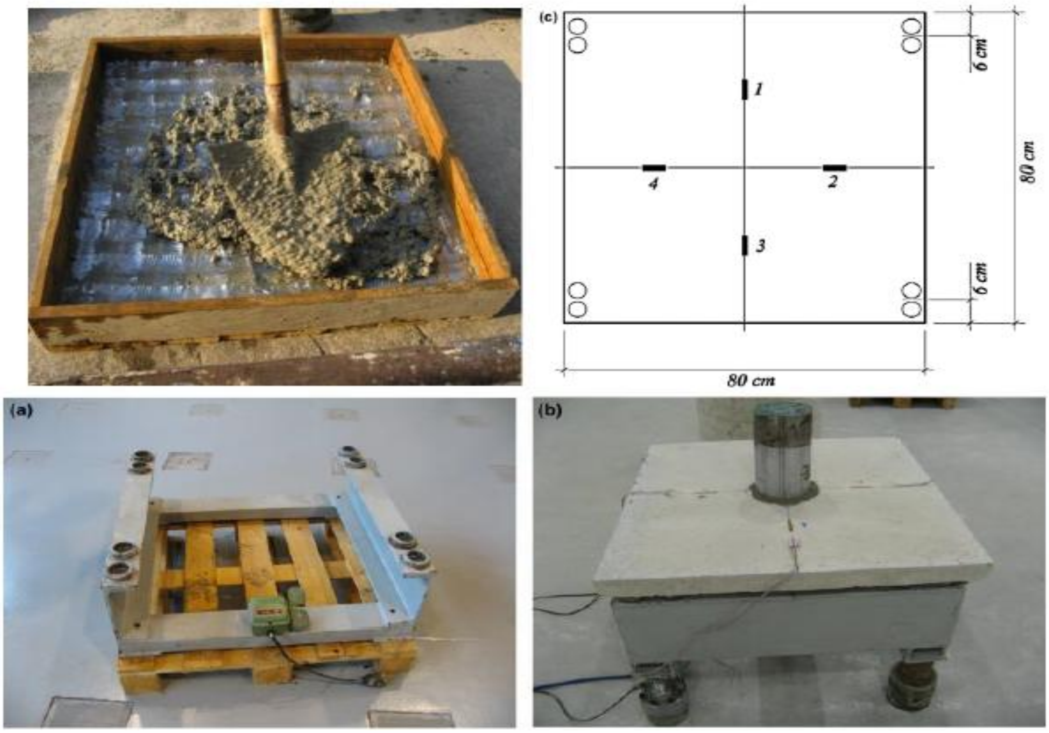


Fig. (2-19): Scheme of the Slab with the position of the strain gauges and the supports [40]

In 2019 Adnan and Dawood [24], investigated using PET waste as a tension bar. They used twelve simply supported beam with dimension 150*200*1400 mm, two of them were reference beams. PET rods were used in various forms. The tension PET bars of first beam consist of rolled big bottles, tied together and filled by wastes of plastic boxes as shown in Fig. (2-20 (A)). Second beam consists of a small bottles of PET putted inside a large bottles of PET as shown in Fig. (2-20 (B)). Third beam contain a large and small bottles of PET rolled together, contacted by a bottle neck, and putted inside each other as shown in Fig. (2-20(C)). Fourth beam contain a rolled small bottles of PET, covered in the middle by neck and filled with wastes of PVC as shown in Fig. (2-20(D)). Fifth beam contain a large bottles of PET divided for two parts, arranged as two layers and connected to stirrups as shown in

Fig. (2-20(E)). Other beam are hybrid reinforcement which reinforced by rebar in addition to different thickness of PET bottles layers, as shown in Fig. (2-20(F)). They displayed failed of all specimens that containing PET bars except the specimen that using rebar with PET bottles layers that cut for two parts ,which presented a deflection and ultimate failure load increment by 213% and 3 % compared to reference specimens respectively.

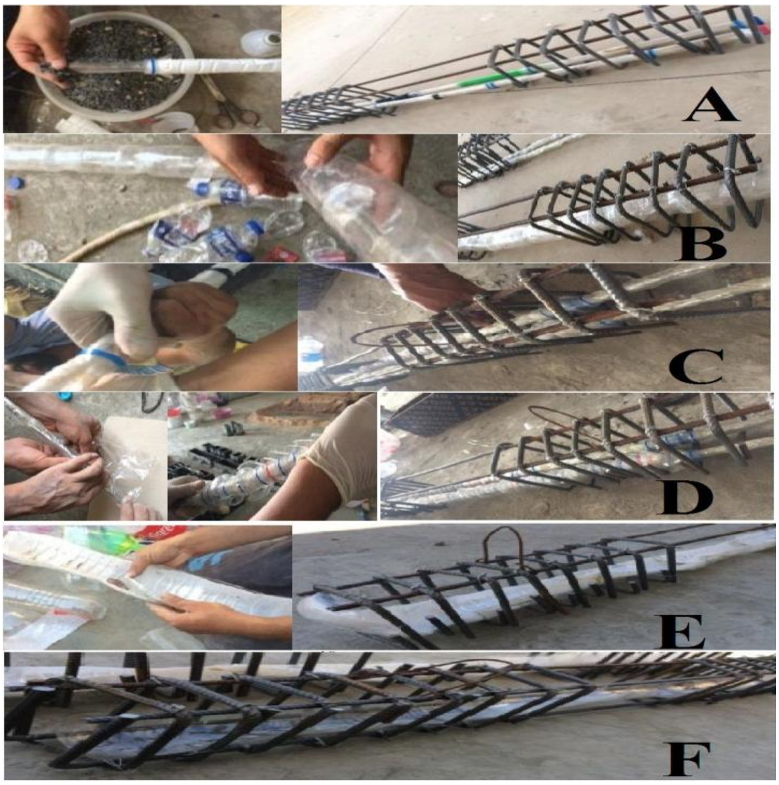


Fig. (2-20):Types of used PET waste bars as a tension reinforcement [24]

2.3 Summary

All uses of PET waste in concrete and the four forms of PET waste that presented by previous studies and reviewed are subjected 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 can summarize the conclusions that most research participated in each of the four areas as follow:-

1- 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 researchers concluded increase in flexural strength, absorbed energy, first crack load, ductility, enhancing tensile and compression strength when the fiber ratio does not exceed 1%. Also decrease in workability and elastic modulus. The maximum use of PET fibers in concrete should not exceed 1.5% calculated from the total volume.

2- The researchers used PET waste particles as a partial substitute for fine aggregate with percentages ranging from 0% to 50% with a steady increase rate of 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.

3- The using of PET waste as a partially substitute for coarse aggregate reduces workability and reduces the mechanical properties of concrete.

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.

2.4 Concluding Remarks

The present study differs from the previous studies that the grading of PET waste particles that used as a fine aggregate partial replacement was close to fine aggregate grading. In addition to conducting scarce tests that have not been addressed in most of the previous research, such as expansion, shrinkage, shear strength, and modulus of elasticity. Sand replacement with PET waste particles were also first time used in full scale concrete beams with a length of 2300 mm, and their effect on the structural behavior of these beams was evaluated. Also in this study, PET waste bottle is used first time in three forms of continues tighten bars as tension reinforcement of concrete beams.

CHAPTER THREE

EXPERIEMNTAL WORK

Chapter Three
The Experimental Work

3.1 General

This chapter includes the evaluation of materials properties which are used in the concrete mixture. The chemical and physical properties, materials details and their proportions, and concrete mix design are presented. In addition, the nature of PET waste is explained to compare concrete mixture with and without PET waste. Also it includes details of concrete beams which contain different percentages of PET waste. Finally, specimen's details, ages, curing, and tests methods are shown. All laboratory tests were done in the laboratories of the Faculty of Engineering, Misan University and Amarah Technical Institute, except the tensile test of plastic braids, where they were conducted in the College of Engineering laboratories, University of Basra.

3.2 Experimental Program

Experimental work is divided into three main parts. The first part included the effect of using different percentages of PET bottle waste as a partial substitute for fine aggregates in concrete mixtures on their mechanical and physical properties. The second part involved the effect of using the same percentages of PET as a substitute for fine aggregate on the structural behavior of steel reinforced beams. The third part is recycled the PET bottle waste in form of reinforcement bar used as alternative for steel reinforcement in beams.

3.3 Materials properties

The local materials available are used in this research. Ordinary Portland cement, fine aggregate, coarse aggregate, tap water, and plastic PET bottle waste are used. Furthermore, superplasticizer is used to improve the workability of mixtures. Generally, the same materials were used in the three parts of the study, with slight differences including the form of used PET waste.

3.3.1 Cement

Ordinary Portland cements type I was used. It was kept at a dry place to avoid the effect of moisture. Tables (3-1) and (3-2) include the chemical composition and physical properties of the cement, respectively. The test is done according to the Iraqi specification No.5/1984 [41] at the laboratory of Material and Construction – Amarah Technical Institute

Table (3-1): Chemical Composition of Cement

Oxide composition	Abbreviation	Content (percent)by weight	Limit of Iraqi specification No.5/1984[41]
Lime	CaO	63.96	--
Silica	SiO2	21.32	--
Alumina	AL2O3	4.58	--
Iron Oxide	Fe2O3	3.25	--
Sulphate	SO3	2.48	< 2.8%
Magnesia	MgO	2.75	≤ 5%
Loss on Ignition	L.O.I	3.46	≤ 4%
Insoluble residue	I.R	1.07	≤ 1.5%
Lime saturation factor	L.S.F	0.97	0.66-1.02
Main compounds(Bogue's equations)			
Tricalcium Silicate	C3S	50.69	--
Di Calcium Silicate	C2S	18.28	--
Tri Calcium Aluminates	C3A	8.14	--
Tetra Calcium Alumina	C4AF	9.89	--

Table (3-2): Physical properties of Cement

Physical properties	Test result	Limits of Iraqi Specification NO.5/1984[41]
Fineness Using Blain Air Permeability Apparatus (m2/kg)	384	≥230
Setting time Using Victa's Method		
Initial (hrs: min.)	2:00	≥ 0:45 min
Final (hrs: min.)	3:45	≤ 10 hrs
Soundness Using Autoclave Method	0.22	< 0.8
The compressive strength of mortar		
3Days, MPa	20.8	≥15
7Days, MPa	27.4	≥23
28 Days, MPa	34.7	

3.3.2 Fine Aggregate

In this study, natural sand is used as a fine aggregate. It was brought from Basra, city in the south of Iraq. Tables (3-3), (3-4) and Fig. (3-3) show the properties of the sand according to Iraqi specification No. 45/1984 [42], which include the grading, specific gravity, sulfate content, and absorption, respectively.

Table (3-3): Grading of the fine aggregate

Sieve size (mm)	Sand percent passing %	Cumulative passing % Limits of Iraqi specification No.45/1984[42]
10	100	100
4.75	95.6	90-100
2.36	85.73	75-100
1.18	72.04	55-90
0.60	48.25	35-59
0.3	17.75	8-30
0.15	3.7	0-10

Table (3-4): Physical properties of fine aggregate

Physical properties	Test results	Limits of Iraqi specification No.45/1984 [42]
Specific gravity	2.56	-
Sulfate content %	0.13	≤0.5%
Absorption %	0.75	-

3.3.3 Coarse Aggregate

Coarse aggregates are available naturally in a region at eastern Amarah (city in the Iraq) called Chilat near Iraqi-Iran border. The maximum size of coarse aggregate is 20 mm. The grading of coarse aggregate according to the Iraqi Specification No. 45/1984[42] is shown in Table (3-5).

Table (3-5): Grading of coarse aggregate

	%Passing	
Sieve size	% Coarse aggregate	Iraqi specification No. 45/1984[42]
37.5 mm	100	100
20 mm	97	95-100
10 mm	42.83	30-60
5 mm	3.145	0-10

3.3.4 Mixing Water

In this work, the Reverse Osmosis (R.O) water was utilized for casting and curing all specimens.

3.3.5 Admixture

In this study, Super plasticizer (pc 260) was utilized as admixture to improve the workability. The used liquid is type PC 260 which is agreed with ASTM C494-99 types A and G [43], according to the technical international specification as shown in Table (3-6).

Table (3-6): Technical description of PC 260 [43]

Chemical base polymer	Modified polycarxylates based
Appearance/colors liquid	Light Yellowish to brownish
Freezing point	-7° C
Specific gravity @25° C	Approximately 1.1±0.02
Air entrainment entrained	Typically less than 2% additional air is above control mix at normal dosages
Dosage	0.5 to 3.0 liter per 100 kg of binder
Storage condition/ Shelf Life	12 months if stored at temperatures between 2° C and 50° C

3.3.6 Steel Reinforcement

The deformed steel bars of 12 mm diameter were used for tension reinforcement, 10 mm diameter for shear reinforcement, and 6 mm were used as a stirrup in the reinforcement of shear specimens .The properties of reinforcing bars are shown in Table (3-7). [44]

Table (3-7): Properties of steel reinforcement [44]

Bar type	Bar diameter mm	Bar area mm2	Yield strength fy (MPa)	Tensile strength fu(MPa)	Yield strain
steel stirrups	6	28.26	533	631	0.0026
Longitudinal steel bars & stirrups	10	78.5	515	624	0.0025
Longitudinal steel bars	12	113.04	493	583	0.0024

3.3.7 Epoxy

High performance building adhesive epoxy based type sikadur 31-41 cf slow, was used in this study. It is composed of two packs A and B that are mixed together to form a paste as shown in Fig. [3-1 (A)]. It is used in the third part of study, in the formation of knots along the PET waste braids bars as shown in Fig. (3-1B). Adhesive for structural bonding tested according to EN 1504-4 and ASTM, C881 M-02, type I, grade 3,class B + C [45]. Table (3-8) shows epoxy information.

Table (3-8): Epoxy chemical base and technical proprieties [45]

Chemical base and technical proprieties	The determinants of epoxy	According to Standard
Colour	Component A: grey Component B: black Components A + B mixed: concrete grey	-
Shelf life	24 months from date of production	-
Density	1.93 ± 0.1 kg/l (component A + B mixed) (+23 °C) (evacuated)	-
Compressive Strength	~52 N/mm^2(7d/ +25 °C)	DIN EN 196
Compression elastic modulus	~2 600 N/mm^2 (14 d / +23 °C)	ASTM D695
Tensile Strength Flexure	~27 N/mm^2 (7 d/+25 °C)	DIN EN 196
Tensile Strength	~13 N/mm^2(7 d/+25 °C)	DIN EN 196
Tension elastic modulus	~3 000 N/mm^2 (14 d / +23 °C)	ISO 527
Elongation at Break	0.6 ± 0.1 % (7 d / +35 °C)	ISO 527
Coefficient of Thermal Expansion	7.9 x 10−5 per °C (Temp. range +23 °C min. / +60 °C max.)	EN 1770
Mixing ratio	Component A : Component B = 2 : 1 (by weight)	-

A  B

Fig. (3-1): A-High performance building adhesive epoxy. B- Using epoxy as knots along PET bars

3.4 Parts of Study

3.4.1 Part One: - Using PET Plastic Waste as a Sand Replacement in the Concrete Mixtures

3.4.1.1 PET Waste

Polyethylene Terephthalate (PET) bottle waste is the plastic type that 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, (i.e. the maximum particle size is less than 4.75 mm) as shown in Fig. (3-2). 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 as shown in Fig. (3-4). A sieve analysis was carried out for PET particles and found that some sieves are approximates to the sieve analysis of sand according to the Iraqi specification No.45/1984 [40] with a difference in fine sieves as shown in Table (3-8) and Fig. (3-3). The specific gravity of PET particles is 1380 kg/m^3 [33].

Fig. (3-2): PET molecules produced by chopping water bottles and soft drinks

Table (3-9): PET waste particles grading

Sieve size (mm)	PET percent passing %
10	100
4.75	95.6
2.36	97.64
1.18	18.72
0.60	2.55
0.3	0.5
0.15	0.19

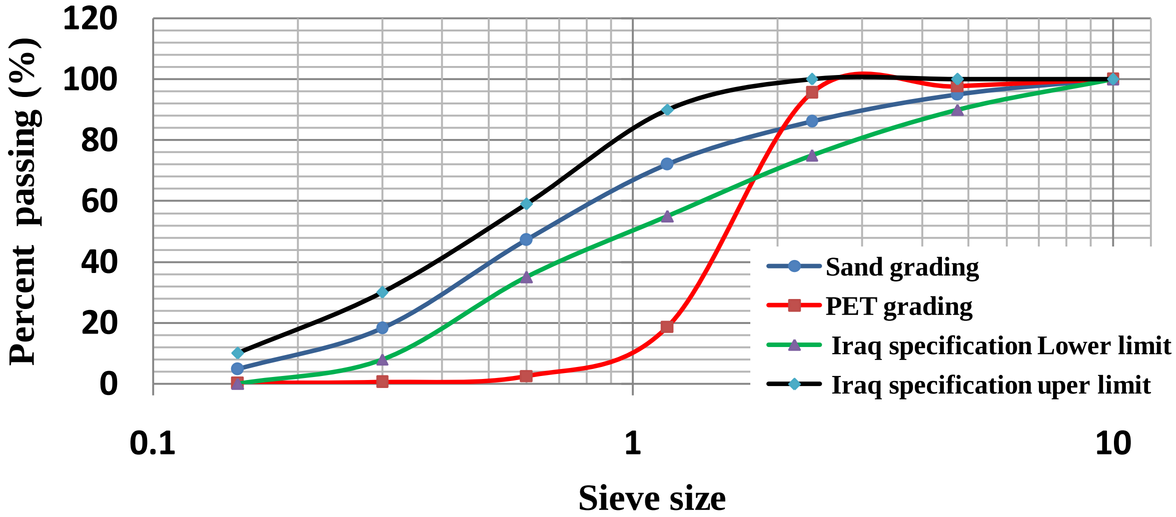


Fig . (3.3): Grading curve for original fine aggregate and PET waste

Fig (3-4): Alnaseri groups, (Sama Pack) branch factories for PET wastes recycling

3.4.1.2 Selection of PET Waste Percentages as a Sand Replacement

In this study, proactive experimental work were adopted to give a specific indication of behavior and properties of concrete containing PET plastic waste, as well as the quantities and percentages of these materials in addition to the nature of the substitution. Due to fact that the PET waste particles used in this part were closed to some sieve analysis of the sand, but with a big difference in densities. Therefore, proactive experimental were conducted to determine a specific range of weighted percentages of PET to be adopted in the concrete mixture. Random weight percentages were selected 0% reference, 1.5%, 3%, 5%, 10%, 25%, and 50% as shown in Fig. (3-4). The compressive strength and density tests were carried out by casting 42 cubes 150×150×150 mm. Six cubes for each percentage. Three tested at age 7 days and the other three at 28 days. The mix proportion is 1: 1.5: 3. The water-cement ratio was 0.41 with the admixture (Super plasticizer) of 2% by hand mixing. The results are indicated that the compression strength of the concrete cubes increases by increasing the waste particles of PET plastic bottles up to 10% as a percentage to replace the sand which is the optimum percentage while density decreases by increasing PET replacement percentage. The results showed that the replacement percentages ranged from 1.5% to 5% were closed; therefore 5% was determined as the lowest percentage weight for replacement in the work. Also, it was found that when the sand is replaced with PET waste with a percentage of 25%, the compressive strength is 50% less than the reference mixture. Therefore the scope of experimental work for replacement is ranged from 5% to 20%. As a result of this trail program, six of PET waste percentages as a sand replacement were used, namely 5%, 7.5%, 10%, 12.5%, 15%, and 20%. In addition, the reference concrete mixture was presented.

3.4.1.3 Concrete Mixture

The mix proportion is 1: 1.5: 3 as a concrete mixe by weight according to Dr. Mohammad M. Salman et al. [46]. The weights of cement, sand and gravel for each cubic meter in this mixture are 444.75, 667, and 1334 kg, respectively. The water-cement ratio was 0.41 with admixture (Superplasticizer) percent of 0.4% to improve workability. Six percentages of PET waste used in this study as a partial replacement of sand, namely 5%, 7.5%, 10%, 12.5%, 15%, and 20%, in addition to reference mixture without PET. Table (3-10) shows all quantities and replacement percentages in the mixtures. The scope of this work includes the use of one type of plastic waste which is PET plastic bottles waste as a sand replacement. Accordingly, this section will focus on the proportion of the mixture and the replacement percentages used in the mix.

Table (3.10): Concrete mixture proportion for all PET replacement

Material (kg/m^3)	0%	5%	7.5%	10%	12.5%	15%	20%
Cement	444.75	444.75	444.75	444.75	444.75	444.75	444.75
Sand	**667**	**633.65**	**616.975**	**600.3**	**583.625**	**566.95**	**533.6**
Gravel	1334	1334	1334	1334	1334	1334	1334
Water	191.25	191.25	191.25	191.25	191.25	191.25	191.25
PET	**0**	**33.35**	**50.025**	**67.7**	**83.375**	**100.05**	**133.4**
SP	1.779	1.779	1.779	1.779	1.779	1.779	1.779

3.4.1.4 Mixing Procedure

The mixtures were mixed by a 240L electric mixer in the structural laboratories at the Faculty of Engineering, Misan University, according to the following steps:

1- Initially, a specified percentage of the PET waste particles are added to the supplementary amount of sand so that their final weight is equal to the weight of the fine aggregate in the concrete mixture and placed in the mixer with gravel and mix for homogeneity.

2- Cement were added in to mixer, and then they mix for two minutes

3- After homogenization of the mixture, water was added to mix with admixture gradually, with continues mixing.

3.4.1.5 Casting and Curing Details

The procedures of casting and curing were done according to specifications. The preparing, casting and curing method for specimens were summarized in Fig. (3-5).

Fig (3-5): Preparing, casting and curing for beams and specimens

3.4.1.6 Experimental work specimens

A. Mechanical and Physical Properties specimens

The mechanical and physical properties of a concrete mixture included nine cubes with dimensions of 150 × 150 × 150 mm, three cylinders with dimensions of 150 × 300 mm, nine cylinders with dimensions of 100×200 mm, six prisms with dimensions of 100 × 100 × 500 mm and two prisms with dimensions of 75×75×300 mm were casted for each PET wastes percentage to calculate density, compressive strength, modulus of elasticity, splitting tensile strength, absorption, pulse velocity, flexural strength, expansion, shrinking, energy absorption, strain and ductility.

B. Shear specimens

Double L- shape wooden mold specimens were used for shear test according to Balaguru and Dipsiadetail detail [47] as shown in Fig. (3.6). Two wooden molds for each replacement percentage with dimensions

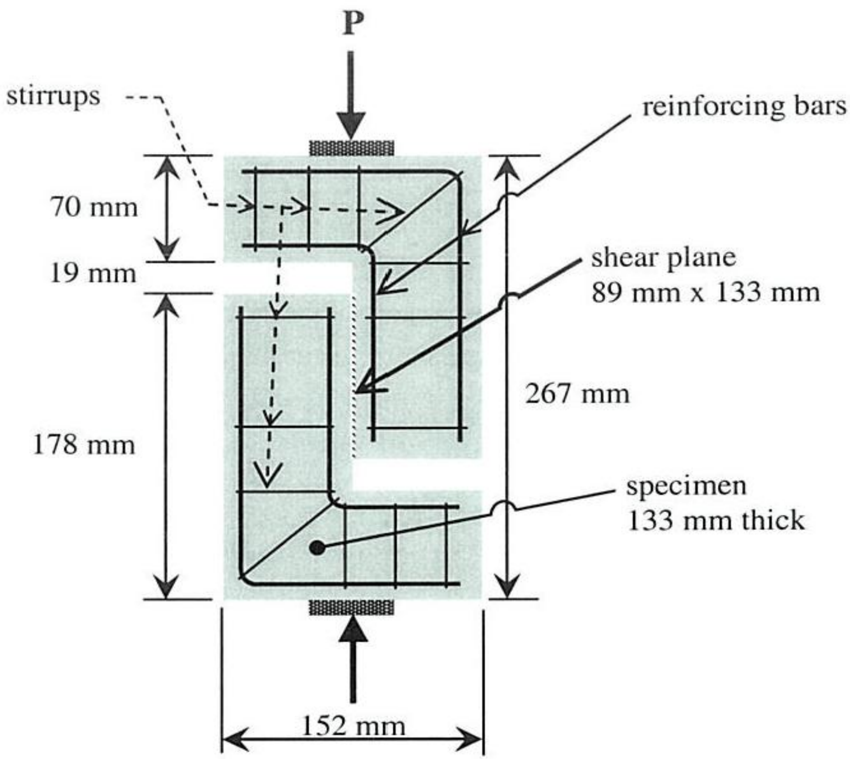


Fig. (3-6): Balaguru and Dipsiadetail detail for shear test [47]

152 × 133×267 mm was used. The spaces in the mold were replaced by using wooden partitions that were lubricated and wrapped with nylon before casting as shown in the Fig. (3.7) to ensure they were removed after concrete hardening. Reinforcement details include using 4 bars with diameter 10mm for each single L- shape. These four L- shape bars have been connected by bars of 6 mm diameter 50 mm c/c as stirrups. The reinforcement is used to ensure that the failure occurs in the shear plan zone and avoid the compression zone failure during the test.

a: Specimen reinforcement b: Preparing specimen

Fig. (3-7): Shear mold and reinforcement detail used in the present study

3.4.1.7 Tests on concrete mixtures

A. Fresh Concrete Test (slump test)

One of the most important characteristics of the concrete mixtures is slump. It gives an indication of the workability of the fresh concrete. The concrete is considered suitable consistent that means the concrete is workable, maintain homogeneity during casting, managed without segregation, and compact it without need the extra effort. The slump test is prescribed according to ASTM C143 [48] as shown in Fig. (3-8).

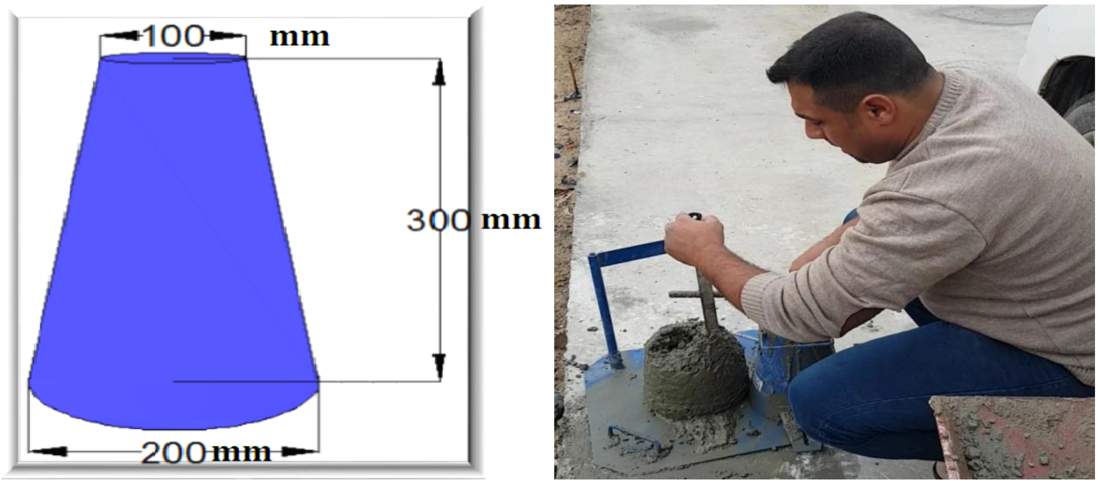


Fig. (3-8): Slump test

B. Hardened Mechanical Tests

1. Compression Strength and Density Tests

The test of compressive strength of concrete was done by using cubical specimens with dimension 150×150×150 mm according to the British standard BS 1881 part 116-83 [49]. A compressive machine of 2000 kN capacity was used herein as shown in Fig. (3-9). The density is measured before compression test for each cubical specimen.

Fig. (3-9): Compression machine test

2. Splitting Tensile Strength

Cylinders specimens were tested with dimensions of (100×200) mm for splitting tensile strength. The Civil Engineering labs were used in the

Engineering College, Misan University according to ASTM- C496 [50] standard. The machine that used in compression test was also used for splitting tensile strength as shown in Fig. (3-10)

Fig. (3-10): Splitting tensile test

3. Flexural Strength Test

Prism specimens with dimensions 100×100×500 mm were used to examine concrete flexural strength test according to the ASTM-C78 [51]. This test was done in the College of Engineering, Misan University,by using machine of flexure with a capacity of 5000 kN as shown in Fig. (3-11).

Fig. (3-11): Flexural strength test

To calculate the flexural strength the following equation is utilized.

$Fr = \frac{3PL}{2bd2}$ ....1 where:

Fr: modulus of rupture (MPa) P: maximum applied load (N)

L: span length (mm) b: average width of the specimen

d: average depth of specimen (mm)

C. Shear Test

Compression machine was used for shear specimens test. A rectangular thin steel section were placed above and below the specimen in a straight line with the shear plane zone to ensure concentrated a higher shear strength on shear plane area as shown in Fig. (3-12).

Fig. (3-12): Shear test method

D. Hardened Physical Tests

1. Volumetric change and plastic Shrinkage Test

The volumetric change and plastic shrinkage test was carried out by using a shrinkage device consisting of a base and two stands of length 400 mm separated by a distance of 100 mm, carrying a 150 mm iron beam with a dial gauge of 0.01mm accuracy as shown in Fig. (3-13). Fourteen prisms of 75 * 75 * 300 mm were used in this test, two prisms for each replacement percentage. This test is done according to Iraqi specification NO. 54/1970 [52], at the Engineering College of Maysan University.

Fig. (3-13): Shrinkage specimens and test method

2. Absorption Test

Cubes specimens were used for this test with dimensions 150 × 150 × 150 mm according to ASTM C642 [53]. The specimens are dried for 72 hours at a temperature of 100 ° C in the oven, then weighed to get a dry weight (D.W), and then submerged for 24 hours in water and weighed again to get wet a weight (W.W), then measured the percentage of absorption from the relationship.

Absorption rate $= 100 \times \frac{(W.W - D.W)}{D.W}$……………….2

3. Ultrasonic pulse velocity test (UPV)

Ultrasonic pulse velocity is measured through concrete cube according to ASTM C597 [54]. Cubes specimens were used for this test with dimensions of 150×150×150 mm and ultrasonic pulse velocity apparatus as shown in Fig (3-14). The UPV test is performed by using PUNDIT PC 1012 with an accuracy of 0.1 micro second, direct methods from two directions.

Fig. (3-14): Ultrasonic device and test method

4. Modulus of Elasticity and Energy Absorption Tests

Three cylinders with dimensions 150 x 300 mm were used to test modulus of elasticity and energy absorption (toughness). This test was set up by using a 2000 kN compression machine as shown in Fig. (3-15). Elasticity modulus and toughness tests are done according to ASTM C469 / C469 M – 14 [55].

Fig. (3-15): Modulus of elasticity and energy absorption tests

3.4.2 Part Two:- Reinforced Beam Specimens Containing PET Waste as a Sand Replacement

This part of work involves using the same materials , mixing ratios, water-to-cement ratio, and additive ratio, and same PET ratios that used as a partial substitute for the fine aggregate, that was used in the first part of the work and shown in a Table (3-10). It is focused on the impact of using PET bottles waste as a sand replacement on the behavior of structural beam specimens.

3.4.2.1 Reinforced Beam Specimens

Six beams with dimensions $150 \times 300 \times 2300$ mm were used for testing the use of PET waste as a partial replacement for sand, one for each replacement percentage, in addition to reference beam (without PET). All concrete beams are casting using wooden formwork, as described in Fig. (3-16). The wooden molds used in this part are made of a fixed wooden base and movable sides connected to each other and with the base by screws and nails. All concrete beams were simply supported. The beams are with a rectangular cross-sectional area with dimensions b = 150 mm, h = 300 mm, and length 2300 mm. This detail was used in all reinforced concrete beams which contained PET particles percentages as a partial replacement of sand. Two points load separated by a distance of 660 mm and two supports with a clear span of 2000 mm were used in this part of study, see Fig. (3-17). The concrete beams were designed in such a way to prevent a shear failure in the beams section, where the distance between each point load and support (a) was of 660 mm while the effective depth (d) of beam section was of 264 mm. So, the ratio of (a) to (d) was equal to 2.5, which indicates that the section of the beams withstand shear force. The flexural beam reinforcement is designed according to ACI 318-14 Code [56] to ensure that the compression zone of the beam section fails in flexure, with controlled failure in tension zone, and designed for shear reinforcement to guarantee that the beam section hold out shear force, according to ACI 318- 14 [56]. All beams were reinforced by 3 ϕ 12 mm bars at the tension zone and 2 ϕ 12 mm bars at the compression zone. Stirrups with diameter of ϕ 10 mm spaced at 60 mm c/c are used at shear span while the middle portion was spaced at 120 mm c/c. as shown in Fig. (3-17).

Fig. (3-16): Wooden molds for beams

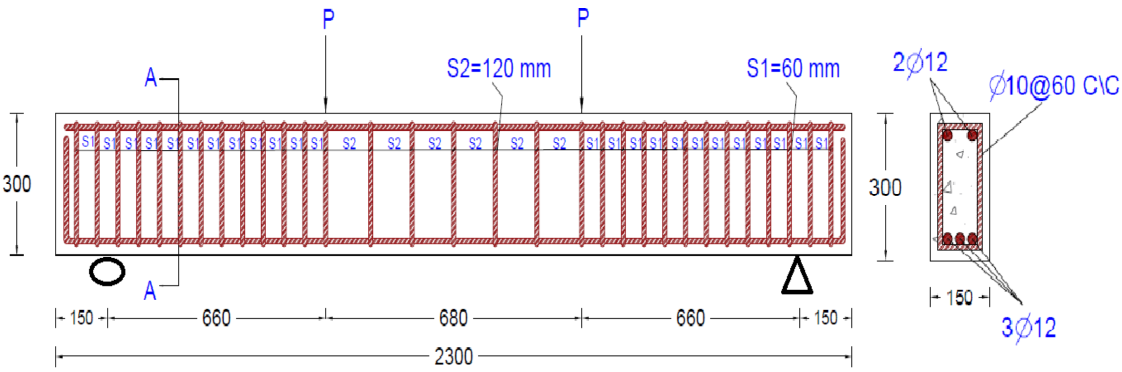


Fig (3-17): Reinforcement details and loading method for concrete beams

3.4.2.2 Testing of Concrete Beams

A. Testing Machine

In the structural laboratories of the Technical Institute in Maysan, an automatic compression machine with a capacity of 600 kN and with dimensions (3000 mm length x 1000 mm height) was used to test a big beams as shown in Fig. (3-18) and (3-19). Also, it can be controlled manually. The applied loads were in successive increments of about 10 kN until reaching to the failure load. Observations were recorded at each load increment, such as the strain value, deflection and first crack and draw crack patterns.

Fig. (3-18): Automatic compression machine

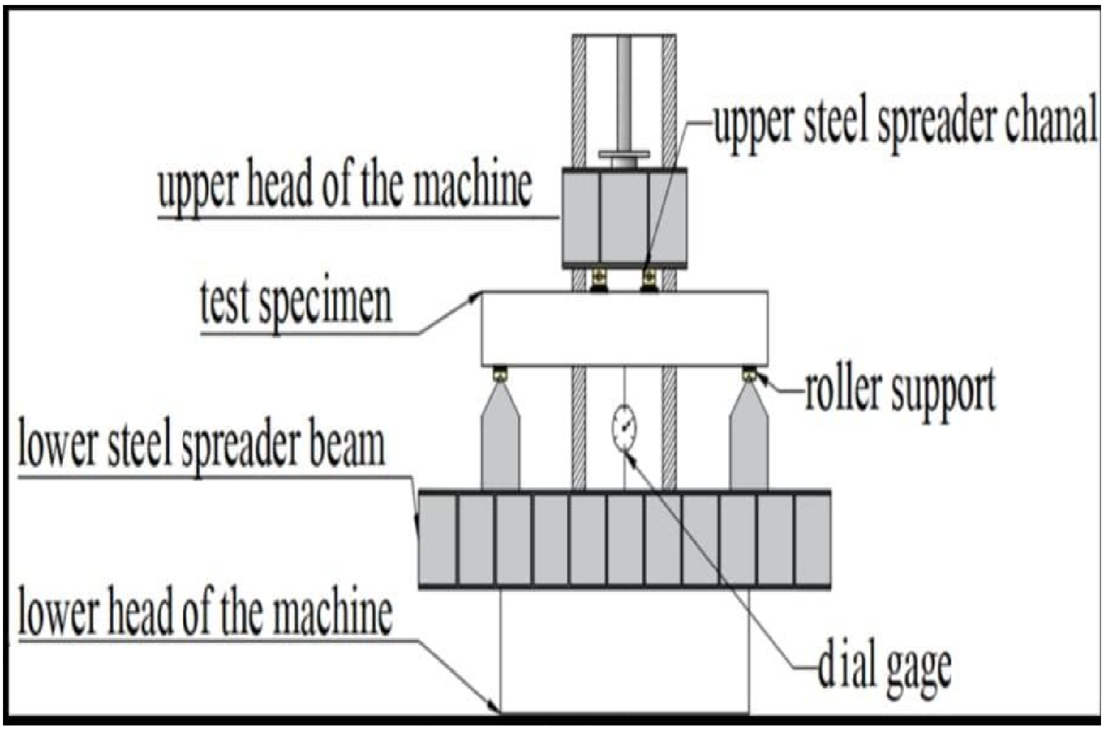


Fig. (3-19): Test setting

B. Dial Gauges

In order to calculate the deflections for all beams at every load stage, two dial gauges were used in the 2300 mm beams. The first one was placed under the mid-span of beam and the other one placed at 2/3 – span of beam. The dial gauges accuracy was of 0.01mm with a maximum reading of 10 cm for mid span gauge and 5 cm for 2/3 – span.

C. Strain Gauge

Two (30 mm) strain gauges were attached at the center of each beam before test. One was placed in the compression zone and the other in the tension zone. It was connected to data acquisition device (data logger consist of 16 channels supplied with DATACOMM software for PC data acquisition) to obtain strain reading at each load increment as shown in Fig. (3-20).

Fig. (3-20): Strain gauges attached to the beam

3.4.3Part three: - Using the PET Bottle Waste as Reinforcement Bars

In this part of the study includes the waste PET plastic bottles were used as an alternative to the main reinforcement for reinforced concrete beams. This is done through the use of strips from waste PET plastic bottles after they are remodeled in different forms as reinforcing bars. This part is focused on the effect of PET plastic waste bottles bars on the behavior of structural beam samples. Five reinforced concrete beams samples with dimensions 1400×200×150 mm were casting. Three of them with different details from waste PET plastic bottles which are (BP1, BP2, BP3). In addition to a reinforced concrete beam with steel bars (CR), and another without reinforcement (CC). Then a comparison is made between these samples.

.3.4.3.1 Materials and Concrete mixture

The same materials that used in the previous parts are used herein. Ordinary cement, fine and coarse aggregate, R.O. water, and Super-plasticizer are used. Also, the concrete mix used in this part is the same one that was used in the first part, reducing the w/c ratio to 0.4, while the super plasticizer amount remains 0.4%. Table (3-11) shows material content for each cubic meter.

Table (3-11): Material content for each cubic meter

Material	Cement	Sand	Gravel	Water	SP
weight (kg/m^3)	444.75	667	1334	177.9	1.779

3.4.3.2 Steel Reinforcement

The 12 mm diameter deformed steel bars were used for tension reinforcement and 10 mm diameter for shear reinforcement. The reinforcing bars properties are as in the first part. The flexural beam reinforcement was designed according to ACI 318-14 Code [56] to ensure that, the compression zone of the beam section fails in flexure, with controlled failure in tension zone. Also, all beams were designed for shear reinforcement to guarantee that the beam section hold out shear force, according to ACI 318- 14 [56].

3.4.3.3 PET Plastic

PET waste bottles were cut by a tool designed for this purpose as shown in Fig. (3-21). The PET plastic bottles were turned into a long strip, with a small width. PET waste bottles were converted into strips of 6 mm width and lengths that differ according to the size of the plastic bottles. The thickness of strips is (0.4-0.5) mm, width is 6 mm and it can be controlled by gradations in the tool as shown in Fig. (3-21). It was noted that the small PET bottle had been given a tape length of 6-7 m if the width of the tape is 6 mm and the large one had been given a length of up to (9-11) m. These tapes were reshaped in two forms, braids and longitudinal bundles.

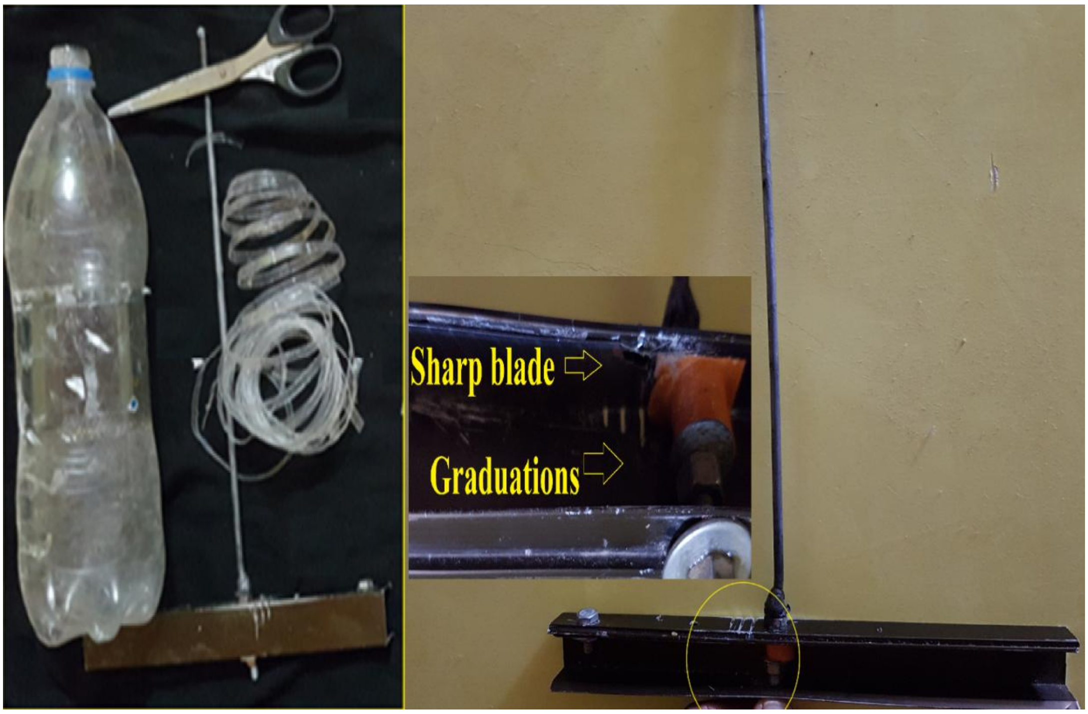


Fig. (3-21): Tool and method of cutting and converted PET bottle to strip

A. Braids

The strips were formed in the form of secondary braids. Twelve strips with a length of at least 4200 mm were manually braided to get a secondary braid length between 2600 - 2800 mm. Every three secondary braids were manually braided together to produce a main braid with length 1800 mm which consisting of 36 strips as shown in Fig. (3-22). Due to the fact that the braid cross section was closed to the circular shape, Bernoulli's principle was used to measure the diameter of the braids. This was done by using a graduated laboratory beaker filled partially with water for a specific size that is recorded, then put a piece of braid of a known length (before tighten) that was recorded too, and it was completely submerged inside this beaker, after that we recorded the new volume of water in the beaker. The difference between the volumes of water in the beaker before and after immersion of the braid represents the volume of the braid. By dividing this volume by the known length, we obtain the cross section area of the braid. In order to be more accurate, made sure to tighten the braids tightly before measuring the length and used two models of braids of two different lengths and took the average readings as shown in the Table (3-12). Through the above experience it was found that the diameter of the braid is 14.71 mm.

Fig. (3-22): Main braid forming method 36 strips (3secondary braids)

Table (3-12): Braids diameter measuring data

Braids length mm	Water Vol. in beaker ml^3		Volume difference		Braids section area mm^2
	before immersion	after immersion	ml^3	mm^3	
160	700	727	27	27000	168.75
240	700	741	41	41000	170.525
					Average area =170mm^2
					Diameter = 14.71mm

B. Longitudinal Bundles

Another formation of plastic strips in which the bundles were assembled in the form of secondary bundles, each secondary bundle consists of 12 strips with a length 1400 mm at least as shown in Fig. (3-23). Then three secondary bundles were assembled to form one main bundle consisting of 36 strips. The length of the main bundle is at least 1400 mm. Types of PET bars with braid cross-section are shown in Figs. (3-24) and (3-25).

Fig. (3-23): Secondary bundles formation

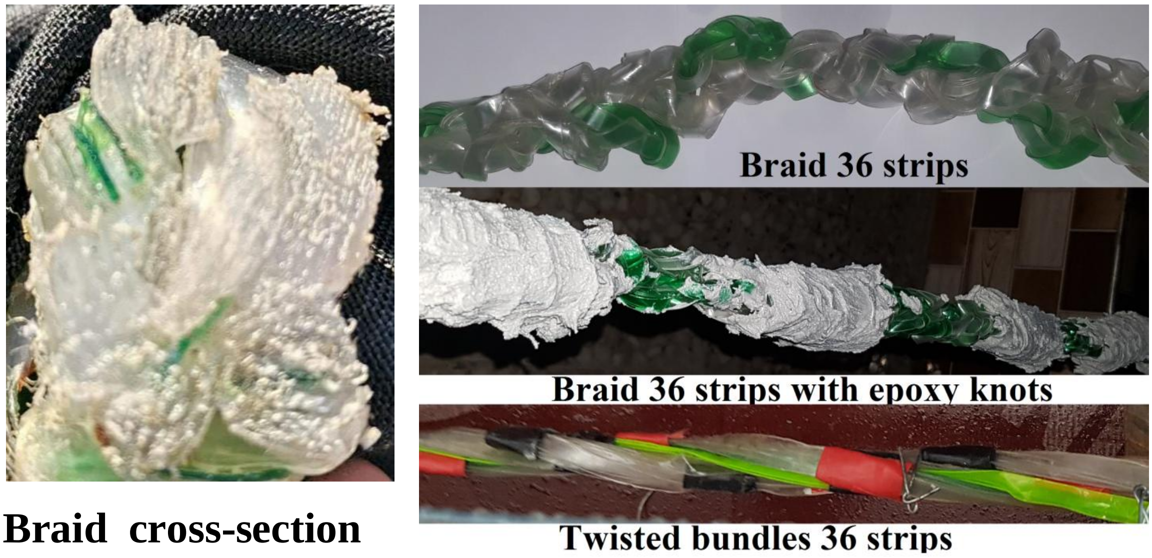


Fig. (3-24): Types of PET bars with braid cross-section

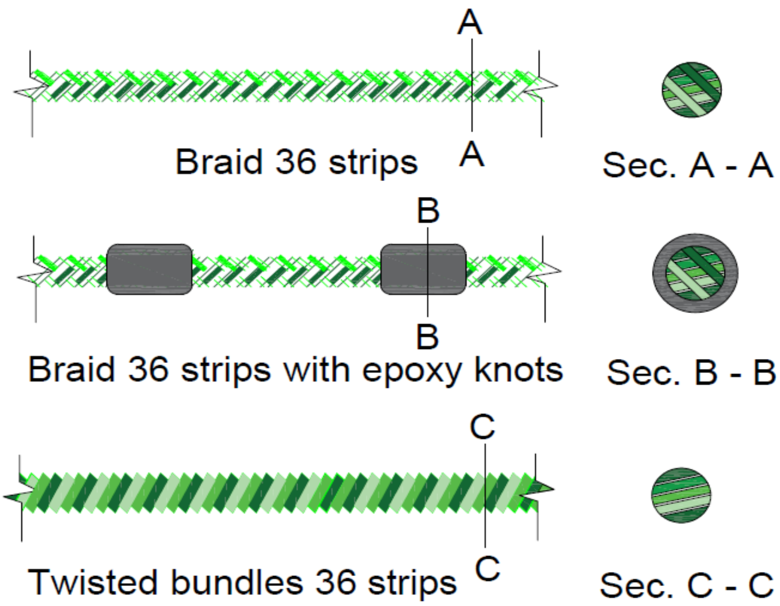


Fig. (3-25): Details of the three types of PET bars with its cross-sections

3.4.3.4 Tension Stress Test for Braids and Strips

Tensile testing of braids and strips is carried out in laboratories of the College of Engineering, Basra University, to determine the maximum tensile stress of the braid or strips, as well as the elongation that occurs during the tensile process. This test was done twice, using the tensile test machine shown in Fig. (3-26). Four samples were selected to examine in each time:-

1- Only one strip of the strips that was used to create braids or bundles with the same cross section dimensions.

2- A secondary braid consisting of 12 strips

3- The main braid of 36 strips

4- A secondary bundle consisting of 12 strips.

In order to reduce the pressure of the tensile machine jaws on the two ends of the specimens; the specimens ends were enclosed by a wire mesh and epoxy dough (section 3.3.7). The test of only one strip was succeeded where it recorded a tensile strength of 78.12 MPa with an elongation ratio of 8.5%. While the other specimens failed in the region of the ends due to the high jaw pressure during the tensile process. Fig. (3-27) showed the two test specimens. In the second trail, the same process was repeated, but the ends of the specimens are enclosed with a thermal silicon and cotton tape. The results were same as the first trail. The tensile stress to strain curve for one strip test is shown in Fig. (3-28). It was drawn according to data of the computer that connected to the tensile testing machine.

Fig (3-26): Braid and strips tensile testing machine

First test Second test

Fig (3-27): Braid and strips before and after tests

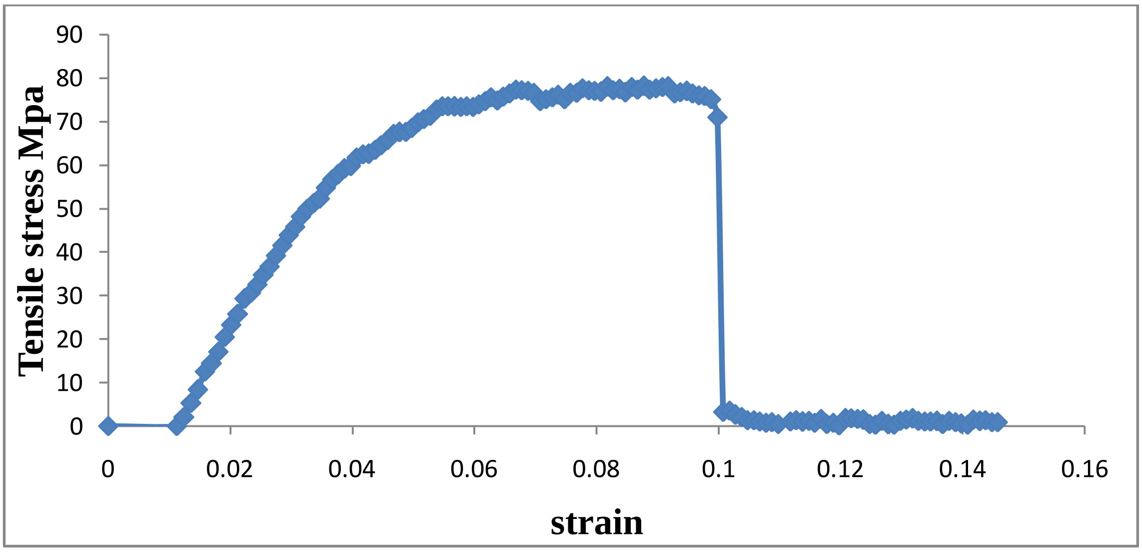


Fig. (3-28): Tensile stress to strain relation for one stripe tensile test

3.4.3.5 Concrete Beams Specimens

All the concrete beams were casted using wooden molds as in the first part of this study. Wooden formwork with a fixed wooden base and movable sides attached to each other and with the base by screws and nails in this part of the work also, the beams are simply supported. Five beams rectangular cross-sectional area with dimensions b = 150 mm, h = 200 mm, and length 1400 mm were tested as shown in Fig. (3-29). Three molds have two openings on each small side with a diameter of 30 mm. These openings used to tighten waste PET plastic bottles as a substitute of steel bars, by using a tightening tool specially made for this purpose. One point load applied at mid span and two supports with clear span of 1200 mm are used as shown in Fig. (3-30).

Fig. (3-29): All five beams wooden molds

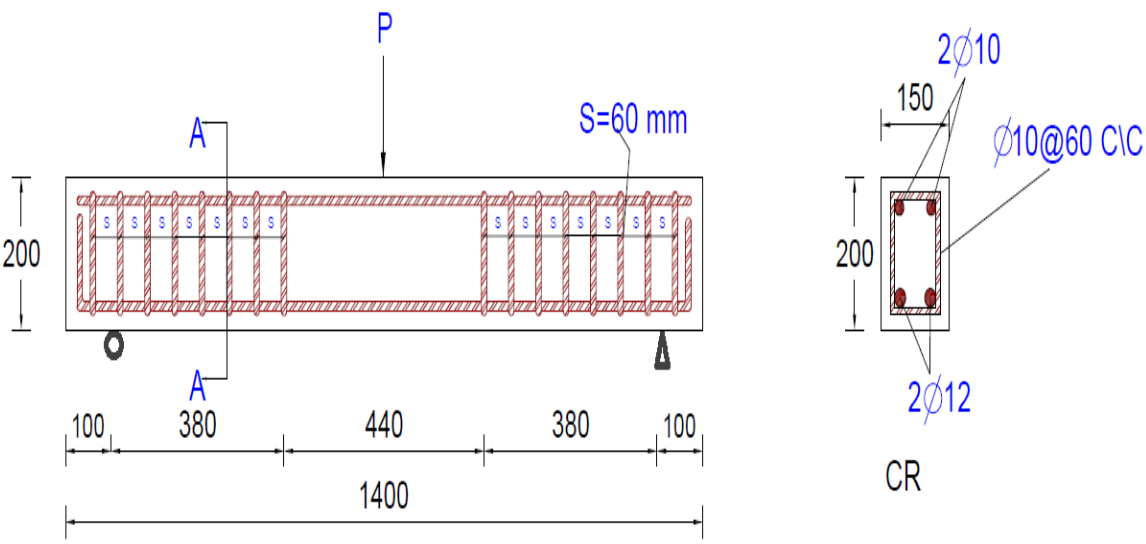


Fig. (3-30): Beams loading and supporting method

3.4.3.6 Details of Concrete Beams Reinforcement

Five beams are caste with different details of reinforcement. Deformed steel bars and PET bars were used in the reinforcement, Figs. (3-31) and (3-32) show the five type details shape. The five Details can be illustrated as follows:-

1- **CR**: Reference concrete beam include two bottom bars ϕ 12 mm diameter for tension reinforcing, stirrups reinforcement bars ϕ 10 mm diameter at 60 mm c/c, and two ϕ 10mm top anchorage bars to fix the stirrups.

2- **CC:** The reference plain concrete beam without reinforcement include only stirrups reinforcement bars ϕ 10 mm diameter at 60 mm c/c and two top bars ϕ 10 mm to fix the stirrups as anchorage bars to eliminate shear effect.

The other three concrete beams have the same detail of reference beam but they were reinforced with PET bottle bundle or braids as tension reinforcement. It is tightened before casting by the tighten tools. This PET bottle bar beams were:-

3- **BP1**: The first type is two bars of PET waste in the form of a braid. Each braid consists of 36 strips placed in the tensile area as an alternative reinforcement of the steel bars of the concrete beam.

4- **BP2:** The second type is similar to the first type, with the addition of epoxy nodes of 8 cm length, distributed to the braid at every 10 cm.

5-**BP3 :** The third type of PET bottle waste rods is longitudinal bundles that are placed in the tensile area and tightly twisted.

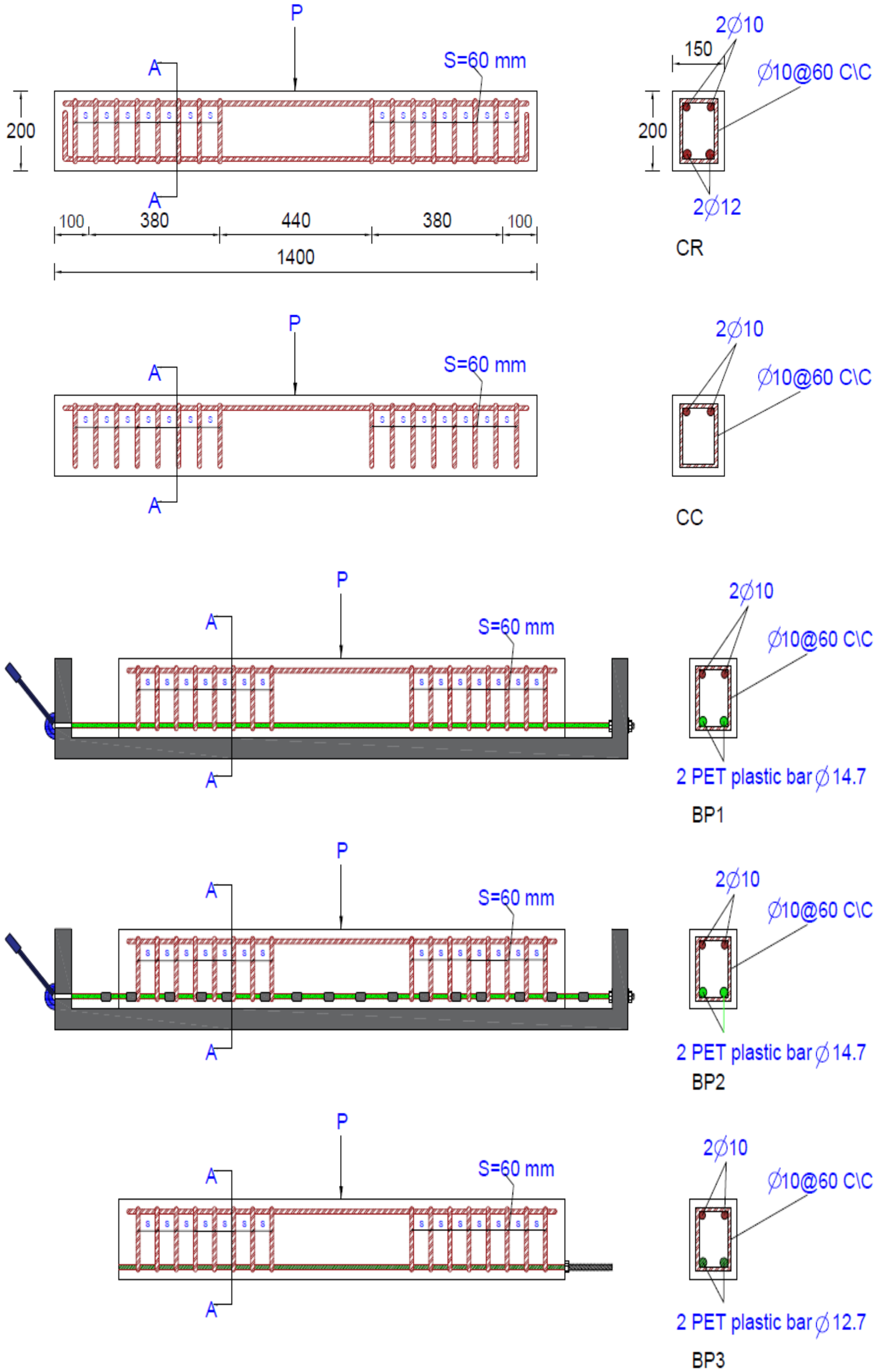


Fig. (3-31): Reinforcement detail for all five beams

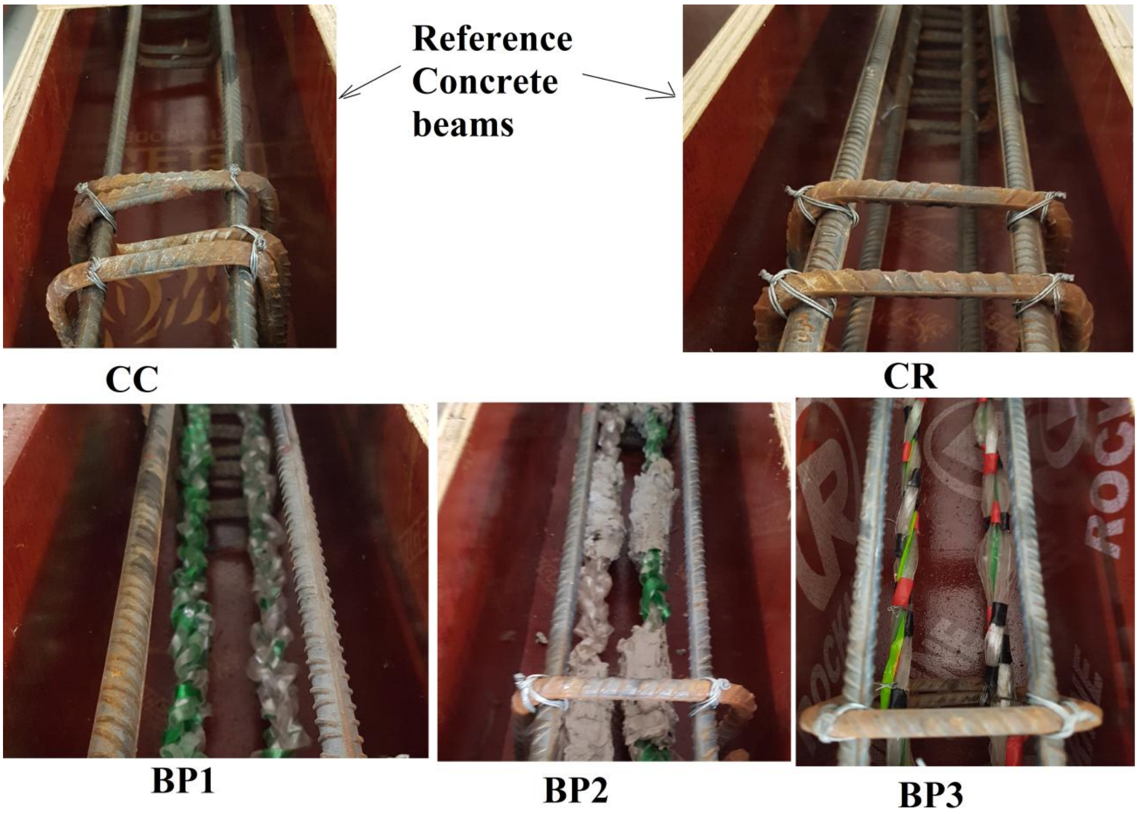
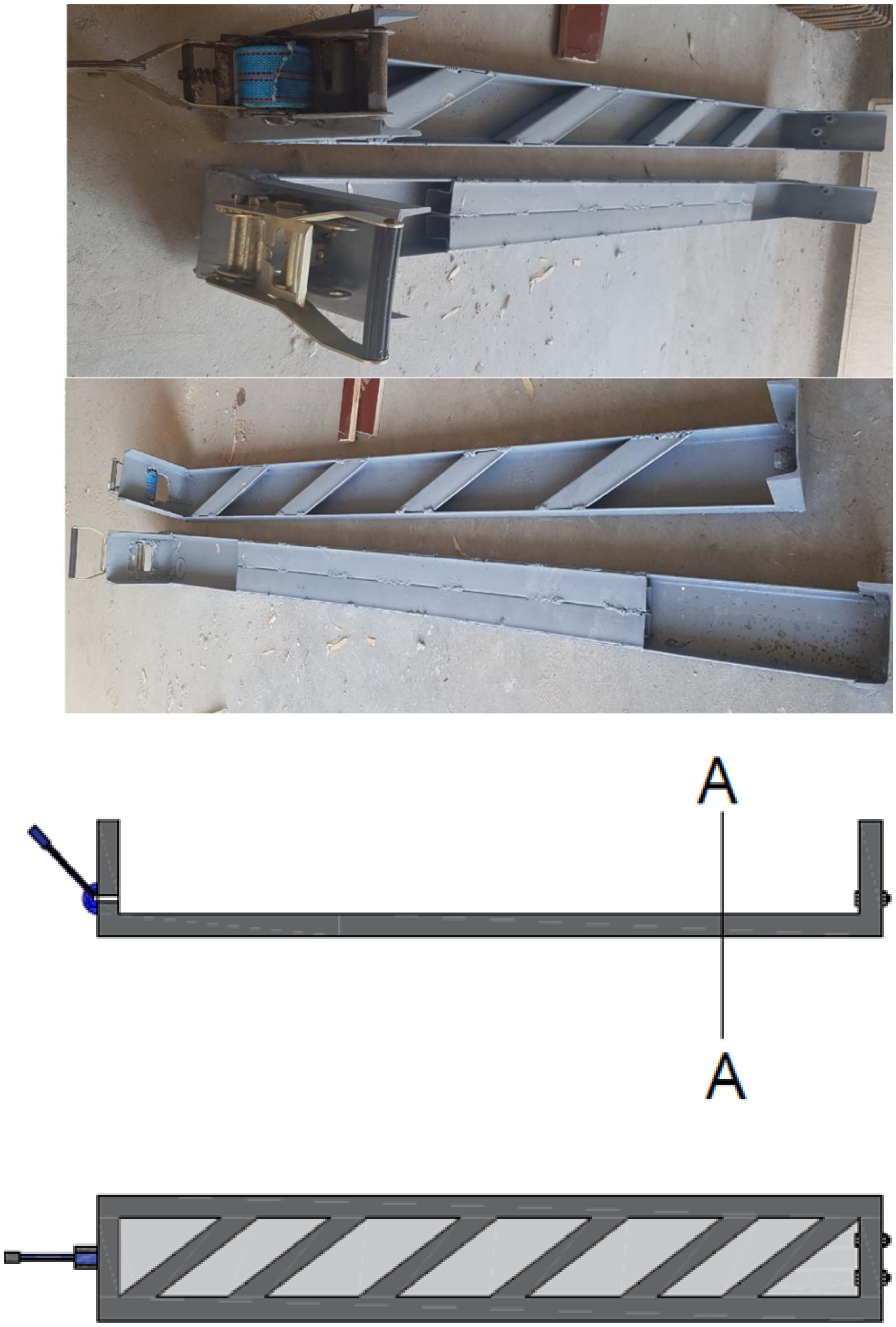


Fig. (3-32): Detail shape for all five beams

3.4.3.7 Tighten Tool

Plastic braids are characterized by a lack of straightness and contain gaps and flexes. It is expand during tension, causing elongation and an increase in the length of the braids. Therefore, it was necessary to make a prior pull the plastic PET braids to eliminate the expected elongation due to tensile, as well as to give it straightness make the conditions of work similar to the conditions of the work of steel bars. Therefore, made a tighten tool, consisting of a steel structure with a base and two ends perpendicular to the base. One end contains nuts to fix the first end of the braids. The second end contains a handle connected to the pull mechanism, the braids is tied to it for the purpose of pulling it as shown in Fig. (3-33).



Section A-A
Fig. (3-33): Tighten tool details

3.4.3.8 Preparation and Tighten of PET Waste Bars

Three types of PET waste bars were prepared and tightened before being used as the main reinforcement in the concrete beams.

A. PET Braids Bars

PET waste braids created as shown in section (3.9.1.4.1) consisting of 36 PET strips are placed inside the wooden molds with shear steel-reinforcement. Then the entire mold is placed inside the tighten tool and it is tightened tightly before casting, as shown in the Fig. (3-34). This type was used in the BP1 concrete beam.

Fig. (3-34): Braids tightening method and installation to the pre tension tool procedure

B. PET Braids Bars with Epoxy Knots

This type is formed and tighten same as first type, but an epoxy knots were added along the braids through the steps below:

A- Pulling the braid tightly.

B-Surround and fix the perimeter of the knot with a wire mesh.

C- Fill it with an high performance building adhesive epoxy (sikadur 31-41 cf slow), making sure that the surface of the dough is rough. Fig (3-35) shows the procedure of forming BP2 braids. The purpose of these nodes is to increase the bonding between the concrete and the braid, as well as to reduce the expected elongation in the braid when exposed to tension .This type was used in the BP2 concrete beam. In the first and second types of PET braids waste, one of the ends of each strand is attached to a serrated bar, which is then attached to one of the ends of the tighten tool by a nut installed in the tool. While the other end is attached tightly to a high-strength cotton tape, which is connected to the installed pull device on the second end of the tighten tool, as shown in the Fig. (3-34).

Fig. (3-35): Forming BP2 braids procedure

C. PET Bundles Bars

This type is created as described in section (3.9.1.4.2), and it also consists of 36 strips. PET bundles are twisted before casting. The twisting is done by connecting the ends of the longitudinal PET bundles to the serrated rods and then tightening them by nuts, as this process provides twisting and tightening the longitudinal PET bundles at the same time as shown in the Fig. (3-36). This type was used in the BP3 concrete beam.

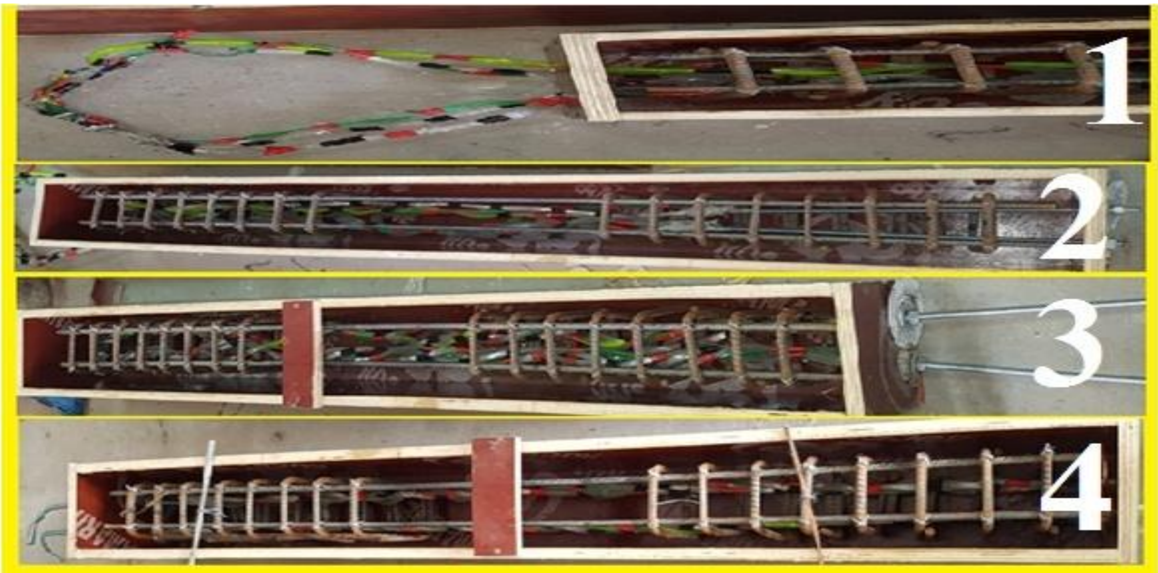


Fig. (3-36): Twisting and tightening BP3 bundles procedure

3.4.3.9 Casting and Curing Procedure

The procedures of casting and curing are done according to the specifications. Fig. (3-37) shows the preparing, casting, and curing for all beams.

Fig. (3-37) : Preparing, casting, and curing for all beams

3.11 Testing of Concrete Beams

The same compression machine that used in the second part section 3.4.2.2.1, was used herein. Also same dial gauge and strain gauges types were used. The difference was only in the loading method as the single point load method was used in the mid- span of the concrete beam and only the mid span dial gauge was used as shown in Fig. (3-38).

Fig. (3-38): Automatic compression machine

3.5 Test Variable

3.5.1 Mechanical and Physical Properties of Concrete Containing PET Waste as a Partial Replacement of Sand

The sand replacement percentages with PET waste is the main test variable. Six replacement percentages of PET waste are used 5%, 7.5%, 10%, 12.5%, 15%, and 20% in addition to reference mix without PET (0%). For each percentage the following properties were determined;

slump, density, compressive strength, elastic modulus of elasticity, splitting tensile strength, absorption, UPV test, flexural strength ,expansion, shrinking, energy absorption, strain, ductility, and shear strength.

3.5.2 Reinforced Concrete Beams with PET as a Sand Replacement

Seven beams were tested with different PET percentage, (i.e. each beam has one PET percentage) and the PET percentages are 5%, 7.5%, 10%, 12.5%, 15%, and 20% in addition, reference beam. These percentages are variables used as sand replacement weight percentages. Its detail are as shown in Fig. (3-39).

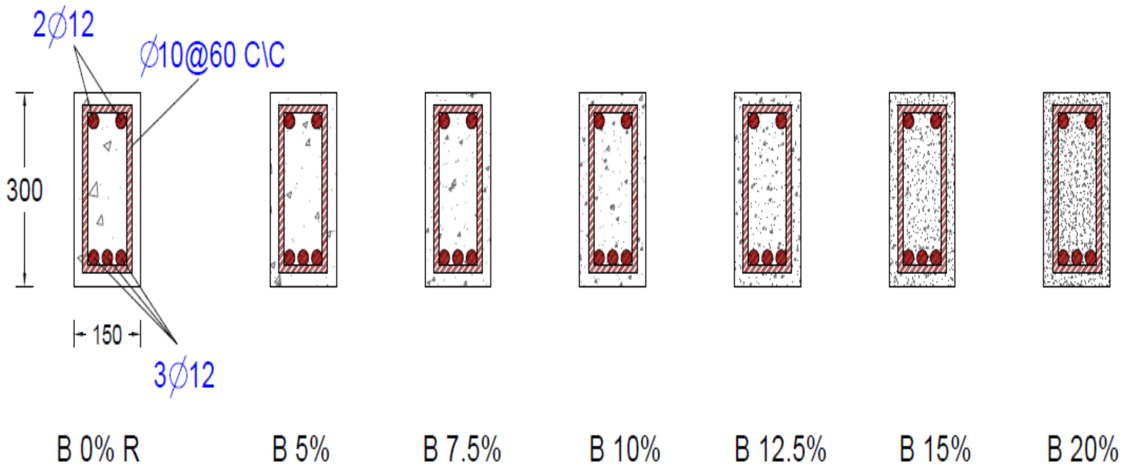


Fig. (3-39): Variables of all seven beams

3.5.3 Concrete Beams Reinforced with PET Waste Bars

In this part of study five beams were tested with limited variables. It is included the replacing the main steel reinforcement bars with PET plastic waste bars. Three type of PET main reinforcement are used and two reference beams, one with main steel reinforcement and other without main reinforcement for comparison. Its details were as shown in the Table (3-16) and Fig. (3-40).

Table (3-13): The detail of five beams that used in third part of study

No.	Beam remark	Tension reinforcement
1	RC	Steel Rebar
2	BC	Shear Steel Rebar
3	BP1	PET Waste braids
4	BP2	PET waste braids with epoxy knots
5	BP3	PET Waste bundles

Fig. (3-40): Variables of all five beams

CHAPTER FOUR

RESULTS

AND

DISCUSSIONS

Chapter four
Results and Discussions

4.1 General

In this chapter, the results and discussion are presented for the fresh and hardened concrete. The slump result test is pointed out for fresh concrete. While for hardened concrete results are presented such as: compressive, splitting, flexural shear, the modulus of elasticity, toughness tests. In addition, volumetric change and plastic shrinkage, ultrasonic pulse velocity, absorption and density tests. Seven mixes design are presented, six mixtures with partial replacement of natural sand by PET and one mixture is reference. Also, the structural behavior results of the full scale beam for each replacement ratio were presented. These results included the ultimate load, the ultimate deflection, ductility, energy absorption, strain, number of cracks, the load at which the first crack occurs, and spacing between cracks, with drawing relationships for each parameter. In addition, the results of concrete beam reinforced with PET waste bars were presented.

4.2 Results of Tested Specimens

The mechanical and physical properties tests for concrete included the use of 217 specimens as follows: 63 cubes with dimensions of (150 × 150 × 150) mm, 63 cylinders with dimensions of (100 × 200) mm, 42 prisms with dimensions of (100 × 100 × 500) mm , 21 cylinders with dimensions of (250 × 300) mm, and 14 prisms with dimensions of(75 × 75 × 300) mm and 14 specimens to examine the shear strength. Structural behavior tests (the part related to the use of PET waste as a substitute for fine aggregate) included seven semi-full scale concrete beams with dimensions of (150 ×

300 ×2300) mm .Five concrete beams with dimensions of (150 × 200 × 1400) mm were tested to investigate the possibility of using PET as a reinforcing bar.

4.2.1 Part One: Physical and Mechanical Properties of Concrete Containing PET Wastes Replacement Percentages

In this section, results of fresh and hardened properties of concrete with different percentages of PET waste as sand replacement were used in the concrete mixture at ages of 7, 14, and 28 days were presented, which include:

1- Workability of mixes.
2- Mechanical properties
   a- Compressive strength
   b- Splitting tensile strength
   c- Flexural strength
3- Shear strength
4- Physical properties
   a- Expansion and Shrinkage test
   b- Density
   c- Absorption
   d- Ultrasonic test
   e- Modulus of elasticity and energy absorption
   f- Axial strain

4.2.1.1 Fresh Concrete Test (Workability)

After mixing process slump test was taken immediately to ensure the workability requirements of mixes with 40% water-cement ratio. Each mix that contains variable percentages of PET particles was tested by slump cone test. The results showed that slump is decreased when the percent of PET is increased as shown in Table (4-1) and Fig. (4-1). Reduced slump is associated with a number of causes, including the shape of the PET bottle waste particles which was irregular with sharp and edges, causing an increase in particles surface area , and another reason is that the PET plastic particles have reduced the homogeneity of the mixtures by isolating the mixture components from each other, i.e. more heterogeneity with the increasing of PET. Therefore, super plasticizer was used to increase workability.

Table (4-1): Results of slump for PET percentages as sand replacement

No.	PET/Sand Percentages	Slump (S) mm	Reduction in slump %
1	0%	160	-
2	5%	140	0.125
3	7.50%	130	0.1875
4	10%	120	0.25
5	12.50%	100	0.375
6	15%	80	0.5
7	20%	60	0.62

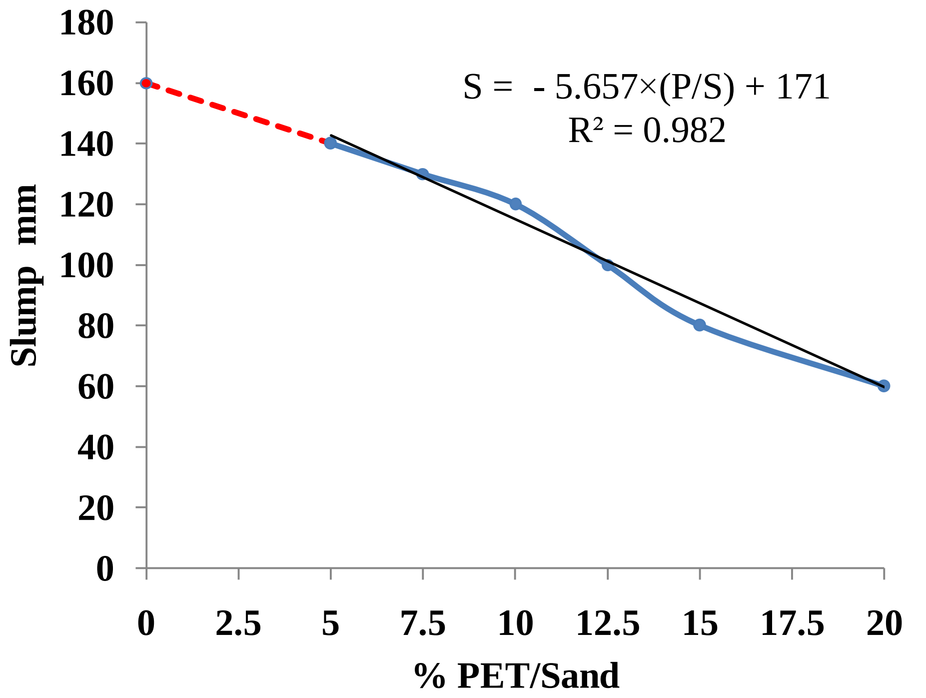


Fig. (4-1): Relation curve of slump to (PET/sand) percentages

4.2.1.2 Mechanical Properties Results

A. Compressive Strength

The compressive strength results are shown in Table (4-2) and Fig. (4-3). It is observed through the results that the replacement percentage which ranges between 5% and 15% achieved an increase in the compressive strength when compared to the compression results of the reference cubes. This increase can be observed in varying proportions at the ages of 7, 14 and 28 days, it can be explained as follows:

Age 7 days:- By noting the results of compression at the age of 7 days, the percentage of substitution that ranges between 5%-15% were achieved an increase in the compression strength compared the reference cubes, where the percentage 10% was achieved a higher compressive strength with an increase of 38.7% compared to reference specimens, followed by percentages 12.5%, 7.5%, 5%, and 15% that achieved an increment of 37.1%, 31.8%, 30.4%, and 30.3% respectively.

Age 14 days: - Strength increased compared to the reference cubes, where the difference shows, especially at percentages 10% and 12.5%, which achieved an increase in compression strength of 43.72% compared to reference cubes, while the difference between the percentages 5% and 7.5% exceeds 12.77% increasing compared to reference cubes.

Age 28 days :- At the age of 28 days, a significant difference in the compression strength curve were recorded. Where the percentage 7.5% was higher than compression strength of reference cubes with an increase of 43.64%, followed by the percentage of 5% with an increase of 34.03%, then the percentages of 10% and 12.5% with an increase of 29.56% and 26.8%, respectively, while the percentage of 15% was close to the results of the reference cubes, finally the percentage 20% decreased in compressive strength by 5.3% from the reference cubes. However, it was observed that the compressive strengths of specimens for ages 7 and 14 days are close, where the replacement percentages of 10 % and 12.5 % representing the higher values. The increment in compressive strength at age 28 days was 34.03%, 42.16 %, and 28.31 % for the specimens with PET percentages of 5, 7.5 and 10 % respectively, as shown in Fig. (4-3). Such behavior is probably due to the presence of plastic fragments at the starting points of failure. At these points (at the failure surfaces), in dealing with flexible plastic fragments, a portion of the shear stress is converted to tensile stress which is consumed to overcome the tensile strength of the plastic fragments. Because of their elongated and sheet-shaped structure, plastic fragments tolerate a part of applied stress before their separation from other materials. In contrast, concrete aggregates are brittle and almost spherically shaped, which make them have less strength against applied stress or be separated from the surrounding cement before the failure.

In contrast, the compressive strength is decreased when the PET waste particles are more than 10 %, as shown in Fig. (4-3). Increasing the presence of plastic fragments at the points of failure had a declining effect on the compressive strength of concrete. The cohesion between mixed materials tends to decrease due to the flat shaped and smooth surface of the plastic fragments. On the other hand, the specimens with higher PET waste percentages 12.5%, 15%, and 20 % caused to more interfacial transition zone between cement paste and PET waste particles, (i.e. it is weaker specimens under compression loads). The values are varied at peak of curves as shown in Fig. (4-3) due to adding superplasticizer. This additive gives early strength to PET percentages 10% and 12.5% at age of 14 days. This increase is about 97% or more when compared to the age of 28 days. By comparing the failure mode for percentages containing PET with reference cubes, it is noted that the cubes containing PET are not crushed suddenly. On the other hand, the cracks were appeared without crushing or separation when applied loading up to failure, but the reference specimens were failed suddenly under loading to achieve failure loading, as shown in Fig. (4-2). This indicates the ductility provided by the presence of PET plastic waste.

Table (4-2): Results of compressive strength for PET percentages as a sand replacement

PET/ Sand (%)	Average compressive strength (*fcu*) MPa			Changing in compressive strength (%)(28 Days)	7/14 ratio	14/28 ratio	7/28 ratio
	7 Days	14Days	28Days				
0	27.2	30.3	34.96	----	89%	86.6%	77.8%
5%	30.4	33.9	46.86	+34.03	89.6%	72.3%	64.8%
7.5%	31.8	34.43	49.7	+43.64	92.3%	69.2%	63.9%
10%	37.73	43.91	44.83	+29.56	85.9%	97.9%	84.1%
12.5%	37.1	43.88	43.46	+26.8	84.5%	100.9%	85.3%
15%	30.3	33.86	35.56	+2.77	89.4%	95.2%	85.1%
20%	26.23	25.4	32.76	- 5.3	103%	77.53%	80%

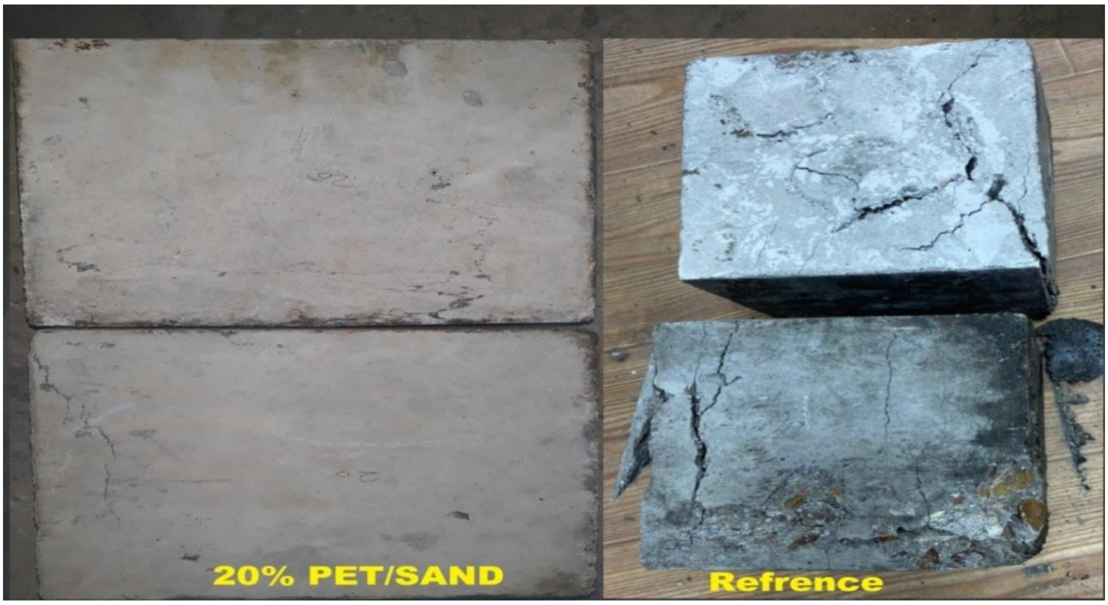


Fig. (4-2): Concrete cubes failure modes for reference cube and 20% (PET/Sand) percentage

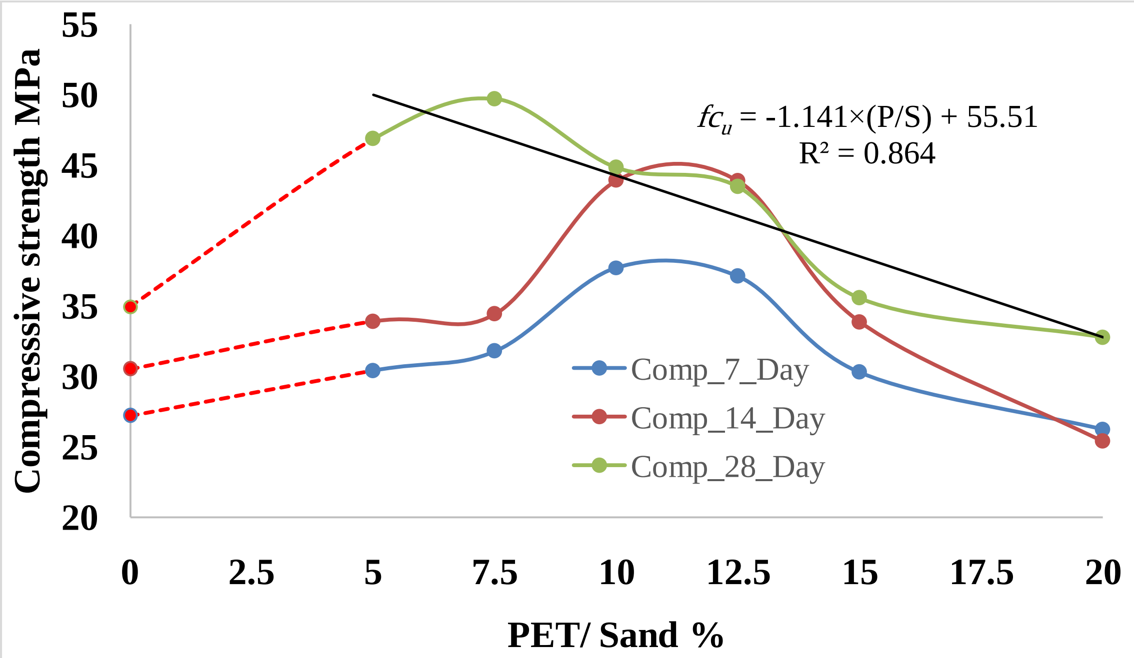


Fig. (4-3): Relation curve of compressive strength to (PET/Sand) percentages

B. Split Tensile Strength

Nine cylinders with dimensions (200×100) mm were casted for each PET percentage for splitting tensile test. Three of them were tested at the age of seven days, three at the age of 14 days, and three at the age of 28 days. The results are shown in Table (4-3) and Fig. (4-4).

The results showed that the use of PET as a sand replacement in the range 5% -15 % increases the splitting tensile strength of the concrete compared to the reference specimens. The splitting tensile strength for the specimens with PET percentages of 7.5% to 15% is more than references specimens, with 7.5% as the optimum percentage which yielded tensile strength greater than the reference mix by 26.9%. The splitting tensile strengths are increased for the specimens with percentages of 5%, 10%, 12.5% and 15 % by 7.8%, 19.08%, 18.6% and 14.93% greater than reference mix, respectively. Whereas, the splitting tensile strength is decreased by 3.7% when the replacement percentage is 20%. Thus, the splitting tensile strength increases by increasing the replacement of sand with PET waste particles in the range 5%-15%, as shown in Fig. (4-4). The increase of splitting tensile stress due to more ductility and sharp edges of the PET waste particles which are caused to reduce slipping when it compared to sand particles, while the specimens with 20 % PET replacement have been decreased in splitting tensile stress. It can explain this behavior cause the number of particles could be collected in one place and stick together. In addition, in this work is used the PET waste as a weight proportion of sand,(i.e. particles number of PET is more than sand particles at the same percentage). Indeed, there is no absorption of water on the smooth surfaces of PET waste particles leads to reduce the hydration of cement; therefore the interaction zone between cement paste and aggregates is lost in bonding at higher PET percentages 20%. The reference cylinder failure mode is suddenly crushed and divided completely into two parts, while there is no separation in the PET waste cylinder specimens, while a surface crack develop and spread on the sample as shown in Fig. (4-5). This indicate that the PET waste provided ductility. On the other hand, the crack pattern is more clear for the specimens with PET than the reference specimens before the failure state, and the specimens are not divided for two parts when achieved ultimate loading.

Table (4-3): Results of splitting tensile strengths for defferent PET/Sand percentages

PET/ Sand (%)	Average split tensile strength (*ft*) MPa			Changing in split tensile strength % (28 Days)	*fc'* *MPa*	*fc'/ft*
	7 Days	14 Days	28 Days			
0	1.73	2.00	2.41	----	29.71	12.33
5%	2.03	2.53	2.60	+7.80	39.83	15.31
7.5%	2.63	2.86	3.06	+26.90	42.24	13.80
10%	2.30	2.56	2.87	+19.08	38.10	13.27
12.5%	2.48	2.52	2.86	+18.60	36.94	12.91
15%	1.80	2.10	2.43	+14.93	30.22	12.43
20%	1.76	1.70	2.32	- 3.70	27.84	12.00

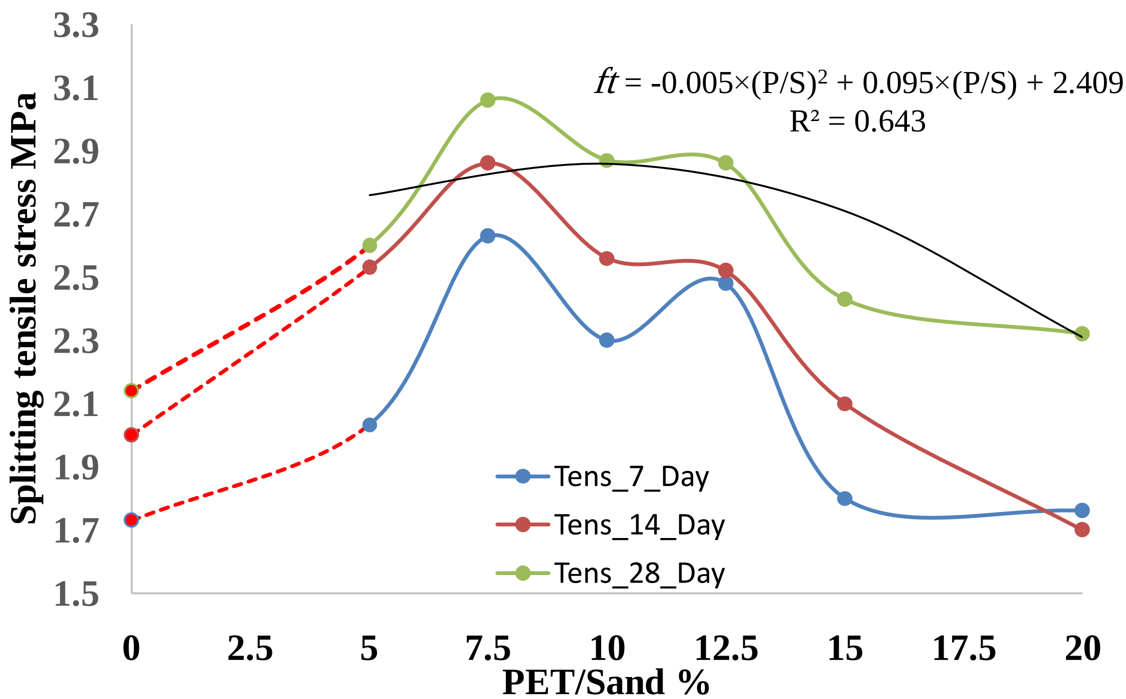


Fig. (4-4): Relation curve split tensile strength to (PET/Sand) percentages

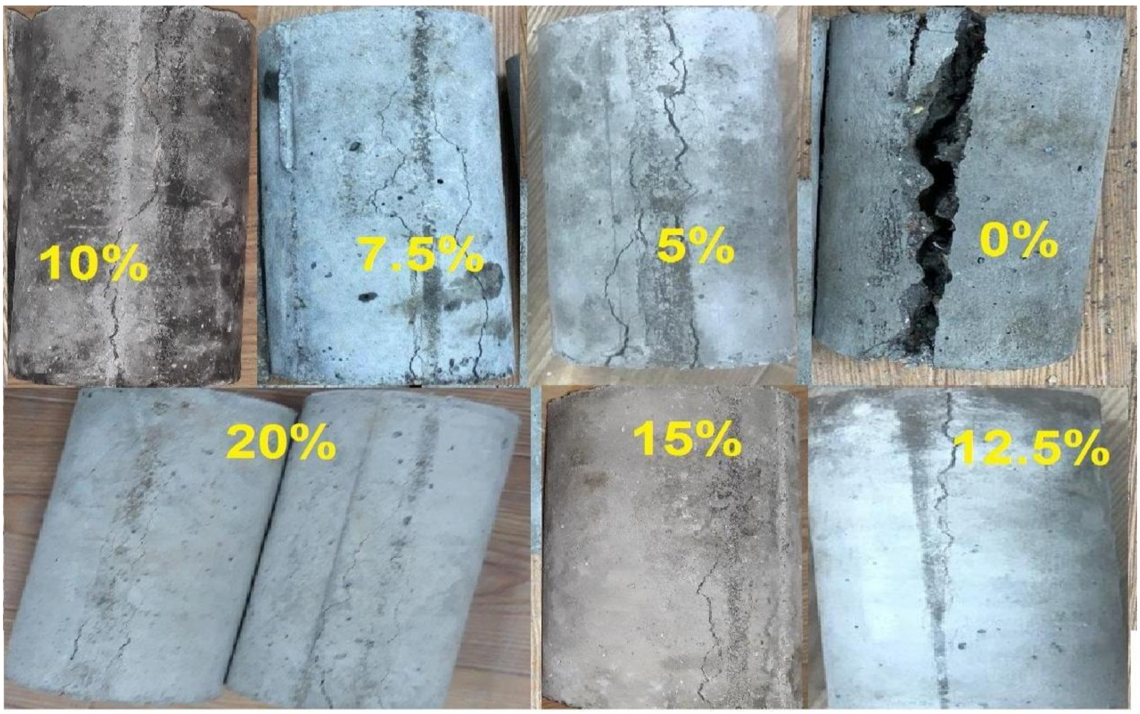


Fig. (4-5): Concrete cylinders failure modes for PET percentages as a sand replacement

C. Flexural Strength

The flexural strength test was performed by casting six prisms with dimensions 100 × 100 × 500 mm for each PET partial replacement of sand.

Three prisms were tested at the age of 7 days and the other three were tested at the age of 28 days. The results of Flexural strength test were shown in Table (4-4) and Fig. (4-6). The results showed that the partial replacement of sand by PET with percentages ranging from 5%-12.5%, achieved an increase in flexural strength compared to the reference specimens. It was observed that the flexural strengths are almost the same for the specimens with 15% PET and references. While the flexural strength is decreased for the specimens with 20 % PET. The replacement percentage of 7.5% achieved the highest flexural strength with an increase of 30.2% when that compared to the reference concrete followed by the percentages 5%, 10% and 12.5% with an increment of 27.1%, 26.2%, and 18.1%, respectively, and the replacement percentage 20% showed a slight decrease from the reference concrete by 3.9%. The concrete is brittle material, and has low tensile strength and PET waste particles are more flexible than fine aggregates (sand). Therefore, using PET particles improve flexural strength. The flexural strength has increased for the specimens with PET waste percentages of 5%, 7.5% and 10 % by 27.15%, 30.24%, and 26.26 % compared to the reference mix, respectively. Since the modulus of elasticity (as in section 4.3.2.9) decreases with increasing the PET particles, that means the concrete specimens are more deformable before failure loading. However, the proportion of PET waste particles is more than 10 % which leads to a decrease in flexural strength. This may be attributed to that the particles of PET are formed groups in the concrete specimens, i.e. an accumulation of these fragments next to each other and a reduction of cohesion between cement and fragments. The prisms failure modes is shown in Fig. (4-7), in which the flexural failure for reference prism (no PET wastes added) cause complete fracture of the prism and divided it into two separate parts. While, although the prism that contain 20% PET replacement percentage are failed, there is no movement in the fracture path and the specimens are stilled appear as one part.Thus, the PET waste has significant impact on the flexural behavior for beams. It reduces spreading and development of cracks which very important property to minimize cracks width and protect the reinforcement.

Table (4-4): Flexural strength results for PET percentages as a sand replacement

PET/ Sand(%)	Average Flexural strength (f_{cr}) MPa		Changing in flexural strength (%)(28 Days)	*fc' MPa*
	7 Days	28Days		
0	3.63	4.53	----	29.71
5	4.58	5.76	+27.1	39.83
7.5	4.65	5.9	+30.2	42.24
10	4.54	5.72	+26.2	38.10
12.5	4.49	5.35	+18.1	36.94
15	4.41	4.55	+0.44	30.22
20	3.84	4.35	- 3.97	27.84

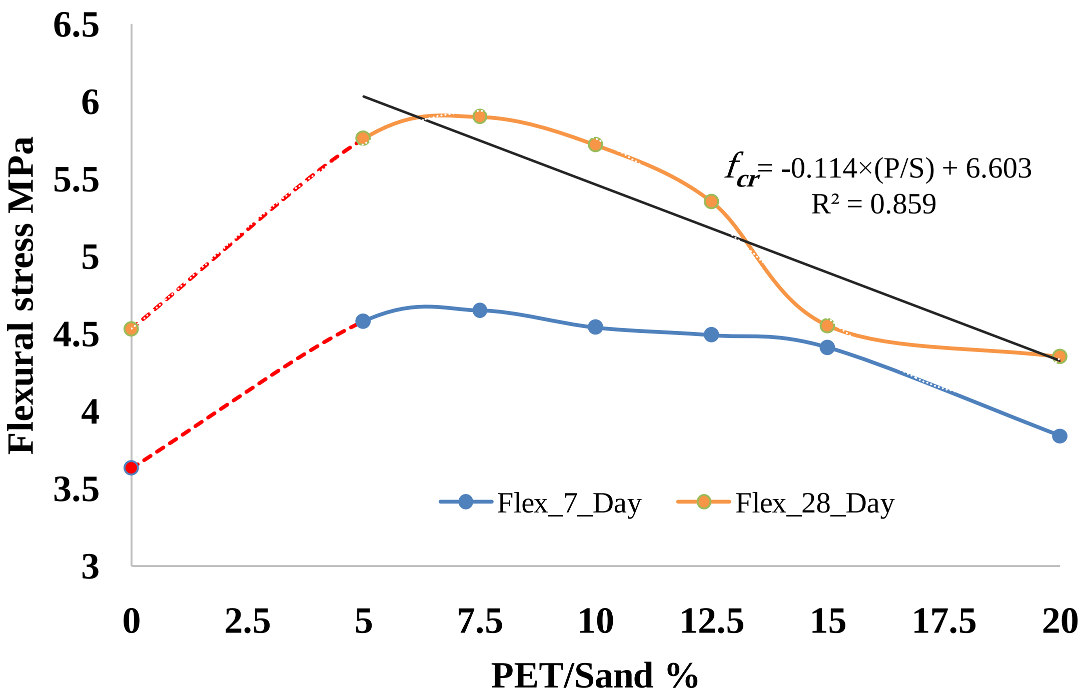


Fig. (4-6): Relation curve of flexural strength to (PET/Sand) percentages

Fig. (4-7): Prisms failure modes for different PET percentages as a sand replacement

4.2.1.3 Shear Strength

Two specimens for each percentage were tested to compute shear strength at age of 28 days as shown in Fig. (4-8). The results of the tests are as shown in Table (4-5) and Fig. (4-9). The results show that the shear strength decreases when the PET waste percentages increase, where the shear strength for reference specimen was 5.08 MPa while the shear strength for the percentages 5%, 7.5%, 10%, 12.5%, 15%, and 20% was 4.4, 4.17, 4.54, 3.76, 3.39, and 2.44 MPa respectively. Sand particles have a rough surface that helps to friction with other sand particles along the shear plane, unlike the PET particles that have a smooth surface. In case of reference specimens, the sand particles, in addition to its bonding with cement, it has a rough surface increases the friction between them along the shear plane, thus increasing its resistance to shear stress. In case of specimens containing PET particles, these particles minimize the adhesion of cement to concrete components also, its smooth surface facilitates sliding one on another along the shear plane if shear force is apply to it, thus its resistance to shear stress decreases as the percentage of PET waste particles increases. The failure mode of the samples shows the clear difference between the specimens that contain PET waste and the reference specimens. The reference specimens were completely destroyed at the zone of the shear plane and separated into two parts as shown in Fig. (4-10). Whereas the failure in the specimens that contain PET waste was on the shape of a crack in the shear plane zone. The length of these cracks and their thickness decreases as the percentage of PET waste increases. This gives a clear indication of the increased ductility when increasing the ratio of PET waste in concrete.

Fig. (4-8): Shear test double L- shape specimens for PET percentages as a sand replacement

Table (4-5): Shear strength results for PET percentages as a sand replacement

PET/Sand (%)	Shear plane area (mm^2)	Average shear stress(V) (MPa)	%Changing in shear strength
Ref. 0%	11837	5.08	0
5%	11837	4.4	-13.38
7.5%	11837	4.17	-17.91
10%	11837	4.54	-10.62
12.5%	11837	3.76	-25.98
15%	11837	3.39	-33.26
20%	11837	2.44	-51.96

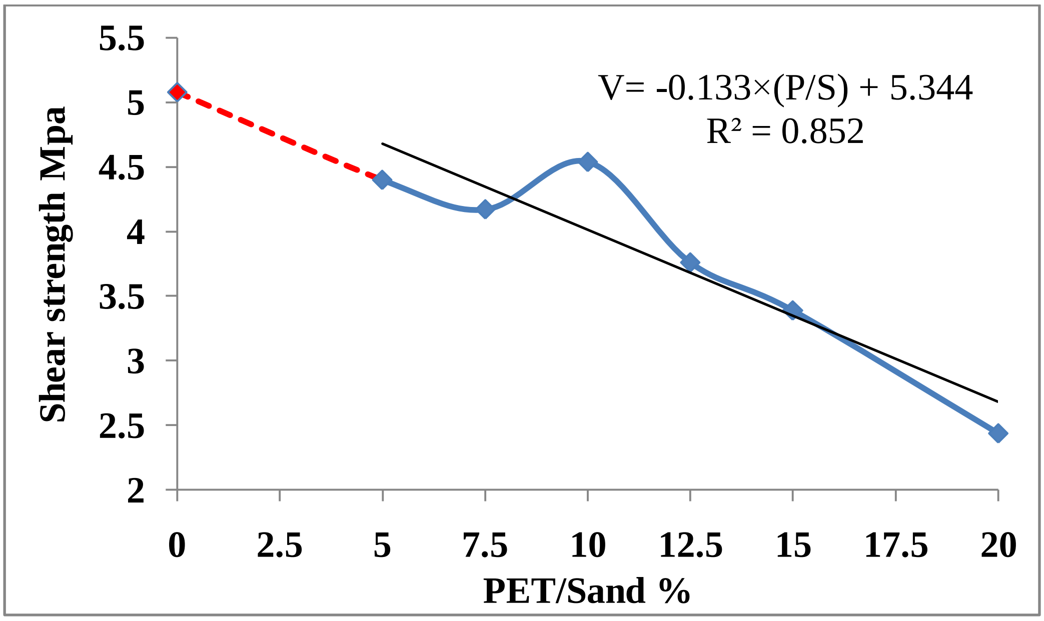


Fig. (4-9): Relation curve of shear stress to (PET/Sand) percentages

Fig. (4-10): Failure mode of double L- shape concrete specimens for PET percentages as a sand replacement

4.2.1.4 Physical Properties Results

A. Volumetric Change and Plastic Shrinkage

Two specimens for each replacement percentage were used to compute volumetric change and plastic shrinkage as shown in Fig. (4-11).

Volumetric change was measured after submerging the specimens in water for 28 days (curing period) and calculating the increase obtained in volume over the original size before curing (immediately after opening the molds). Volumetric change results was as shown in Table (4-6) and Fig. (4-12).

Table (4-6): Volumetric change results for different PET percentages

PET/ Sand	Samples	Dial gauges reading mm (1) Before Immersion in water (B.I)	(2) After Immersion in water for 28 days (A.I)	(3) Sample length + dial gauge reading before Immersion 300+ (1)	(4)=(2)-(1) A.I –B.I mm	(5)=(4/3) Volumetric change
0%	**1**	11.79	11.93	311.79	0.14	0.000449
	2	11.4	11.5	311.4	0.10	0.000321
		Average volumetric change				**0.000385**
5%	1	16.87	16.95	316.87	0.08	0.000252
	2	16.23	16.33	316.23	0.10	0.000316
		Average volumetric change				**0.000284**
7.5%	1	17.7	17.79	317.7	0.09	0.000283
	2	16.88	16.95	316.88	0.07	0.000221
		Average volumetric change				**0.000252**
10%	1	12.9	12.97	312.9	0.07	0.000224
	2	12.18	12.22	312.18	0.04	0.000128
		Average volumetric change				**0.000176**
12.5%	**1**	13.61	13.66	313.61	0.05	0.000159
	2	17.14	17.18	317.14	0.04	0.000126
		Average volumetric change				**0.000143**
15%	1	10.77	10.78	310.77	0.01	3.22E-05
	2	14	14.06	314	0.06	0.000191
		Average volumetric change				**0.000112**
20%	1	10.23	10.27	310.23	0.04	0.000129
	2	5.8	5.82	305.8	0.02	6.54E-05
		Average volumetric change				**0.000097**

Plastic shrinkage was measured after drying the same samples in the oven for 44 hours, at a temperature of 50 ° C **[**48**]** and then left in the natural atmosphere until the readings were stable. Plastic shrinkage results are shown in Table (4-7) and Fig. (4-12).

Table (4-7): Plastic shrinkage results for different PET replacement percentages

PET/ Sand	Samples	Dial gauges reading mm		(3) Sample length + dial gauge reading before immersion 300+ (1)	(4)=(2)-(1) A.I –A.D mm	(5)=(4)/(3) Plastic Shrinkage ratio
		(1) After immersion in water (A.I)	(2) After drying in oven for 44 hour (A.D)			
0%	1	11.93	11.78	311.93	-0.15	-0.00048
	2	11.5	11.43	311.5	-0.07	-0.00022
		Average plastic shrinkage				**-0.00035**
5%	1	16.95	16.89	316.95	-0.06	-0.00019
	2	16.33	16.26	316.33	-0.07	-0.00022
		Average plastic shrinkage				**-0.00021**
7.5%	1	17.83	17.79	317.83	-0.04	-0.00013
	2	16.97	16.94	316.97	-0.03	-9.5E-05
		Average plastic shrinkage				**-0.00011**
10%	1	12.97	12.98	312.97	0.01	3.2E-05
	2	12.22	12.26	312.22	0.04	0.000128
		Average plastic shrinkage				**+0.00008**
12.5%	1	13.66	13.73	313.66	0.07	0.000223
	2	17.18	17.25	317.18	0.07	0.000221
		Average plastic shrinkage				**+0.000222**
15%	1	10.78	10.87	310.78	0.09	0.00029
	2	14.06	14.16	314.06	0.10	0.000318
		Average plastic shrinkage				**+0.000304**
20%	1	10.27	10.36	310.27	0.09	0.00029
	2	5.82	5.93	305.82	0.11	0.00036
		Average plastic shrinkage				**+0.000325**

The results shown in Table (4-6) presented that the volumetric change that occurs to the concrete after immersion in water for a period of 28 days is decreased as the percentage of PET waste increases. The reference specimens have been achieved the highest volumetric change rate by 0.000385. Then the volumetric change rate started to decrease gradually with the addition of PET waste particles, where the percentages of 5%, 7.5%, 10%, 12.5%, and 15 % recorded an expansion of 0.000284, 0.000252, 0.000176, 0.000143, and 0.000112 with decreasing of 26.2%, 34.5%, 54.2%, 62.8%, and 70.9% compared to reference specimens respectively, while the PET percentage of 20% was the least expanding by 0.0000972 with decreasing of 74.7%. These results could be considered accepted if consider that the Iraqi sand contains a percentage of sulfates (SO_3) other than the PET particles. Sulfate, after its interaction with the cement components, and could be increases the size of the hardened cement paste, and the products of this reaction fill the pores and reduce the voids, thus increasing the volume. Therefore, it noted that the increase in volume after curing was higher for reference specimens that contain only sand. This volume increment will decrease when the percentage of sand decrease or in other words, when PET percentage increases. On the other hand, it is observed that the plastic shrinkage percentage decreases as the percentage of PET waste in concrete increases. After drying specimens in the oven, the highest plastic shrinkage rate was recorded for the reference prism by -0.00035. Then the plastic shrinkage rate decreased gradually by increasing the percentage of PET waste, where the samples 5% recorded plastic shrinkage of -0.00021 (i.e. 40% less than reference prism) while the lowest plastic shrinkage level was at 7.5% with an amount of -0.00011 (i.e. 68.5% less than reference prism). Beyond 7.5% percentage, the results took another trend, as the specimens began to expand despite drying, with an increase in the percentage of PET waste, where the percentage of 10% recorded an volumetric change of + 8E-05, while the volumetric change rate for the percentages 12.5%, 15%, and 20% were +0.000222, +0.000304, and +0.000325, respectively. To evaluate these results, the volumetric change and plastic shrinkage cases must be studied simultaneously. As the results showed that the most volumetric change rate achieved was 0.000385, which is the same reference rate, the largest plastic shrinkage was recorded with approximately the same amount of -0, 00035. This yielded that the increase in the proportion of volumetric change in the specimen after its immersion has corresponded with an increase in the rate of plastic shrinkage after its drying in the oven. This hypothesis is valid within a range of 0% - 7.5%. For higher PET percentages (greater than 7.5%), it recorded an expansion in volume in cases of water immersion and drying. The reason could be due to the relative expansion of the PET waste particles after exposure to heat in the oven.

Fig. (4-11): a-Specimens of all PET percentages of shrinkage and expansion test. b-Testing method .c- Oven used for drying specimens

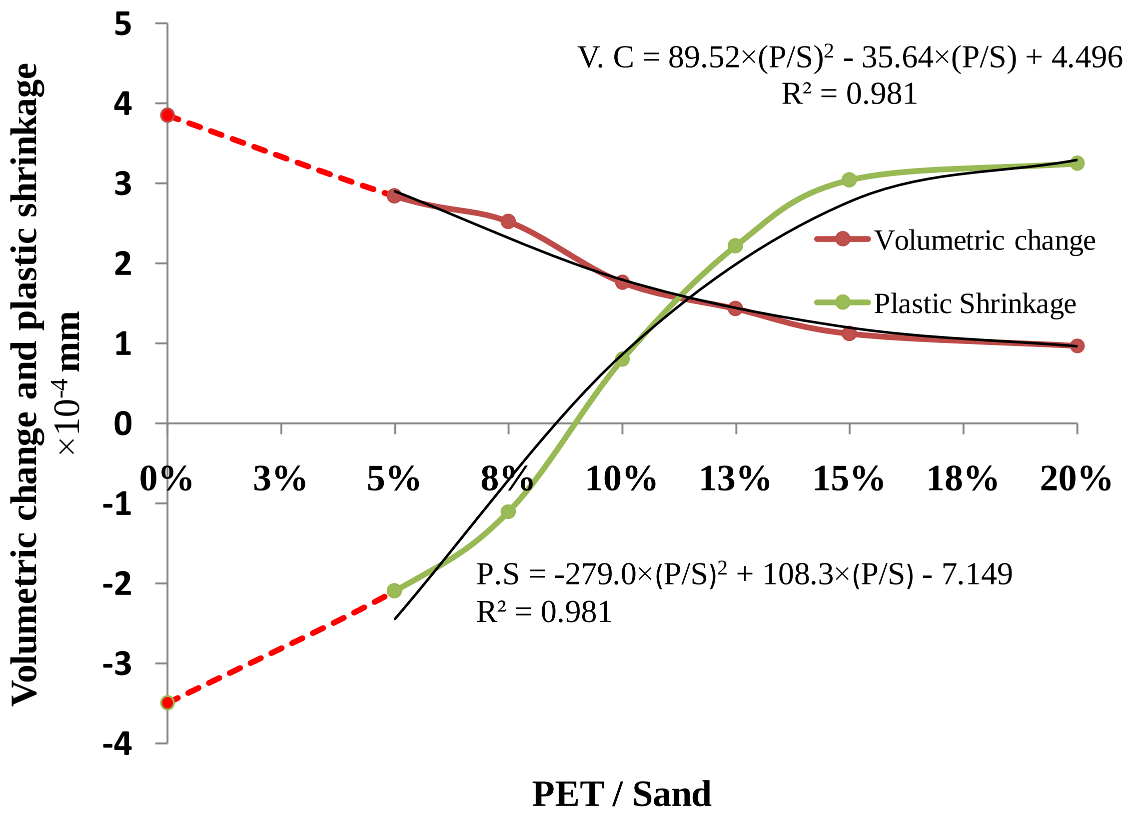


Fig. (4-12): Relation curve of shrinkage and expansion to (PET/Sand) percentages

B. Density

All cubes specimens were used to measure dry density measurement before compression strength testing. Dry density was calculated at age 7, 14, and 28 days as the same as the compression test. The results showed that the density decrease as the PET particles ratio in concrete increase PET as shown in Table (4-8) and Fig. (4-13). At age of 28 days the density of reference specimens is 2361.4 kg/m^3, then its slightly decreased when the replacement ratio increase. The 5% PET replacement ratio has recorded density of 2355.3 kg/m^3 with decreasing of 0.25% compared to reference specimens. On the other hand, the increasing of PET replacement percentage to 20%, achieved a concrete density of 2193.5 kg/m^3 with decreasing of 7.11% compared to reference mix. The low density of PET particles which was 1380 kg/m^3 is the main reason for the decreasing concrete density.

Table (4-8): Density results for PET percentages as a sand replacement

Pet/sand	Density (ɣ) kg/m³ Age 7 days	Age 14 days	Age 28 days	%Change rate for age 28 days	*fc'* *MPa*	*fc'/ɣ*
0%	2357.49	2390.17	2361.4	0	29.71	12.5
5%	2342	2328.87	2355.3	-0.25	39.83	16.9
7.5%	2312.8	2320	2304.16	-2.42	42.24	18.3
10%	2287.3	2296.28	2296.27	-2.75	38.10	16.5
12.5%	2260.73	2286.37	2278.5	-3.51	36.94	16.2
15%	2240.96	2217.26	2222.17	-5.89	30.22	13.6
20%	2214.31	2229	2193.5	-7.11	27.84	12.6

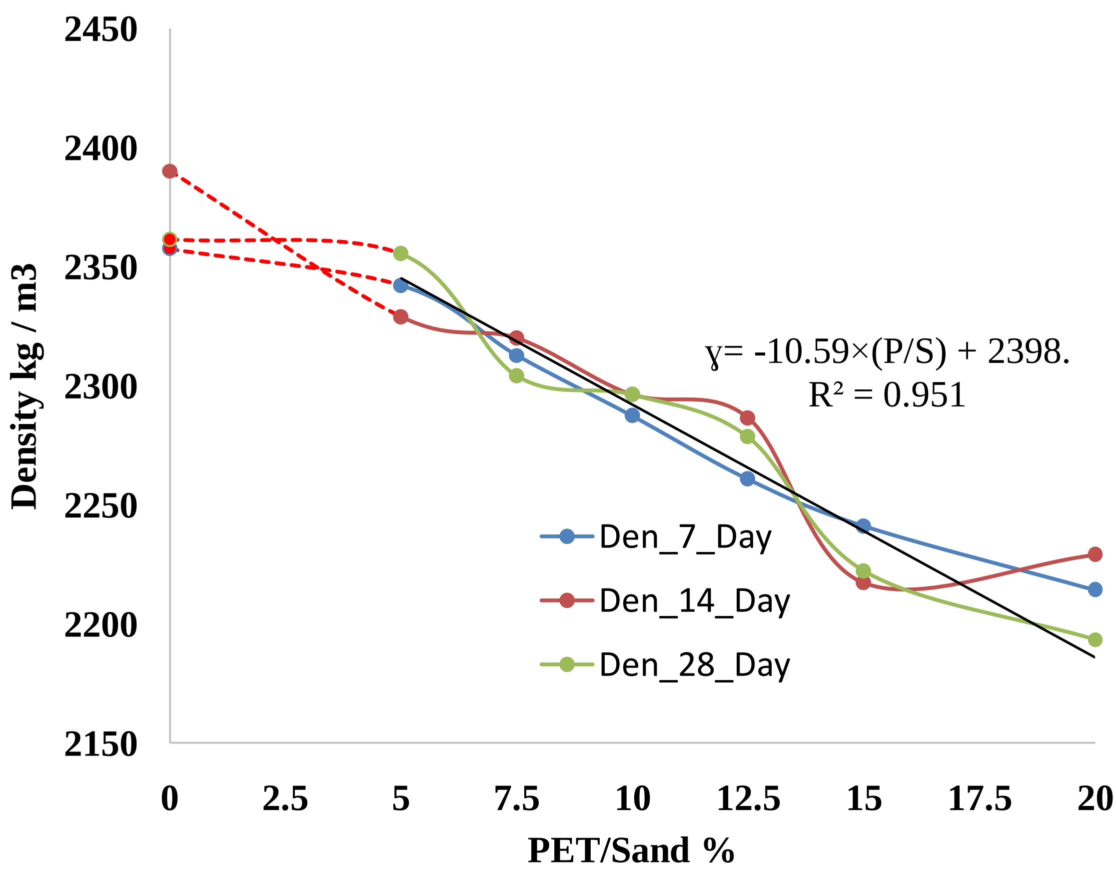


Fig. (4-13): Density for different PET percentages as a sand replacement

C. Absorption Test

Seven concrete cubes were used to conducting an absorption test as shown in Fig. (4-15). One cube was used for each percentage of PET particles. The cubes were dried in the oven for 72 hours and collected its dry weight and then immersed in water for 24 hours at a temperature of 105 ° C, to find its wet weight according to ASTM C642 [50]. The results are shown in the Table (4-9) and Fig. (4-14). The results show that the absorption ratio increase as the PET waste /sand increase. The reference cube record an absorption ratio of (1.55%), then the absorption ratio increase gradually with increasing PET waste /sand ratio. The PET percentages of 5%, 7.5%, 10%, 12.5%, 15%, and 20% had an absorption ratio of 1.63%, 1.65%, 1.72%, 1.77%, 1.90%, and 2.41%, i.e. greater than the reference mixture by 5.1%, 6.4%, 10%, 9%, 14.1%, 22.5%, and 55.4% respectively. The increase in the percentage of PET waste in the aggregate means an increase in its particles that collect in irregular shapes, sharp edges and large surface areas compared to sand particles, forming voids and gaps between them. These voids increase with increasing the percentage of PET waste, which is filled with water after curing, causing an increase in the absorption rate.

Table (4-9): Absorption results for PET percentages as a sand replacement

Pet/ sand	Dry weight (D.W)kg	Wet weight (W.W)kg	W.W-D.W kg	%Absorption ratio	% Changing
0%	7.915	8.038	0.123	1.55	-
5%	7.805	7.932	0.127	1.63	5.16
7.5%	7.764	7.892	0.128	1.65	6.45
10%	7.688	7.82	0.132	1.72	10.96
12.5%	7.583	7.717	0.134	1.77	14.19
15%	7.53	7.673	0.143	1.90	22.58
20%	7.353	7.53	0.177	2.41	55.48

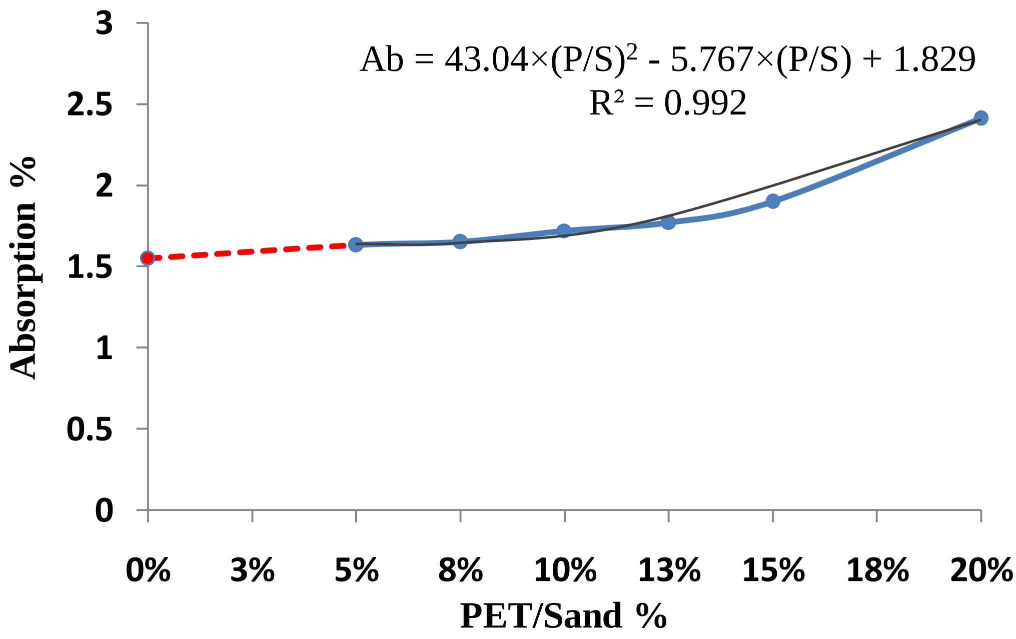


Fig. (4-14): The absorption curve for different PET percentages as a sand replacement

Fig. (4-15): Drying the Specimens of absorption test in the oven

D. Ultrasonic Pulse Velocity Test

Ultrasound pulse velocity was measured by testing seven concrete cubes to demonstrate the concrete quality, one cube for each percentage of PET waste as shown in Fig. (4-17). The test was carried out directly for two directions. The results are shown in Table (4-9) and Fig. (4-16). The results showed that there is a slight decrease in the pulse velocity as the percentage of PET particles increases. Reference specimens recorded a pulse velocity estimated at 3906 m/s, while the velocity through specimens with a replacement ratio of 5% was estimated at 3900 m/s, with a decrease of 0.13% compared to the reference specimens. The increase in the replacement ratio of PET in specimens lead to gradually decreasing in pulse velocity, in which the percentages 7.5%, 10%, 12.5%, 15%, and 20% are recorded a pulse velocity of 3864, 3845, 3768, 3654, and 3409 m/s, namely less than the reference mixture by 0.15%, 1.07%, 1.56%, 3.53%, 6.45%, and 13.0% respectively. The density and pulse velocity in a symmetric trend are decreased with increasing of the PET waste percentage in concrete where, the 20% replacement percentage is recorded a 7.11% and 13% decreasing in density and pulse velocity compared to the reference specimens respectively while, the 15% replacement percentages was recorded 6% and 6.4% decreasing in density and pulse velocity compared to reference specimens.

Table (4-10): Ultrasonic test results for PET percentages as a sand replacement

PET/ Sand	Ultrasonic velocity reading (m/s)		Average velocity (m/s)	% Changing	Concrete quality according to the BS 1881[57] limits Standard
	Axis 1	Axis 2			
0%	3906	3906	3906	-	Good
5%	3895	3905	3900	-0.15	Good
7.50%	3872	3856	3864	-1.07	Good
10%	3826	3864	3845	-1.56	Good
12.50%	3768	3768	3768	-3.53	Good
15%	3658	3650	3654	-6.45	Good
20%	3409	3385	3397	-13.0	Medium

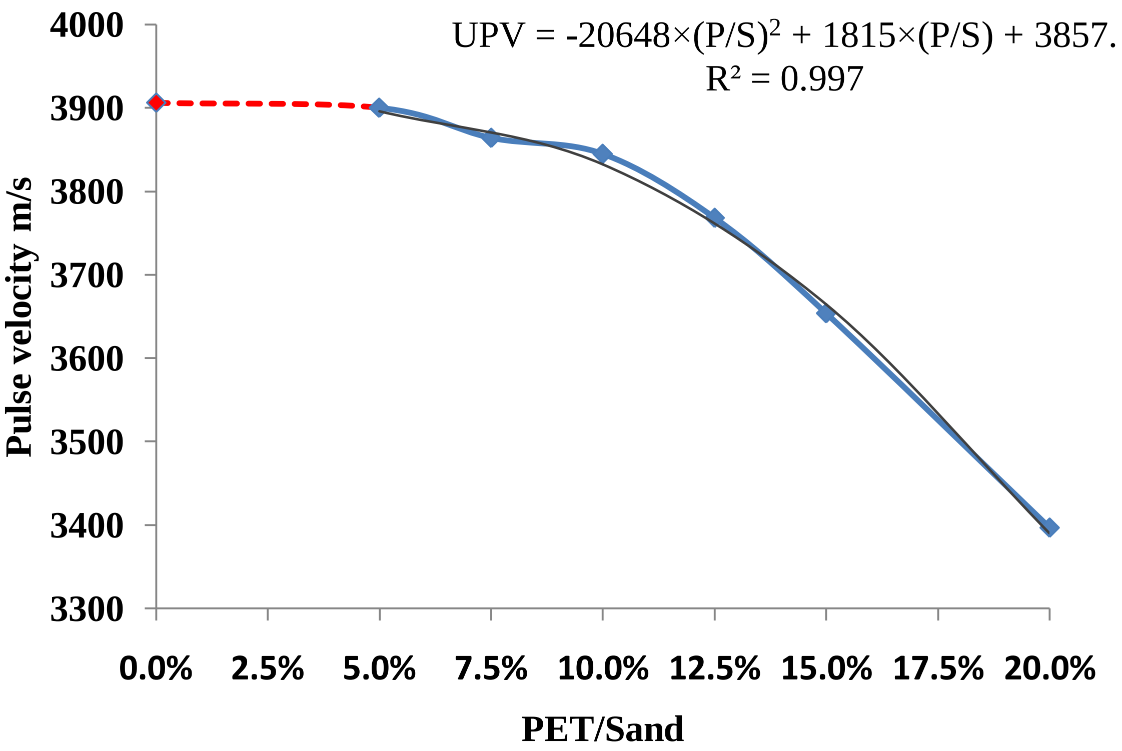


Fig. (4-16): Relation curve of ultrasonic pulse velocity to (PET/ Sand) percentages

Fig. (4-17): Ultrasonic testing method

E. Modulus of elasticity and Energy absorption

Modulus of elasticity is calculated according to ASTM C-469 [21] from stress-strain curve by using the following formula:-

$$\mathbf{E} = \frac{\sigma 2 - \sigma 1}{e2 - 50 \times 10^{-6}} \text{ ....3}$$

Where:-

$\boldsymbol{\sigma}_2$: Stress corresponding to 40% of the ultimate load.

$\boldsymbol{\sigma}_1$: Stress corresponding to longitudinal strain =$50*10^{-6}$.

$\mathbf{e}_2$: Longitudinal strain produced by $\boldsymbol{\sigma}_2$.

The results of elasticity modulus are shown in Table (4-11) and Figs. (4-19). The results and relations obviously are showed that the elastic modulus decreases with the increasing in the percentage of PET plastic particles. The reference cylinders recorded an elastic modulus of 24.72 GPa, and then the elastic modulus started to decrease as the substitution ratio increased and a gradual increase in strain was also observed. Where the cylinders with replacement rate of 5% was achieved an elastic modulus of 24.43 GPa, with a decrease of 1.17% compared to the reference cylinders. It was observed that the elastic modulus for cylinders with substitution ratios of 7.5%, 10%, 12.5%, and 15% were decreased with each increase in the ratios of PET particles, and yielded a value of 23.47, 23.19, 23.11, and 23.1 GPa respectively with an average decrease of 6%, while the elastic modulus of cylinders with 20% replacement ratio was of 22.15 GPa with decrease of 10.39% compared to the reference cylinders. This result is expected with consideration of the inverse proportion between the modulus of elasticity and strain, as the strain increases with the increase of PET particles ratio as shown in Fig (4-21) and, consequently, decrease the modulus of elasticity. Fig. (4-18) show test method and specimens. Energy absorption is calculated as the area under the stress- strain curve. The results are showed that the value of energy absorption (Toughness) (T) rises with increasing replacement percentage of PET particles in fine aggregates as shown in Table (4-11) and Fig. (4-20).

Table (4-11): Modulus of elasticity, and energy absorption, for PET percentages as a sand replacement

PET/ Sand %	Modulus of elasticity		Energy absorption(T)	
	Value GPa	% Changing	Value $*10^{-2}$ kN.mm	% Changing
0	24.72	-	1.3744	-
5	24.43	-1.17	2.0628	50.08
7.5	23.47	-5.05	2.7468	99.85
10	23.19	-6.18	2.8609	108.15
12.5	23.11	-6.51	2.8626	108.28
15	23.10	-6.50	2.6178	90.46
20	22.15	-10.39	2.6142	90.20

Fig. (4-18): a- Modulus of elasticity and energy absorption specimens. b- Modulus of elasticity test.

The reference specimens recorded an energy absorption of 0.01374 kN.mm and then gradually increased, as the replacement percentages increased, the percentages 5%, and 7.5% have achieved energy absorption of 0.0206 and

0.0274 kN.mm with an increment of 50%, and 99.8% compared to the reference mixture, respectively.

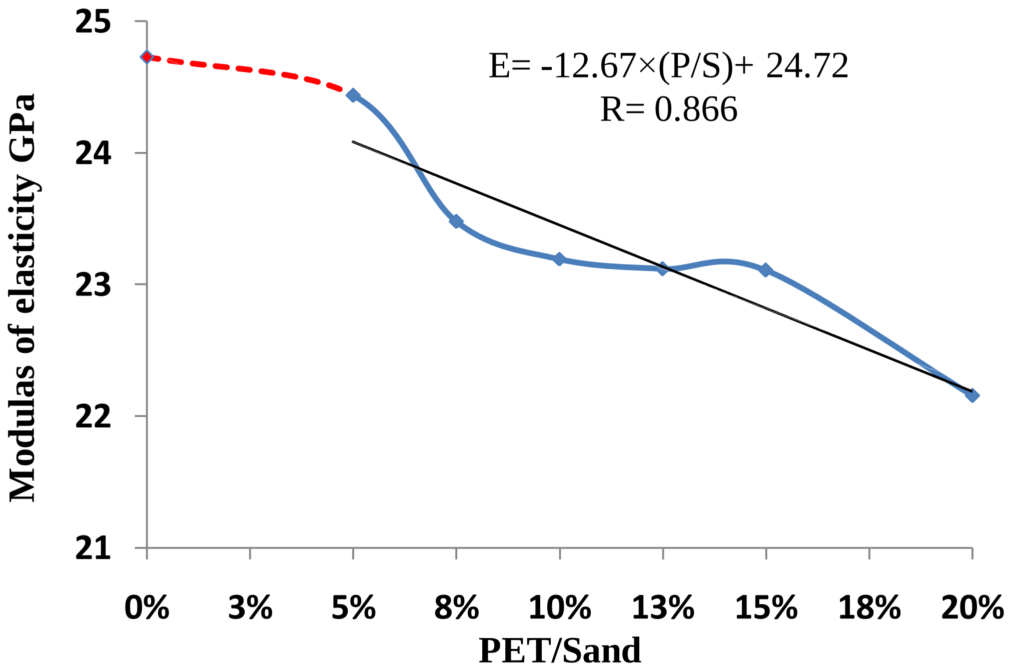


Fig.(4-19): Relation curve of modulus of elasticity to(PET/Sand) percentages

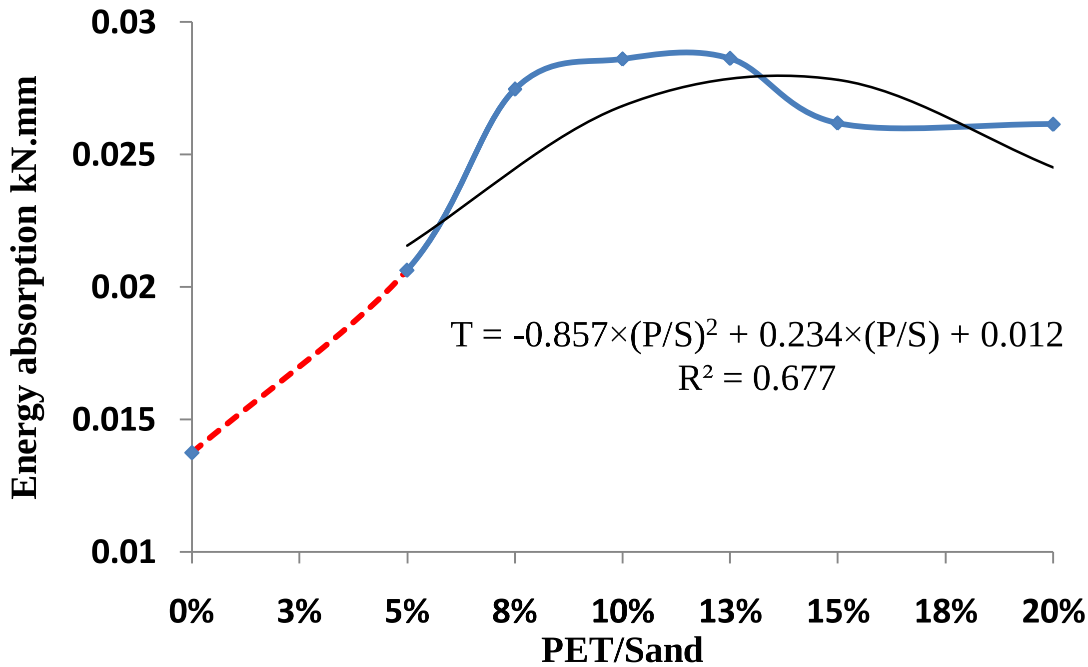


Fig.(4-20): Relation curve of energy absorption to(PET/Sand) percentages

The best value of energy absorption was of 0.0286 kN.mm for both replacement percentages 10% and 12.5%, namely larger than reference cylinders by 108%. While the replacement percentages 15% and20% recorded energy absorption of 0.0261 kN.mm with an increase of 90%. The results reflect the reality of the increase in stresses and strains, with an increase in the replacement percentages compared to reference cylinders.

F. Axial Strains at Failure Load

The brittle behavior of the concrete changes to more flexible behavior with the presence of PET waste particles, as the axial strain at failure load increases with the increasing PET waste content in concrete as shown in Table (4-12) and Figs. (4-21).

Table (4-12): Axial strain at failure load & for PET percentages as a sand replacement

Pet/sand (%)	Axial strain	
	Value $*10^{-3}$	Changing%
0	0.92	0
5	1.22	32.2
7.5	1.47	59.6
10	1.53	65.9
12.5	1.58	71.2
15	1.60	73.7
20	1.63	76.7

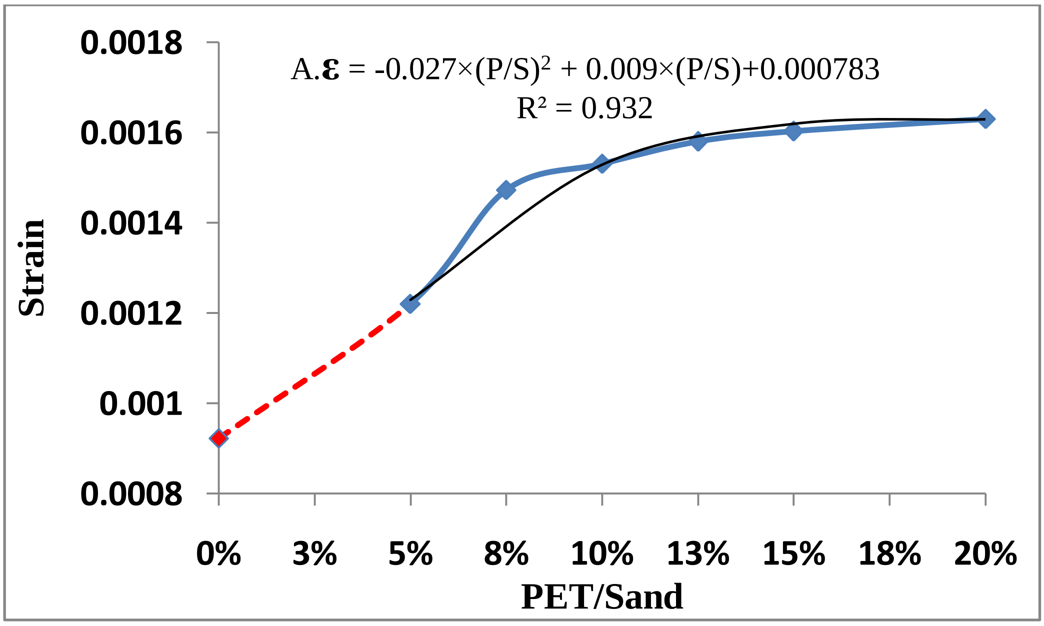


Fig. (4-21): Relation curve of axial strain to (PET/sand) percentages

The reference specimens achieved axial strain at a failure load of 0.92E-3. Then, the axial strain started to increase gradually, with the increase of PET waste in the concrete, where the replacement percentages 5%, 7.5%, 10%, 12.5%, 15%, and 20% was recorded an axial strain of (1.22, 1.47, 1.53, 1.58, 1.6, and 1.63) $*10^{-3}$ with increment of 32.2%, 59.6%, 65.9%, 71.2% , 73.7 %, and 76.7% compared to reference specimens, respectively. This behavior is due to high flexibility of PET waste particles. The axial strain measured in this test till the failure load fc' which corresponding according to the stress-strain curve 0.002 as the highest value and no load readings were recorded after the failure load. Therefore all readings were within these limits, (i.e, the sensitivity of the strain measures is useful only at the elastic stage).

4.2.2 Part Two: Structural Behavior of Beams Containing PET as a Partial Sand Replacement

The flexural behavior of the concrete beams via the ultimate load, ductility, the deflection at mid span, and the crack pattern is investigated. One reference beam with normal reinforced concrete and six specimens with different PET particle replacement percentages were tested as shown in Fig. (4-22). The mid-span deflection is measured and the beams crack pattern is investigated based on crack path growth for each load increment.

Fig. (4-22): Reinforced concrete Beam specimens for all PET/Sand percentages

4.2.2.1 Ultimate Load

The ultimate loads for all concrete beams are recording and presented in Table (4-13. The ultimate failure load of the reference beam B 0% C (without PET) was 164.9 kN. The beams B 5% which have a 5% PET plastic waste as sand replacement, showed an ultimate failure load of 164.3 kN closed to the reference beam. While the concrete beams B 7.5% PET replacement ratio recorded an ultimate failure load of 165.4 kN. As for the concrete beam B 10% with PET waste content of 10% as a sand replacement, it observed that the maximum failure load was 166.2 kN with increasing by 0.78% compared to the reference beam. While the beam B 12.5% which containing 12.5% of PET waste as a sand replacement recorded a very slight decrease rate of 0.6% compared to reference samples with an ultimate failure load of 163.9 kN, whereas, an increase in the ultimate of specimens B 15% and B 20% which recorded failure load of 168.7 and 171.5kN with an increment of 2.3% and 4.0%, respectively, compared to the reference beam. The beam B20% achieved the best failure load characteristic. Fig. (4-23) illustrates the relationship between maximum failure load and the PET waste replacement ratio for all beams.

Table (4-13): Ultimate load for beams specimens containing PET as a sand replacement

Beam remark	*fcu* *MPa*	*fc'* MPa	*Pu* *kN*	Pu/Pu (Reference beam) %	Change in ultimate load %
B0% C	34.96	29.716	164.9	100	0
B5%	46.86	39.831	164.3	99.636	-0.364
B7.5%	49.7	42.245	165.4	100.3	0.3032
B10%	44.83	38.106	166.2	100.79	0.7884
B12.5%	43.46	36.941	163.9	99.394	-0.606
B15%	35.56	30.226	168.7	102.3	2.3044
B20%	32.76	27.846	171.5	104	4.0024

The slight variation in the results of the failure load could be due to the difference in the quality of the used concrete or the specific control of the test machine.

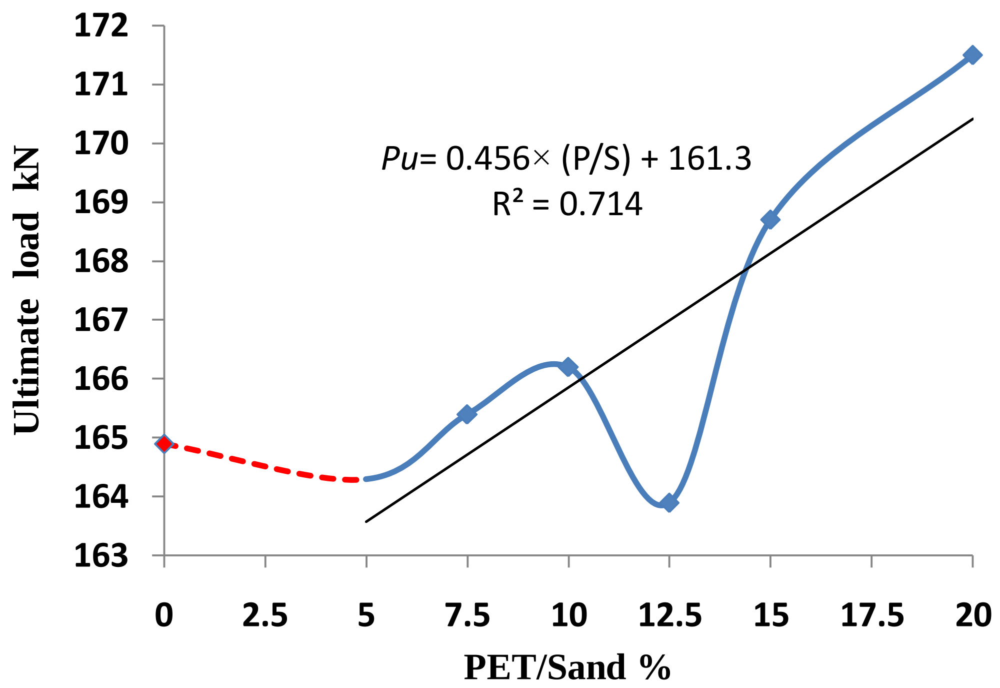


Fig. (4-23): Ultimate failure load to (PET/Sand) relation curve for beams specimens containing PET as a sand replacements

4.2.2.2 Load-Deflections Behavior

Table (4-14) presents the deflection of all concrete beams. Load-deflections at (mid-span) curves were graphed for all beams as shown in Figs. (4-24) and (4-25). The results are showed that the reference beam B0% had the max deflection of 28.4 mm, lower than all other beams that contained PET plastic waste as a partial replacement of sand. The results also showed a gradual increase in the maximum deflection as the PET replacement rate increase in the concrete beams, where the concrete beam B5% is recorded a deflection of 32.1mm with an increment of 23.2% compared to the reference beam. The results showed that the increase of the maximum deflection with increasing PET waste, beams B7.5%, B10%, B12.5%, and B15% yielded a maximum deflection of 34.1, 35.3, 39.63, and 48.22mm with an increment of 30.9%, 35.5%, 52.1%, and 85.1% compared to the reference beam respectively. While the beam B20% achieved the best maximum deflection of 50.47mm with an increase of 93.7% compared to the reference beam.

Table (4-14): Maximum deflection for beams specimens containing PET as a sand replacement

Beam remark	Ultimate Load Pu(kN)	Maximum deflection Δu (mm	Δu/Δu (Reference beam) %	Change in deflection %
B0% C	164.9	26.05	100	0
B5%	164.3	32.1	123.22	23.2
B7.5%	165.4	34.1	130.9	30.9
B10%	166.2	35.3	135.51	35.5
B12.5%	163.9	39.63	152.13	52.1
B15%	168.7	48.22	185.11	85.1
B20%	171.5	50.47	193.74	93.7

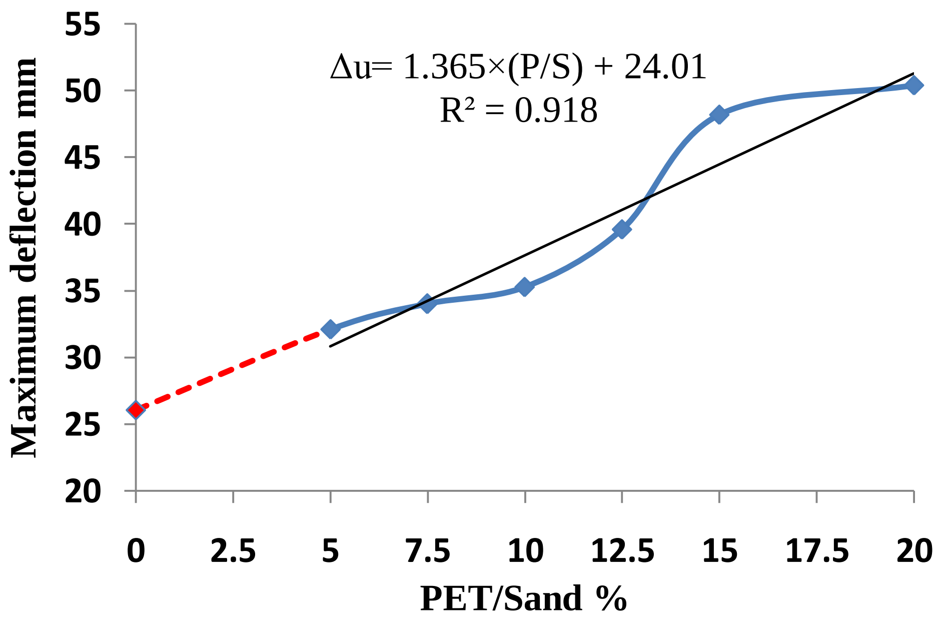


Fig. (4-24): Relation curve of maximum deflection to (pet/sand) percentages for beams specimens

The behavior of concrete beams through the upward max deflection path, which increases with the increase of PET particles in concrete beams, is a clear indication that the presence of PET waste has changed the brittle behavior of concrete to another more flexible behavior. The connection between the ultimate failure load results and the maximum deflection refer to that the beam B20% was the optimum. It is also an indication of prolonging the fraction time and giving early warning before failure. It is a very important characteristic of concrete to reduce the impact of dynamic loads, earthquakes, and impulsive loads.

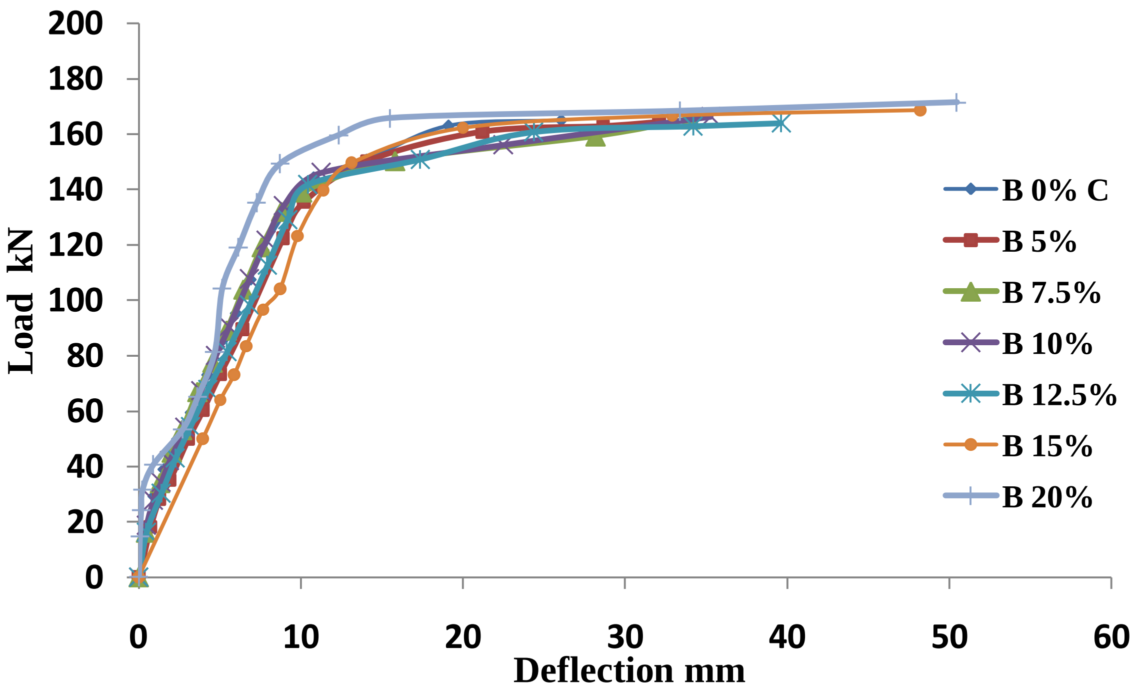


Fig. (4-25): Load to deflection curves for beams specimens containing PET as a sand replacement

4.2.2.3 Ductility Index

Ductility is the ability of reinforced concrete members to undergo considerable deflection prior to failure. The ductility index (μ) can be obtained from the load-deflection curve, which equals the ratio of the maximum deflection (Δu) to the yield deflection (Δy). Table (4-15) shows the ductility for all concrete beams. It is noticed from the Table (4-15) and Fig. (4-26) that the ductility index follows a path that is very similar to the maximum deflection curve, even the increase rates of ductility show a compatibility with the percentages of maximum deflection when compared to the reference samples. Ductility is began to increase gradually with increasing the percentage of PET waste in the concrete, where the beams B5%, B7.5%, B10%, B12.5%, B15%, and B20% recorded a ductility of 3.21, 3.78, 3.83, 4.40, 5.18, and 5.47 with an increment of 12.13%, 32.04%, 34.03%, 53.82%, 81.12%, and 91.37% compared to the reference beam respectively. The reason for this can be attributed to the higher flexibility that PET particles have compared to the fine aggregate particles.

Table (4-15): Ductility indices for beams specimens containing PET as a sand replacement

Beam remark	(Δu)Max deflection (mm)	(Δy)Yield Deflection mm	Ductility Index(D.I)	Changing in ductility%
B0% C	26.05	9	2.89	-
B5%	32.1	10	3.21	12.13
B7.5%	34.1	9	3.78	32.04
B10%	35.3	9.2	3.83	34.03
B12.5%	39.63	9	4.40	53.82
B15%	48.22	9.3	5.18	81.12
B20%	50.47	9.2	5.47	91.37

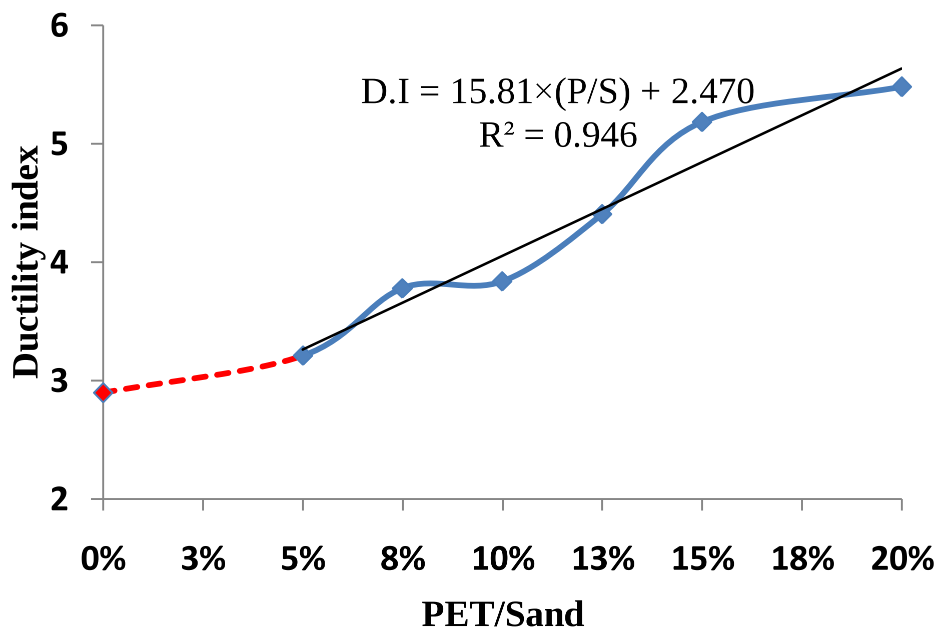


Fig.(4-26): Relation curve of ductility index to (PET/Sand) percentages for beams specimens

4.2.2.4 Flexural Compression Strain at Failure Load

Table (4-16) showed the results of flexural strains at failure loads. The results showed that the compression strain at failure loads increases with the PET percentage increase in reinforced concrete. Also, it was noticed through the compression strain curve in Fig. (4-27), that the compressions strain in the reference specimens B 0% C is 0.000197. Then a significantly increased observed in compression strain for concrete beams that containing PET particles, where the B5% beam recorded compression strain of 0.001049 with increasing of 432% compared to control beam, while the beams B7.5%, B10%, B12.5%, B15%, and B 20% achieved a compression strain at failure load of 0.001634, 0.001742, 0.001866, 0.002208, and 0.002443 with increasing ratio of 729%, 784%, 784%, 1020%, and 1140% compared to control beam, respectively. It is noted that all the values of the compression strain came within the limits of compressive (crushing) flexural strain, which should not exceed 0.003 and close to the strain limit at (fc^{-}) of 0.002 according to stress strain curves specified by the Indian Code IS: 456-2000 [58]. The load-strain curves for all specimens in Fig. (4-28) illustrates the difference between the brittle behavior of the reference concrete beams and those containing PET particles.

Table (4-16): compression Strain at failure load for beams specimens containing PET as a sand replacement

Beam remark	PET/ Sand %	Compressive strain	Changing %
B 0% C	0	0.000197	0
B 5%	5	0.001049	432
B 7.50%	7.50	0.001634	729
B 10%	10	0.001742	784
B 12.50%	12.50	0.001866	847
B 15%	15	0.002208	1020
B 20%	20	0.002443	1139

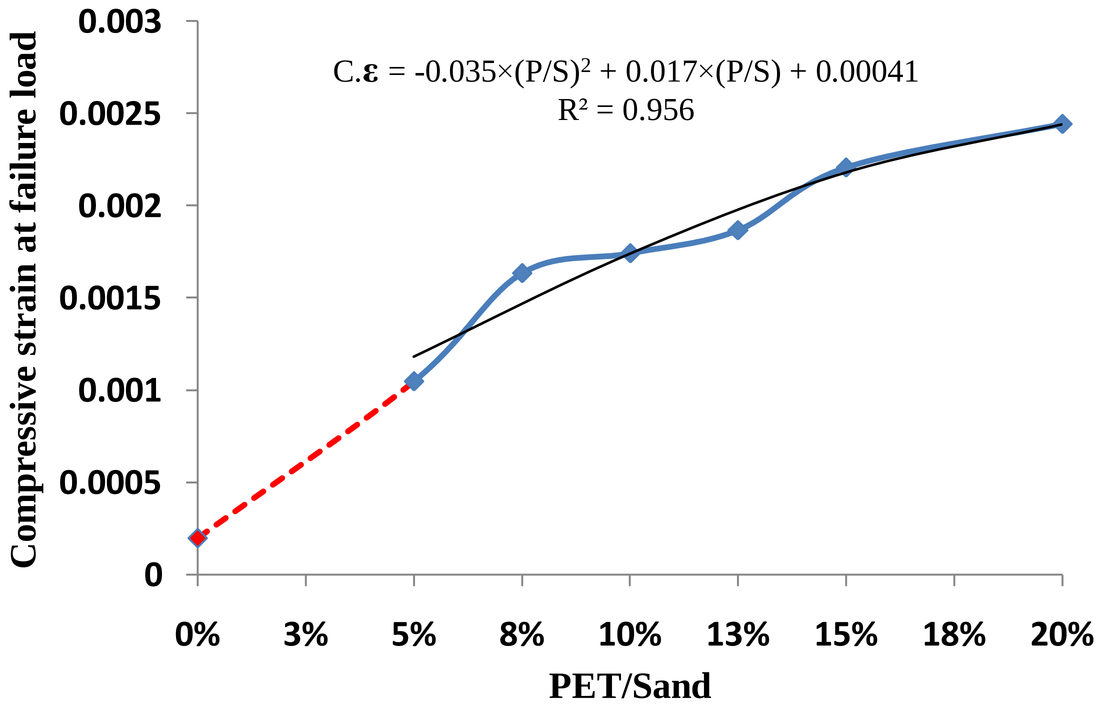


Fig. (4-27): Relation curve of compressive strain to (PET/Sand) percentages for beams specimens

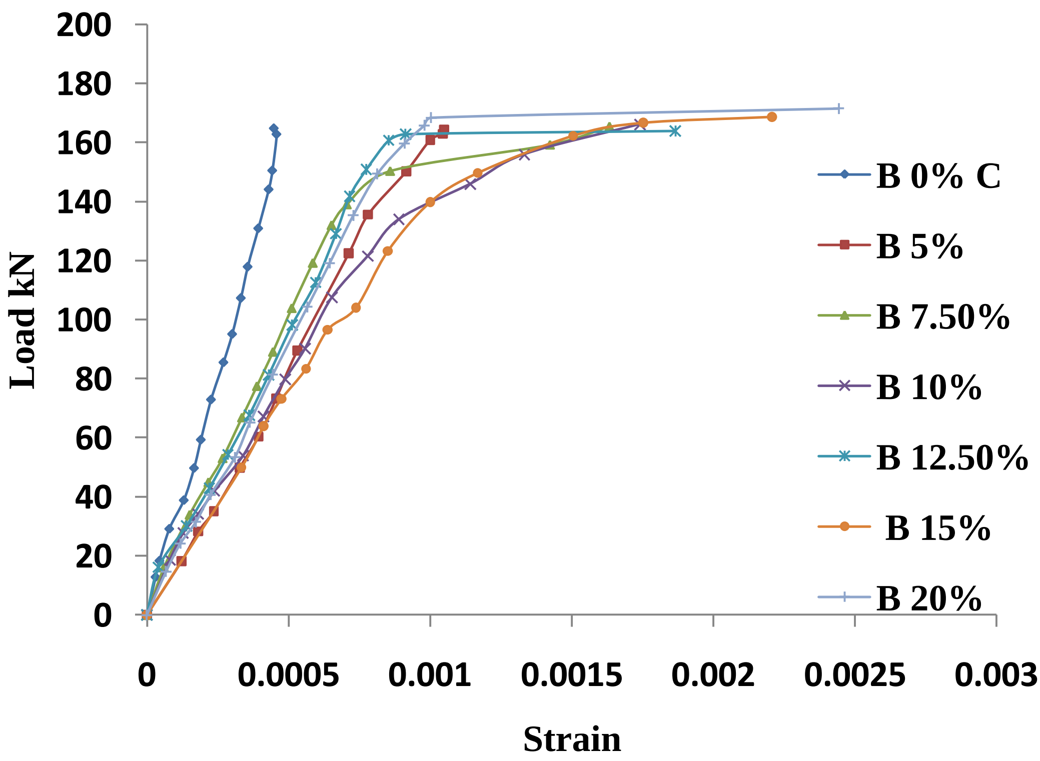


Fig.(4-28): Load to compressive strain relation for beams specimens containing PET as a sand replacement

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4.2.2.5 Stiffness

Initial stiffness and secant stiffness (effective stiffness) was calculated based on the load-deflection curve by dividing the maximum applied load (Pu) either on the yield deflection (Δy) in the case of initial stiffness or on the maximum deflection (Δu) in the case of secant stiffness. The equations used are shown below:

Initial stiffness = Py / Δy

Secant stiffness =Pu/ Δu

Stiffness calculation is carried out according to N. Priestley study [59] as shown in Fig. (4-29). The results that is presented in Table (4-17) show that the initial stiffness of the reference concrete beam B 0%C or the beams with a low content of PET B5% and B 7.5% were closed , namely 35.83, 33.72, and 32.12 kN/mm, respectively. The beams B10%, B12.5%, and B15% are recorded initial stiffness of 30.21, 28.18, and 25.95kN/mm respectively, with a reduction of 15.67%, 21.35%, 27.56% compared to the reference beam .While for the beam B20% it recorded the lowest initial stiffness of 22.05 kN/mm with a reduction of 38.44% compared to the reference beam. Thus it is noticed that the initial stiffness decreases with the increase of PET waste as shown in Fig. (4-30). Secant stiffness decreases with increasing the PET waste content in the concrete beams as shown in Table (4-17) and Fig. (4-31). The reference beam B 0% C is recorded a secant stiffness of 6.33 kN/mm, then, with increasing of PET content in concrete beams, the secant stiffness started to decrease gradually, where the beams B5%, B7.5%, B10%, B12.5%, B15%, and B20% were achieved a secant stiffness of 5.11, 4.86, 4.70, 4.13, 3.49, and 3.39 kN/mm with a reduction ratio of 19.27%, 23.22%, 25.75%, 34.75%, 44.86%, and 46.44% compared to the reference specimen respectively. Generally, the increase of PET waste content in reinforced concrete beams reduces secant stiffness and initial stiffness. This result is consistent with the results of the deflection in the beams, where an inverse relationship between the deflection and the stiffness.

Table (4-17): Initial and Secant stiffness results for beams specimens containing PET as a sand replacemen

Beam remark	PET/ Sand %	Initial stiffness kN/m	Changing in stiffness %	Secant stiffness kN/mm	Changing in Secant stiffness %
B 0% C	0	35.83	0	6.33	0
B 5%	5	33.72	-5.88	5.11	-19.27
B 7.50%	7.50	32.12	-10.36	4.86	-23.22
B 10%	10	30.21	-15.67	4.70	-25.75
B 12.50%	12.50	28.18	-21.35	4.13	-34.75
B 15%	15	25.95	-27.56	3.49	-44.86
B 20%	20	22.05	-38.44	3.39	-46.44

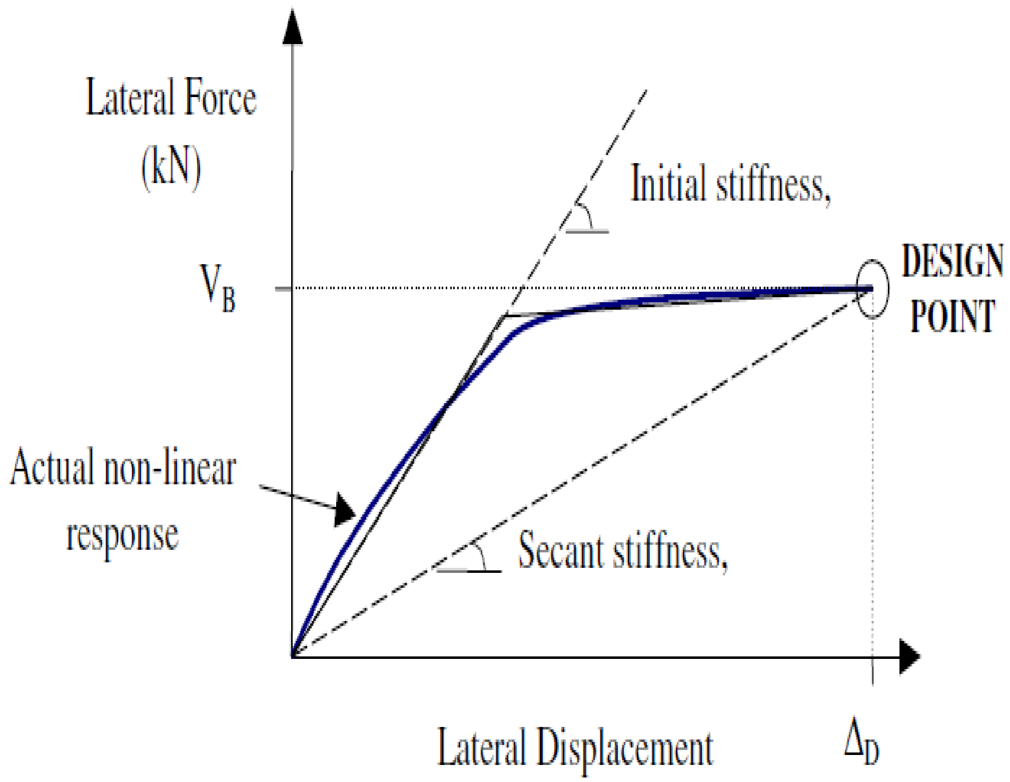

Fig. (4-29):The calculation method of Initial and Secant stiffness [59]

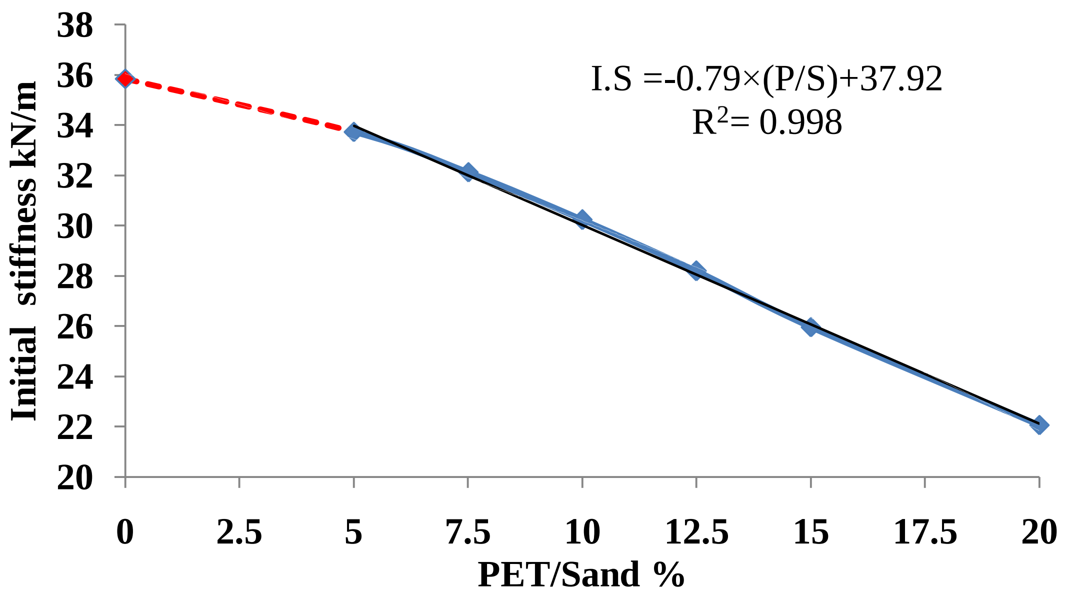

Fig. (4-30): Relation curve of initial stiffness to (PET/Sand) percentage for beams specimens

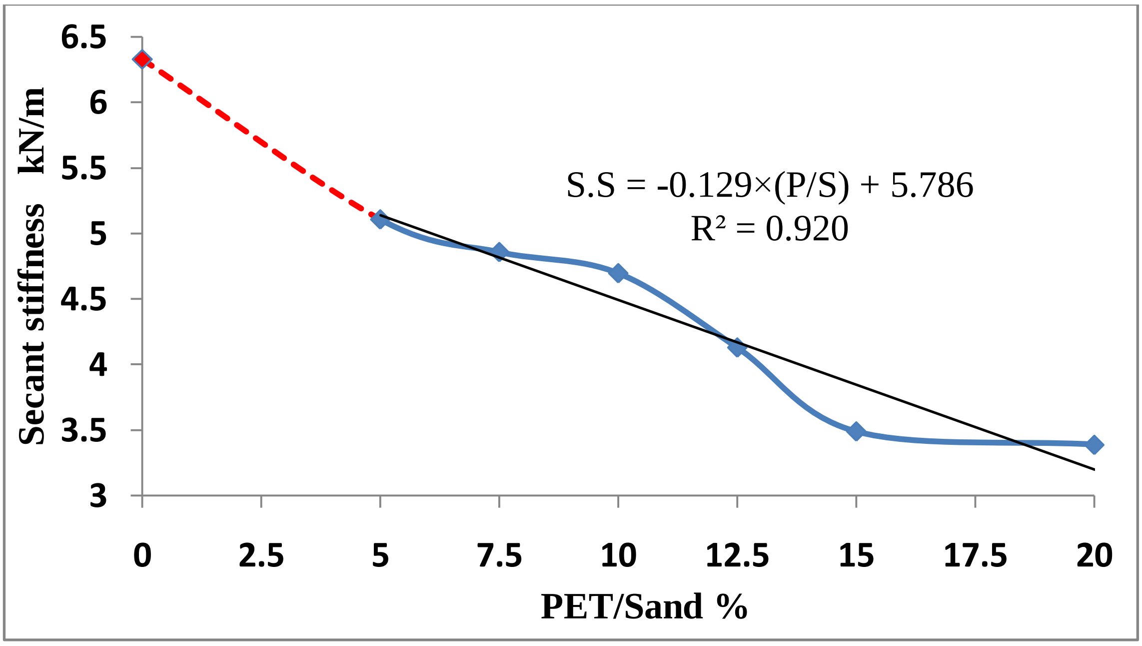

Fig. (4-31): Relation curve of secant stiffness to (PET /Sand) percentages for beams specimens

4.2.2.6 Energy Absorption

The energy absorption or toughness (T) is computed as the area under load-deflection curve. Table (4-18) presented the energy absorption results (toughness) for all concrete beams, which showed a large increase in energy absorption due to the presence of PET waste particles. The reference beam recorded energy absorption of 339.24 kN.mm. The energy absorption increased with increasing the percentage of PET waste, where beams B5%, B7.5%, B10%, B12.5%, B15%, and B20% achieved an energy absorption of 515.06, 578.6, 623, 785.15, 1154.74, and 1273.6 kN.mm, i.e. larger than reference beam by 51.8%, 70.5%, 83.6%, 131.4%, 240.3%, and 275.4% , respectively. The relation between energy absorption and PET waste percentages was showed in Fig. (4-32).

Table (4-18): Energy absorption results for beams specimens containing PET as a sand replacement**.**

Beam remark	PET/ Sand %	Energy Absorption(T) kN.mm	Changing in toughness %
B 0% C	0	339.24	0
B 5%	5	515.06	51.82
B 7.50%	7.5	578.6	70.5
B 10%	10	623	83.6
B 12.50%	12.5	785.15	131.4
B 15%	15	1154.74	240.3
B 20%	20	1273.6	275.4

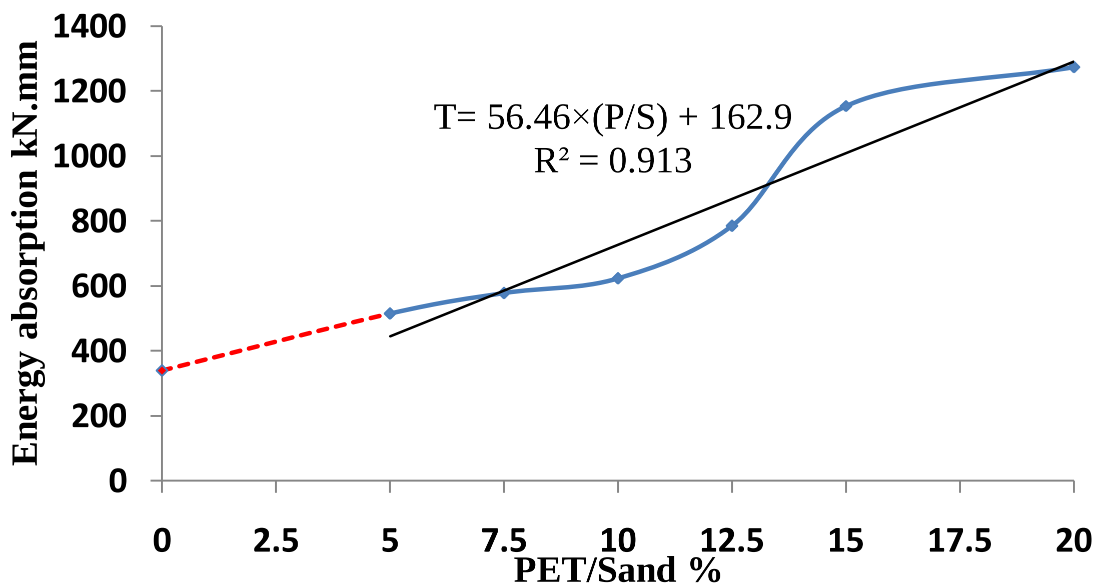

Fig. (4-32): Relation curve of energy absorption to (PET/Sand) percentages for beams specimens

4.2.2.7 Cracking

The crack investigation is accomplished according to the following:

A. First cracking load.

B. Crack pattern.

A. First Cracking Load (P_{cr}) for Concrete Beam

The first crack loads for all concrete beams were recorded and presented in Table (4-19), and Fig. (4-33). Table (4-20) showed that the first crack in the reference beam is appeared at load 18.2 kN, while with the increase of the ratio of PET waste in concrete; the load at which the first crack appears is gradually increased. The first crack of the beam B5% appeared at load 28.3kN with an increase of 53.80% compared to the reference beam, whereas the first crack of the beams B7.5%, B10%, B12.5%, B15%, and B20% appeared at loads 31.8, 34.2, 35.8, 37.9, and 40.7 kN, i.e. larger than reference beam by 72.8%, 85.8%, 94.5%, 105.9%, and 121.19%, respectively.

Table (4-19): First cracking load results for beams specimens containing PET as a sand replacement

Beam remark	P_{cr} (kN))	P_u (kN)	P_{cr}/P_u %	Changing in first cracking load
B0% C	18.4	164.9	11.15	0
B5%	28.3	164.3	17.22	53.80
B7.5%	31.8	165.4	19.22	72.82
B10%	34.2	166.2	20.57	85.86
B12.5%	35.8	163.9	21.84	94.56
B15%	37.9	168.7	22.46	105.97
B20%	40.7	171.5	23.73	121.19

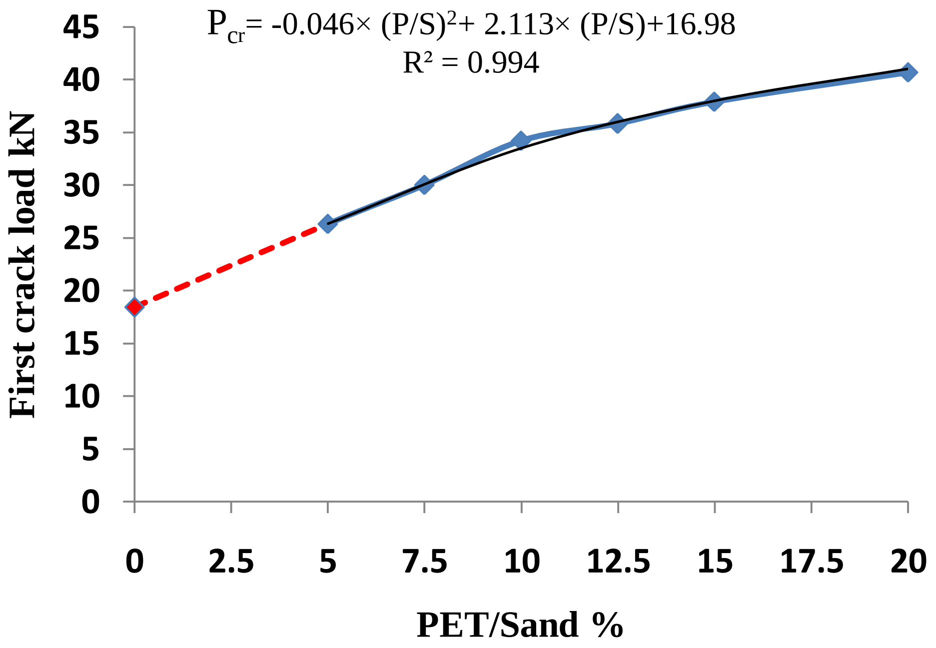

Fig. (4-33): Relation curve of first crack loads to (PET/Sand) percentages for beams specimens

B. Cracks Pattern

The crack patterns for all beams at failure were showed in Fig. (4-35). Also, the first load in which the crack started to appear is shown. The patterns of the cracks in the beams are different and appeared in different shapes. All beams that contained on PET plastic waste with different percentages within the concrete mixture, the cracks appeared at the mid-span in the tension zone and increased until they reached to the compression zone. The lengths of cracks are decreases as the PET content increases in the concrete beams as shown in Table (4-20). The reference beam B 0% C has been recorded the maximum crack length of 272 mm with ratio to the cross section depth of 90.6%. The lengths of cracking began to decrease as the content of PET waste increased in beams. The concrete beams B 5%, B7.5%, B10%, B12.5%, B15%, and B 20% recorded a lengths of 270, 235, 233, 220, 216, and 211mm with ratio of 90%, 78.3%, 77.6%, 73.3%, 72%, and 70.3% compared to the depth of cross section, respectively. These results are identical to the ductility indices, as the increasing of PET content in the concrete beams led decrease in the lengths of cracks. The relations between crack lengths and replacement percentages for all beams are shown in Fig. (4-34).

Table (4-20): Average lengths of crack for different beams containing PET as a sand replacement**.**

Beam remark	Pet/sand	Average lengths of crack mm	Crack length/ section depth
B 0% C	0%	272	90.6 %
B 5%	5%	270	90 %
B 7.5%	7.5%	235	78.3%
B 10%	10%	233	77.6 %
B 12.5%	12.5%	220	73.3%
B 15%	15%	216	72 %
B 20%	20%	211	70.3%

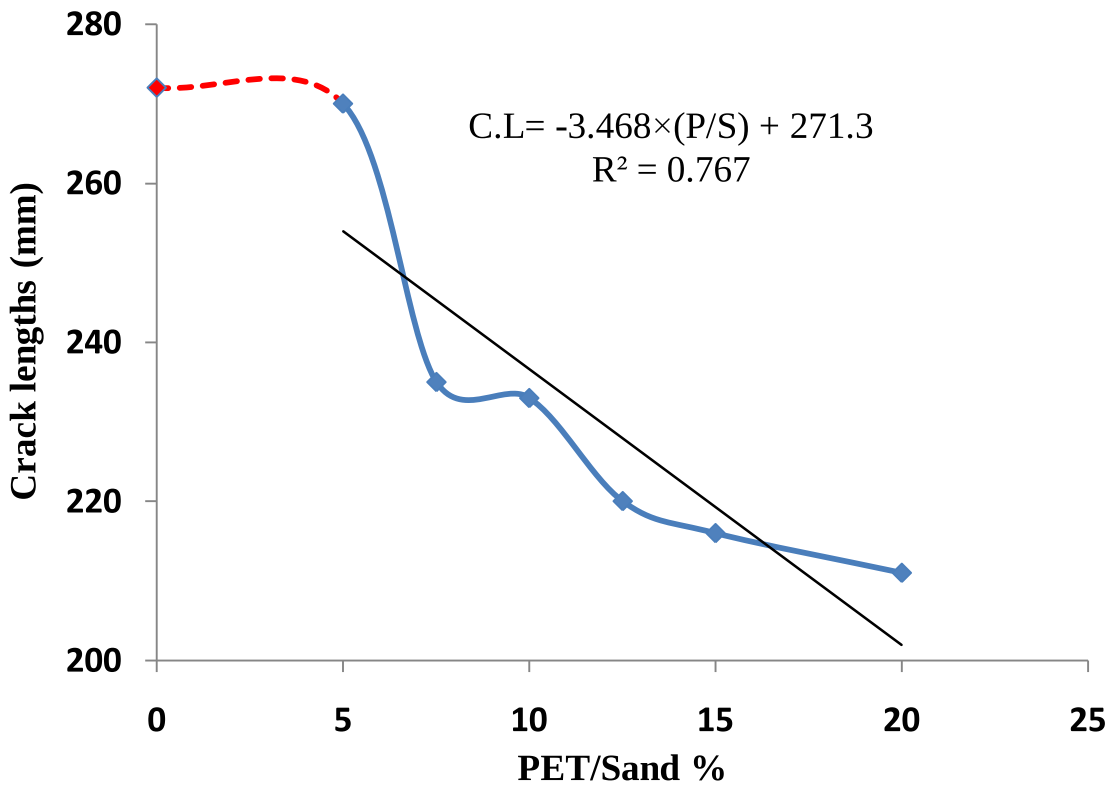

Fig. (4-34): Relation curve of crack length to (PET/Sand) percentages for beams specimens

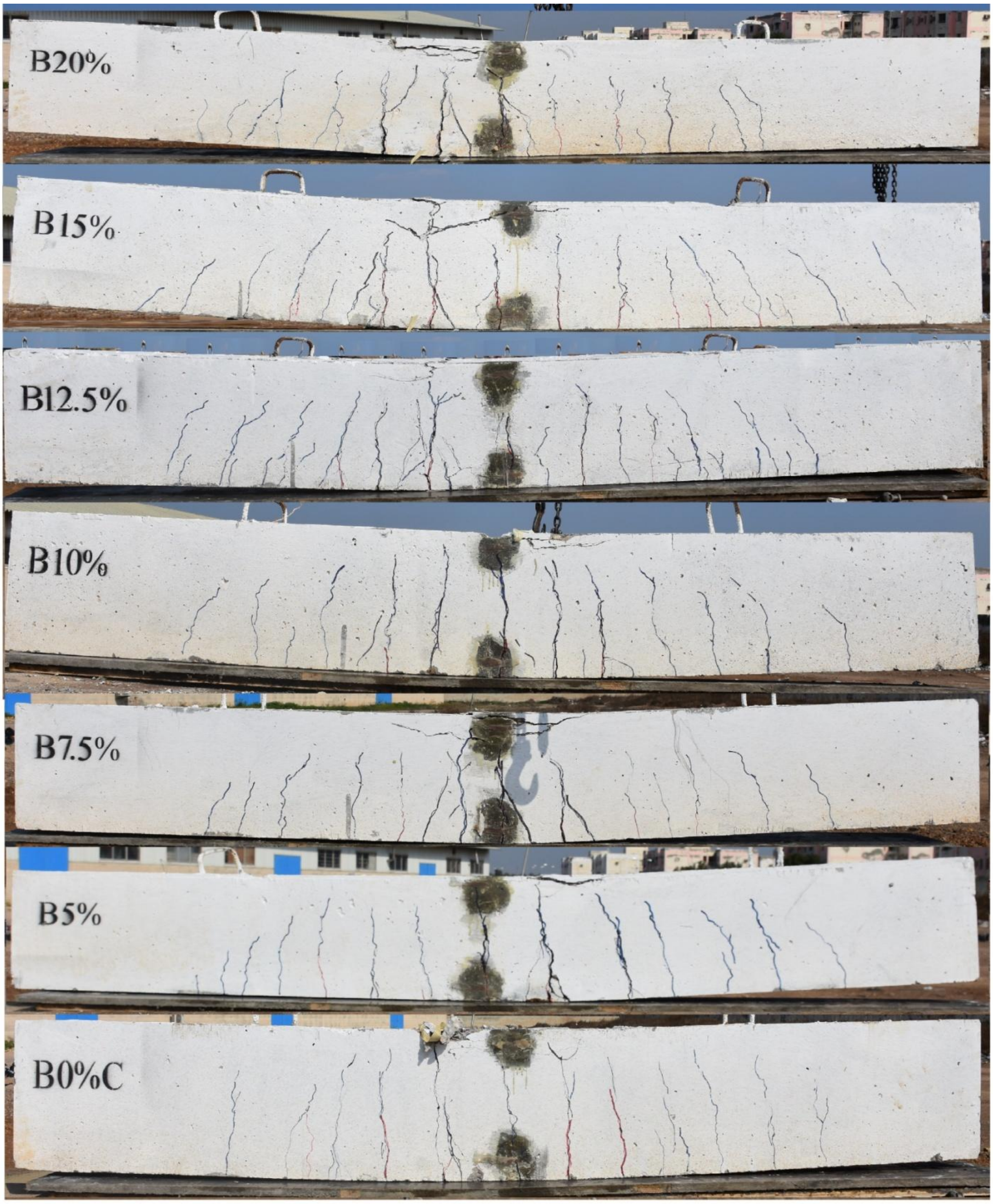

Fig. (4-35): Cracks pattern for beams specimens containing PET as a sand replacement

4.2.3 Part Three: Structural Behavior of Concrete Beams used PET Strips as a Reinforcement Bars

In this part, PET waste bars are used as the main reinforcement in the tension zone. Five concrete beams with dimensions 150 × 200 × 1400 mm were tested in terms of the ultimate load and maximum deflection as shown in Fig. (4-36). Two beams are reference, one with steel reinforcement and the second without any reinforcement (plain concrete beam), and three beams reinforced with PET waste bars in different forms, were tested. The mechanical properties of the used concrete, such as (compression, splitting tensile and flexural strength) were also shown.

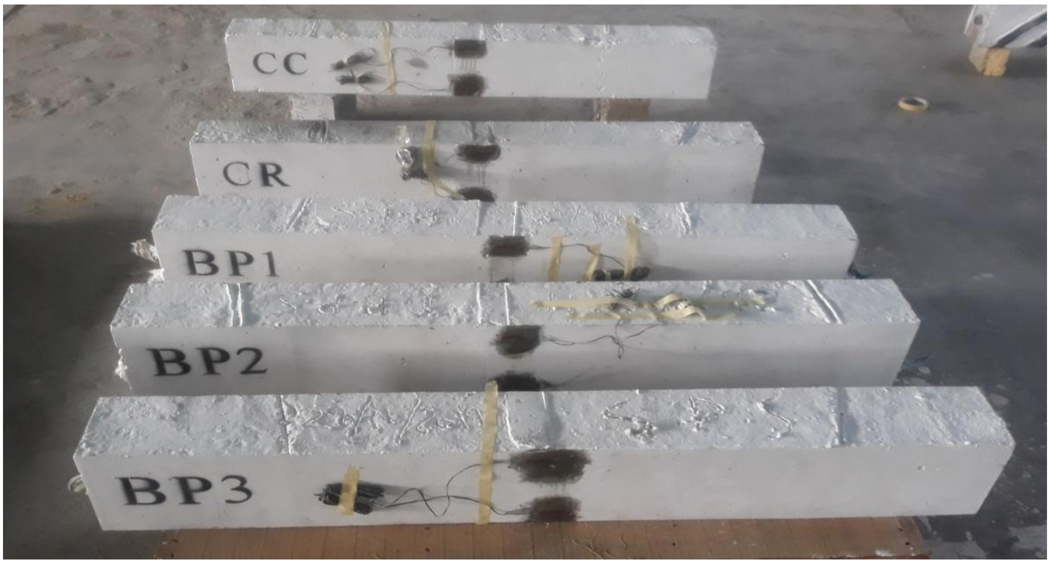

Fig. (4-36): Beams specimens for the part of replacing main reinforcement by PET bars

4.2.3.1 The Mechanical Properties of Concrete

The results of the mechanical tests of concrete are presented in Table (4-21). Compressive strength, splitting tensile strength, and flexural strength at ages 7 and 28 days are tested. At age 28 days, the results showed that the compressive strength is 53.6 MPa, splitting tensile is 3.01 MPa, and the flexural strength is 7.11 MPa. The used rebar is same as that used in the previous parts, which tested for tensile and achieved fy value of 515 MPa for 12 mm diameter and 495 MPa for 10 mm diameter

Table (4-21): Mechanical properties results of the used concrete

Type of test		Age 7 days	Age 28 days
Compression strength	MPa	49.8	53.6
Splitting tensile	MPa	2.63	3.01
Flexural Strength	MPa	6.567	7.11

4.2.3.2 Structural Behavior of Concrete Beams

A. Ultimate Failure Load

Table (4-22) and Fig. (4-37) show the results of the ultimate failure load of all concrete beams. Where the reference reinforced concrete beam RC recorded a maximum failure load of 68.5 kN, while the unreinforced reference concrete beam CC recorded an ultimate failure load of 5.1 kN. As for the concrete beams BP1, BP2, and BP3 which reinforced with PET waste bars, they achieved an ultimate failure load of 15.1, 13.3, and 16.8 kN with ratios of 22%, 19.4%, 24% as a percentage of reinforced concrete beam respectively. The concrete beam PB3 achieved an ultimate load equivalent to a quarter of the reinforcement steel beam ultimate load, while beams BP1 and BP2 achieved an ultimate load equivalent to 22% and 19.5% of the steel reinforced beam load respectively.

Table (4-22): Ultimate load results for beams reinforced with PET bars

Beam I.D.	No. of reading	Ultimate load KN	Percentage with respect to (CR)
CR	15	68.5	100%
CC	2	5.14	7.44%
BP1	8	15.1	22%
BP2	3	13.3	19.4%
BP3	3	16.8	24.5%

It was noticed through the calculations that the moment capacity of the concrete beams BP1 and BP3 were slightly higher than the moment of the section that contains the least limit of the reinforcing steel (P_{min}). This property indicates that it is possible to adopt PET bars to control cracks due to shrinkage stress.

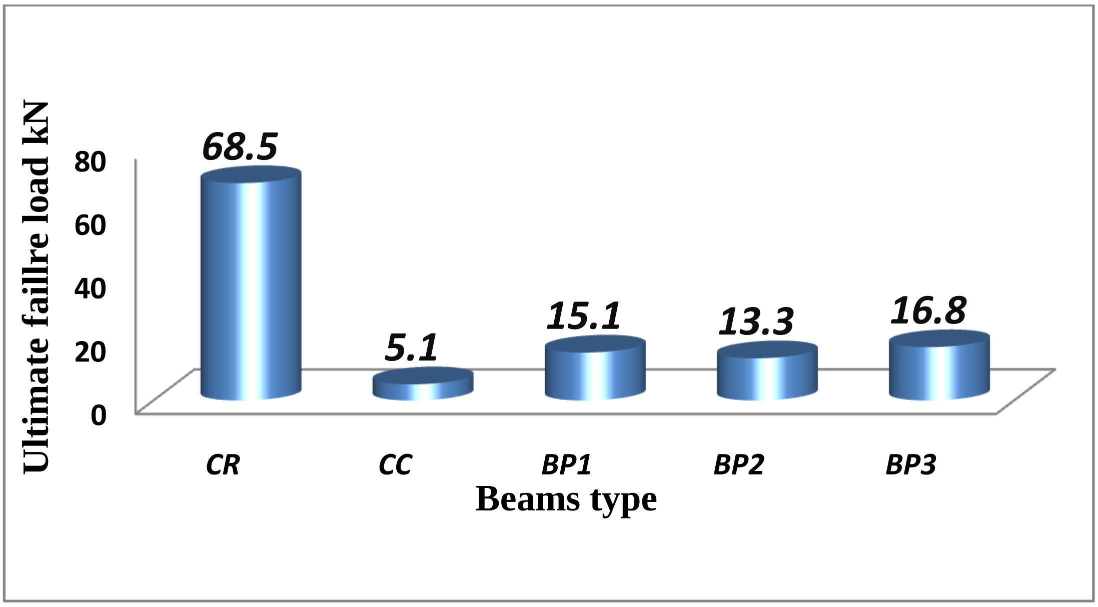

Fig. (4-37): Ultimate failure load for beams reinforced with PET bars

B. Maximum Deflection

The relationship between the maximum deflection and ultimate load (failure load) was as shown in Table (4-23) and Fig. (4-38).The maximum deflection at failure load is occurred to the reinforced concrete reference beam CR with value of 23.5 mm, followed by concrete beams BP1, BP2, BP3, and CC which recorded deflection of 20.2, 0.96, 0.85, and 0.7 mm respectively. It is observed from the results that the concrete beams CC exhibit a brittle behavior compared to other beams. It was also noted that in the case of releasing the load from the concrete beam BP1, there will be a decrease in the reading of the dial gauge of 10 mm and a decrease ratio of 50% as a percentage of failure load deflection.

Table (4-23): Maximum deflection results for beams reinforced with PET bars

Beam remark	Type of reinforcement	Maximum deflection (mm)
CC	Without main reinforcement	0.7
CR	Steel reinforcement	23.52
BP1	PET waste reinforcement	20.2
BP2	PET waste reinforcement	0.96
BP3	PET waste reinforcement	0.84

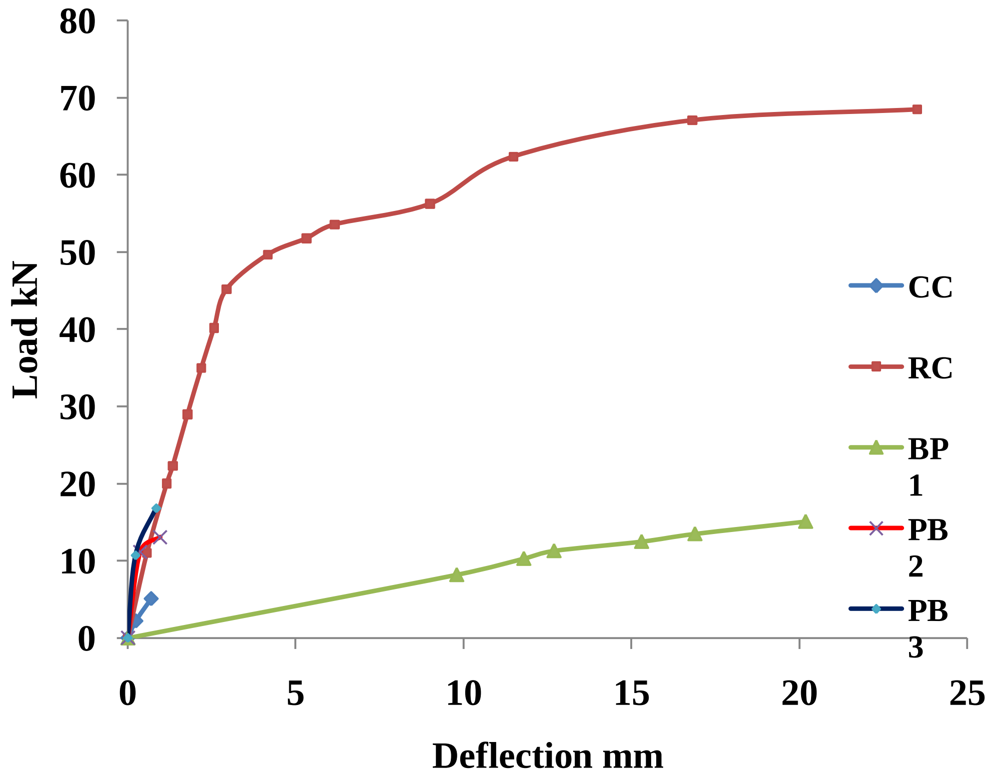

Fig. (4-38): Load - deflection relation for PET –bars reinforced beams

C. Cracks Pattern

All beams have been a compression failure mode except RC beam which has a set of cracks began at tension zone and tend to compression zone as shown in Fig. (4-39).

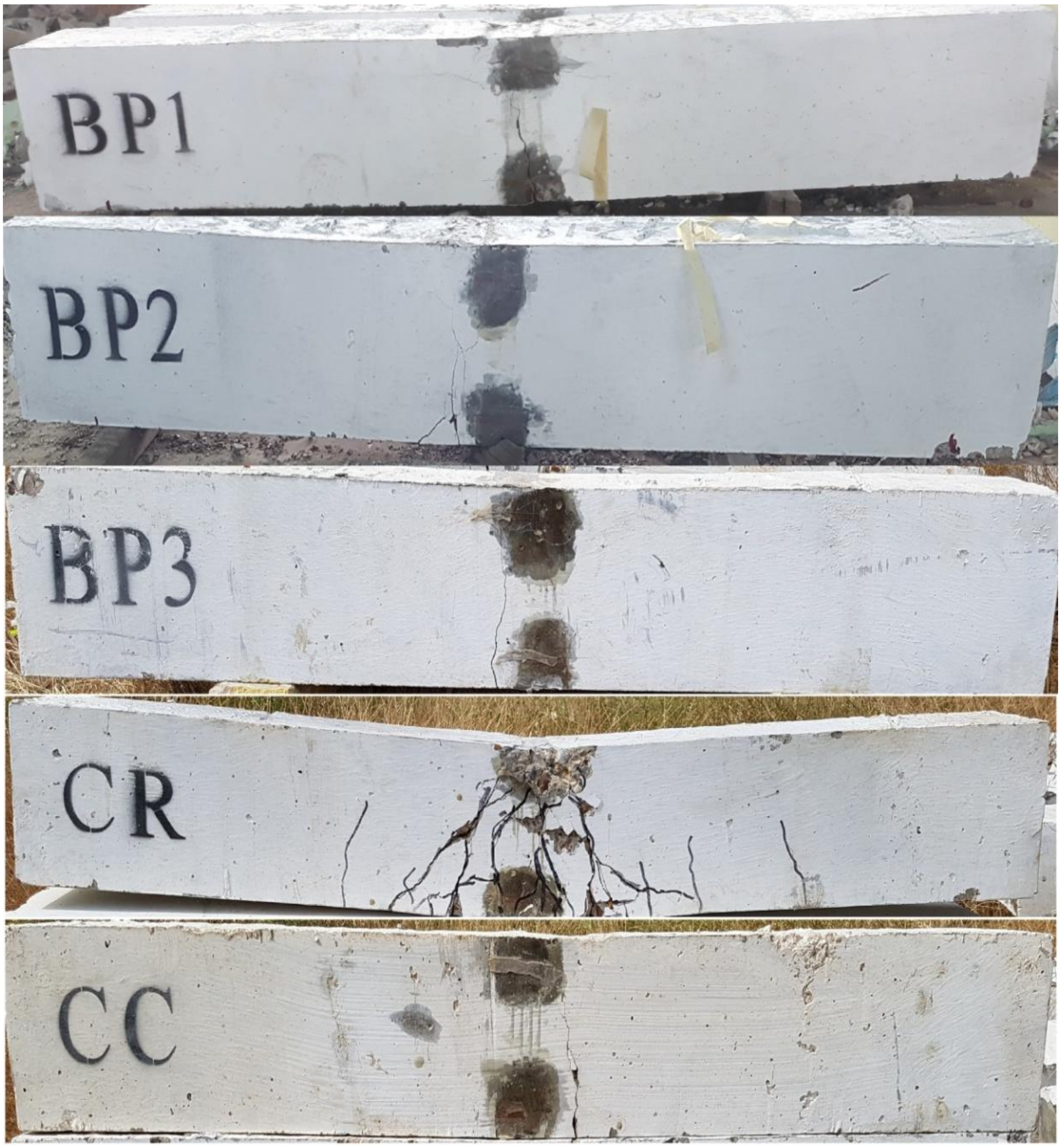

Fig. (4-39): Beams cracks patterns for beams reinforced with PET bars

Table (4-24): Mechanical and Physical Properties results of concrete containing PET as a partial replacement of fine aggregate

Pet/sand %	Slump mm	Compressive Strength MPa	Tensile Strength MPa	Flexural strength MPa	P. shrinkage $*10^{-4}$	Absorption	U.P.V. m/s	Density γ Kg/m^3	Modulus of elasticity GPa	Toughness kN.m	shear stress (MPa	fc'/γ
0	160	34.96	2.41	4.53	-3.5	1.55	3906	2361.4	24.72	1.374	5.08	12.5
5	140	46.86	2.60	5.76	-2.1	1.63	3900	2355.3	24.43	2.062	4.4	16.9
7.5	130	49.7	3.06	5.9	-1.1	1.65	3864	2304.1	23.47	2.746	4.17	18.3
10	120	44.83	2.87	5.72	0.8	1.72	3845	2296.2	23.19	2.860	4.54	16.5
12.5	100	43.46	2.86	5.35	2.2	1.77	3768	2278.5	23.11	2.862	3.76	16.2
15	80	35.56	2.43	4.55	3.04	1.9	3654	2222.1	23.10	2.617	3.39	13.6
20	60	32.76	2.32	4.35	3.25	2.41	3397	2193.5	22.15	2.614	2.44	12.6

Table (4-25): Structural Behavior results of Concrete Beams containing PET as a partial replacement of fine aggregate

Beam I.D	Ultimate load kN	Maximum deflection Δu (mm)	*Ductility index*	Compressive Strain	Initial stiffness kN/m	Secant stiffness kN/mm	Energy absorption kN.mm	First crack loads(kN)
B 0%R	164.9	26.05	2.89	0.000197	35.83	6.33	339.24	18.4
B 5%	164.3	32.1	3.21	0.001049	33.72	5.11	515.06	28.3
B 7.5%	165.4	34.1	3.78	0.001634	32.12	4.86	578.6	31.8
B 10%	166.2	35.3	3.83	0.001742	30.21	4.70	623	34.2
B 12.5%	163.9	39.63	4.40	0.001866	28.18	4.13	785.15	35.8
B 15%	168.7	48.22	5.18	0.002208	35.56	3.49	1154.74	37.9
B 20%	171.5	50.47	5.47	0.002443	32.76	3.39	1273.6	40.7

CHAPTER FIVE

CONCLUSIONS

AND

RECOMENDATIONS

Chapter Five

Conclusions and Recommendations

5.1 General

In this chapter, the main conclusions from experimental work are presented. Based on the type of results, the conclusions are divided into three themes:

1. Mechanical and physical properties of concrete containing PET waste as a partial substitute of sand.
2. Structural behavior of steel reinforced concrete beams containing PET waste particles as a partial replacement of sand.
3. Structural behavior of concrete beams reinforced with PET waste bars as the tension reinforcement.

5.2 Conclusions

5.2.1 Physical and Mechanical Properties

The experimental program of evaluation of the physical and mechanical properties of concrete containing PET waste as a partial substitute for sand was yielded the following conclusions

1-The workability decreases as the percentage of PET waste in the concrete mixture increases at constant w/c. The reference mixture recorded the highest workability, while the PET percentages 5%,10%, and 20% were recorded a reduction of 12.5% ,25%, and 62% compared to reference mixture respectively

2-The compressive strength, splitting tensile strength and flexural strength, are increased as the PET percentages as a sand replacement in concrete increased up to 15% with optimum replacement percentages 7.5%. While the 20% PET percentage showed reduction in compressive, tensile, and flexural strength by (5.3%, 3.7%, and 3.97%) compared to the reference specimens.

3- Expansion in concrete is decreased as the replacement percentage of PET increased. Reference specimens recorded the highest expansion, while the replacement percentages 20% showed an expansion reduction of 74.7% compared to reference specimens respectively. Shrinkage in concrete is decreases by increasing the PET replacement percentage up to 7.5%. Reference specimens were recorded a highest shrinkage rate while the lowest shrinkage rate was at the PET replacement percentage of 7.5%. Beyond 7.5% percentage, the specimens began to expand despite drying with amount increases with the increase of the replacement rate.

4-The density and ultrasonic pulse velocity of concrete are decreases while the absorption increased when PET replacement percentage increased. Reference specimens recorded a highest density and pulse velocity and lowest absorption rate. This is an indication of the consistency of the results, as the pulse velocity decreases with the decrease in the density and thus the voids increases, which increases the absorption rate.

5-The shear strength decreased with increasing in the percentage of PET in the concrete specimens. The reference specimens recorded the highest shear strength, while the PET percentages 20% showed the lowest reduction in shear strength by 51.96% compared to reference specimens respectively.

6- The axial strain increased and modulus of elasticity decreased as the PET replacement percentage increased. The PET percentages 20% yielded highest axial strain increment of 76.7% compared to reference specimens , while it recorded an elastic modulus less than reference specimens by 22.48%.

7- The energy absorption increase as PET content in concrete increased, but with varying proportions, The PET percentages 10% and 12.5% showed the optimum absorbed energy, higher than reference specimens by 108.28% respectively.

8- The failure mode in the various tested specimens showed that the reference specimens were completely destroyed and divided into parts, while the specimens that containing PET replacement percentages particles showed stability in the shape and the failure was limited to the small cracks appearance whose numbers and lengths decreased as the percentage of replacement increased.

5.2.2 Structural Behavior of Steel Reinforced Concrete Beams

Structural behavior of steel reinforced concrete beams containing PET waste particles as a partial replacement to sand was studied via seven reinforced concrete specimens and the following conclusions were obtained

1-The ultimate failure load of all concrete beams with or without PET were closed. The beams B5%, B7.5%, B10%, and B12.5% were closed to control beam while beams 15% and 20% recorded a failure load increment of 2.3% and 4.0% compared to reference specimens respectively.

2-The deflection and ductility index were increased as the percentage of PET waste in the reinforced concrete beams increased, where the beam B20% recorded a maximum deflection and ductility index increments of 97% and 91.37 compared to control beam respectively.

3-The compression strain at failure load and energy absorption were clearly increased with increasing of PET replacement percentages in the reinforced concrete beams. The beam B20% yielded an axial strains and energy absorption increments greater than control beam by 1140% and 275.4%) respectively.

4-The initial stiffness and secant stiffness are decreased with increasing of PET content in concrete beams, where the beam B20% achieved lowest initial and secant stiffness with reduction of 38.4 % and 46.44% compared to the reference specimen respectively.

5- The load at which the first crack is appeared was increased gradually with the increasing of PET content in concrete beams, where the beam B20% recorded highest load at which first crack were appeared with increment of 121.19% compared to the reference beam.

6- The lengths of cracks decrease slightly, as the PET content increases in the concrete beams. It's observed that cracks tend to be less in lengths when PET percentage increased.

5.2.3 Structural Behavior of Concrete Beams Reinforced with PET Waste Bars as Tension Reinforcement

1-The concrete beams reinforced with PET bars BP1, BP2, and BP3 were achieved an ultimate failure load less than that of control specimen of reinforced concrete beam RC by 22%, 19.4%, and 24.5% respectively.

2- The maximum deflection of the five concrete beams was varied. The highest deflection was demonstrated at the steel-reinforced concrete beams RC while the lowest was deflection for beams CC, BP2, and BP3 which was closed. The concrete beam BP1 was close to the steel reinforced reference beam, but it is reduced by 50% when the load was released.

5.3 Recommendations

The following recommendations are suggested for future studies.

1- Due to good participation of PET waste when it used as a partial replacement of sand in improve concrete characteristics and structural behavior of beams, so it's strongly recommended to investigate its impact on the behavior of other structural members like slabs and of concrete filled steel tubes CFST under biaxial bending and uniaxial bending.
2- As a result of PET impact on increasing the ductility of concrete, we recommend studying the effect of its use in different proportions with steel fibers on the production of concrete with high or ultra strength and evaluating that effect from several sides.
3- Study the effect of PET waste used as sand replacement on R.C. beams under impact, cyclic and dynamic loadings.
4- Study the behavior of hybrid reinforced concrete beams included large percentages of PET as sand replacement in tension zone.
5- Study the behavior of concrete slab reinforced with PET bars to resist shrinkage and temperature stresses.
6- Study quality control, compaction mechanism, and workability improving for concrete containing PET waste as a partial sand replacement.

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جامعة ميسان / كلية الهندسة
قسم الهندسة المدنية

خصائص الخرسانة المتضمنة نفايات تريفثالات البولي اثلين وتأثيرها على التصرف الإنشائي للعتبات الخرسانية المسلحة

أطروحة
مقدمة إلى كلية الهندسة جامعة ميسان كجزء من متطلبات الحصول على درجة الماجستير في علوم الهندسة المدنية / الإنشاءات

من قبل

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الملخص

في هذه الدراسة تم التحري عن تأثير استخدام نفايات البولي إيثيلين تيريفثاليت (PET) كبديل جزئي للرمل الطبيعي لدراسة الخواص الميكانيكية والفيزيائية للخرسانة بجانب تأثيرها على السلوك الإنشائي للعتبات الخرسانية الكاملة. تم تقسيم الدراسة الحالية إلى ثلاثة أجزاء. يتناول الجزء الأول تأثير الاستبدال الجزئي للرمل بجزيئات مخلفات PET على الخواص الميكانيكية والفيزيائية للخرسانة ، حيث تم استخدام ستة نسب استبدال في هذه الدراسة 5٪ ، 7.5٪ ، 10٪ ، 12.5٪ ، 15٪ ، 20٪ . تم إجراء الفحوصات الميكانيكية للخرسانة بأعمار 7 و 14 و 28 يومًا وتشمل فحوصات الانضغاط والانشطار والانثناء ومعامل المرونة والمتانة ، بالإضافة إلى الاختبارات الفيزيائية كالكثافة والتغيير ألحجمي وانكماش البلاستيك والسرعة فوق الصوتية والامتصاص ، كما تم فحص مقاومة القص للخرسانة في هذا الجزء. أظهرت النتائج أن العينات المحتوية على نسب إحلال جزئي تتراوح بين (5٪ - 12.5٪) أظهرت زيادة تتراوح بين (18.1٪ -30.2٪)، (18.6٪ -26.9٪)، (26.8٪ -43.64٪) في مقاومة الانضغاط والشد والانثناء على التوالي ، مقارنة مع العينات المرجعية. وكانت نسبة الاستبدال الأمثل لجزيئاتPET هي 7.5٪ وتنخفض الخواص الميكانيكية عندما يتجاوز محتوىPET نسبة 15٪ كبديل عن الركام الناعم . كما أظهرت النتائج زيادة في الصلابة وانخفاض معامل المرونة وقوة القص والانكماش مع زيادة محتوى PET في الخرسانة بشكل عام.

يتناول الجزء الثاني تأثير استخدام نفايات PET كبديل جزئي للركام الناعم على السلوك الإنشائي للعتبات الخرسانة المسلحة. تم فحص ستة عتبات خرسانية بتفصيل تسليح متماثل و بإبعاد 150 * 300 * 2300 مم بواقع عتبة واحدة لكل نسبة PET، بالإضافة إلى العتبة الخرسانية المرجعية. تم اختبار الحزم من خلال الحمل الاقصى للفشل ، والهطول النهائي ، وامتصاص الطاقة ، والصلابة ، ومؤشر الليونة ، والانفعال. كما تم دراسة التشققات والتي تشمل حمل الشق الأول ونمط التصدع ، ثم مقارنتها مع العتبة المرجعية لتقييم تأثير نفايات PET على سلوكها الإنشائي. أظهرت النتائج أن زيادة محتوى نفايات البولي إيثيلين تيرفثالات في العتبات الخرسانية أدى إلى زيادة الحمل الأقصى للفشل ، والهطول النهائي ، ومؤشر الليونة ، والانفعال ، وامتصاص الطاقة بمعدل يتراوح بين(0٪ - 4٪) ،(23.2٪ - 93.7٪) ، (12.13٪ -93٪) ،(432٪ -1139٪)، (51٪ -275٪) على التوالي. بينما لوحظ انخفاض في الصلابة الابتدائية والثانوية بمعدلات تتراوح بين (5٪ -38٪)و(19.2٪ -46.4٪) على التوالي.

يتناول الجزء الثالث تأثير استخدام نفايات زجاجات PET كقضبان تقوية في العتبات الخرسانية. تم إعادة تشكيل نفايات زجاجات PET كشرائط طويلة تستخدم في تشكيل قضبان PET, ثم تستخدم قضبان PET المشدودة كبديل للقضبان الفولاذية في منطقة الشد. وقد استخدم في هذا الجزء خمسة عتبات خرسانية بأبعاد (150 * 200 * 1400) ملم ، اثنان منها عبارة عن عوارض تحكم مع حديد التسليح وبدون حديد تسليح ، وتم تقوية العوارض الثلاثة الأخرى بثلاثة أشكال مختلفة من قضبان PET المشدودة. حققت إحدى العتبات المسلحة بقضبان PET حمل فشل أقصى يصل إلى 25٪ من حمل الفشل للعينات التي تحتوي على قضبان فولاذية.