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FLEXURE BEHAVIOUR AND PROPERTIES OF REINFORCED CONCRETE BEAMS USING RECYCLED PLASTIC WASTES

A THESIS
SUBMITTED TO THE COLLEGE OF ENGINEERING OF MISAN UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL ENGINEERING
(STRUCTURES)

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بسم الله الرحمن الرحيم

قَالَ تَعَالَىٰ: ﴿وَيَسۡـَٔلُونَكَ عَنِ ٱلرُّوحِۖ قُلِ ٱلرُّوحُ مِنۡ
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الإسراء: ٨٥

صدق الله العظيم

Dedication

I dedicate this work to…

My Parents

For their help, moral, encouragement,
and material support

My brother

For helping me in my research

My Friends

For their encouragement

My Colleagues

for their help practically

Certification of the supervisor

*I certify that this thesis entitled "**Flexure Behaviour and Properties of Reinforced Concrete Beams Using Recycled Plastic Wastes**", which is being submitted by **Hamsa Mahir Adnan**, was made under my supervision at University of Misan/College of Engineering, in partial fulfillment of the requirements for the Degree of Master of Science in Civil Engineering (Structures).*

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*We certify that we have read this thesis entitled "**Flexure Behaviour and Properties of Reinforced Concrete Beams Using Recycled Plastic Wastes**", and as an Examining Committee, we examined the student (**Hamsa Mahir Adnan**) in its content and in what is connected with it and that in our opinion it meets standard of a thesis for the degree of Master of Science in Civil Engineering (Structures).*

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Abstract

The problem of accumulation plastic waste can be reduced by recycling concept, and one of the possible ways of recycling these wastes is using them in concrete construction. This research aims to study the possibility of re-using the plastic wastes such as Polyvinyl chloride (PVC) and Plastic boxes for producing fine aggregate as partial replacement of sand within the concrete mixture in addition to re-using Polyethylene terephthalate (PET) as a fiber within the concrete mixture. Then, the behavior of simply supported concrete beams included different percentages of these wastes within the concrete mixture or reinforced with PET bars in different patterns are investigated via influenced of these wastes on the strengths and serviceability of concrete beams. Nineteen beams with dimensions of (150*200*1400) mm were cast and tested. Experimental tests were carried out to evaluate the mechanical properties of mixtures that contain these waste materials and compared with that of the control mixture. PVC particles is used in the mixture with replacing percentages of (0%,1.25%,2.5%,3.75%, and 5%) from weight of sand, while Plastic boxes used with replacing percentages of (0%,2.5%,5%, and10%) from weight of sand, and PET fiber added by volume of mixture with percentages of (0%,1.5%, and 3%).The evaluated mechanical properties included compressive strength, split tensile strength and flexural strength. The results showed that the mixture which contains 1.25 % of PVC, 5% of Plastic boxes, and 1.5 % of PET fiber with two shapes are the best percentages for using this waste within the concrete mixture, where it gave strengths higher than the strength of reference mixture.

The tests variables of reinforced concrete beams included ultimate load, deflection, ductility, and crack patterns. Testing of concrete beams showed a

decreasing in the ultimate load for all beams which contain on PET bars as tension reinforcement. The reductions in ultimate load were (63.63% - 84.84%), but all these beams increase the ductility. While the beams with 1.25% PVC plastic waste and 5% plastic boxes waste as a sand replacement show higher ultimate failure load than the reference beam by about 6.06% and 1.81%, respectively and the increase in ductility by about 8.27% and 124.14%, respectively. While the beams with percentages of 1.5% PET fiber by volume of the mixture, the little decrease in load was 9.09% and 12.12%, respectively and increasing the ductility by about 22.4% and 28.27%, respectively. The beams which have the hybrid section of the concrete beam with 1.25% PVC plastic wastes and 5% plastic boxes wastes as sand replacement in compression zone and 10% sand replacement for both PVC and plastic boxes in tension zone show a relatively small reduction in ultimate load by 14.5 % and 10.3 %, respectively but these beams increase the ductility by about 95.17% and 140.7%. While for the beam which has 1.5% and 3% of PET fiber in compression and tension zones, respectively, show a reduction in the ultimate load of 14.5% and increase in ductility by about 45.17%. Thus, the best hybrid section was the beam with plastic boxes waste in which only about 10.3% reduction in ultimate load and this beam gave the higher ductility about 140.17%.

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List of Abbreviations and Symbols

ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British standard
CFRP	Carbon Fiber Reinforced Plastic
E-plastic waste	Electronic plastic waste
f_{cu}	Cube Compressive Strength in MPa
f_r	Modulus of rupture in MPa
HDPE	High-density polyethylene
LDPE	Low-density polyethylene
MPW	Metalized plastic waste
PBWF	Plastic Bag Waste Fibers
PE	Polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PVC	Polyvinyl chloride
SP	Superplasticizer
w/c	Water to cement ratio

Chapter One
Introduction

CHAPTER ONE

INTRODUCTION

1.1: GENERAL

Concrete is a composite material composed of coarse aggregate bonded together with a cement mortar which hardens over time. It’s an artificial stone made of sand, gravel, water, and cement.

Plastic wastes are the main environmental problem facing worldwide in general and Maysan province in particular nowadays, which was exposed to the elements of the environment such as soil, water, and air pollution, and consequently lead to the depletion of natural resources, as well as absence the correct ways for collection, transmission and processing of the plastic waste. The weakness of the environmental awareness of the citizens in the minimize of this phenomenon, due to population increases and the development of polluting industries led to complicate this problem [1].

Amara city is the administrative center of Maysan province. It’s located in the south-eastern part of Iraq at about 400 km south of Baghdad. Amara area is about 55.2 km^2 which represent approximately 0.3% of the whole Maysan province area and 0.01% of Iraq area [1]. The population of Amara is 515014 Capita according to the estimation of the Ministry of planning for 2016.

The amount of waste is depended on the population size, and it's proportional to the population growth. The problem of solid waste is related to population size, cultured level, population concentration, social characteristics, and economic characteristics. With technology progress and the increasing living requirement for modern life led to an increase and complicated the disposal material process, which negative effect on the people themselves and the environment [1].

For Amara city, the rate of population growth is listed in Table (1-1) below, which based on forecasting data of (1977 -2016). It is noted that there is a big difference between growth rates. The growth rate during the period (1977-1987) is 6.2% as the natural growth rates in Iraq, while the period (1987-1997) the decrease in the rate of growth to 3.3% due to the deterioration of the economic conditions of the country, while in the interval (1997-2016), a rise in natural growth rates, attributed the growth to 3.4% as a result of the relative improvement of the situation of living of people [1] as shown in Table (1-1) and Fig. (1-1) Below:-

Table (1-1): Number of Population and Population growth rate for the city of Amara for the duration (1977-2016) [1]

Years	*City Population(people)*	*Growth rate*
1977	106348	-
1987	195014	6.2
1997	272286	3.3
2016	515041	3.4

1.2: STATEMENT OF THE PROBLEM

The problem of plastic waste is a global problem and is not confined to a particular country without another, but for all the countries of the world, with different degrees of seriousness. The developed countries have been able to reduce many of the indirect environmental impacts affecting the lives of citizens every day than third world countries. The cities of Iraq, including the province of Misan, manifest the accumulation of solid waste in the huge random phenomenon. It is filling the roads, streets, and squares in nearby residential neighborhoods, or inside, and often reflect the scenes of uncivilized and therefore became the perfect location for the random wastes led to the negative impact to public health and the environment [1], as shown in Fig. (1-2).

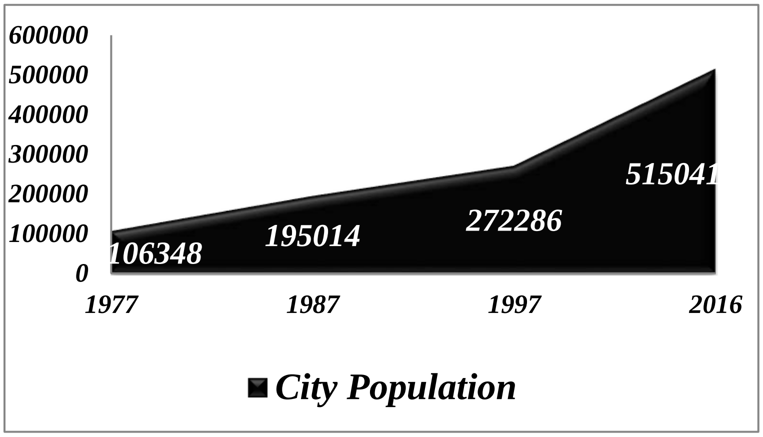


Fig. (1-1): Population growth of Amara city through (1977-2016) [1].

Fig. (1-2): Random accumulation of waste

People deal with plastic waste with many disregards, and this is mainly due to lack the knowing of their risks to the environment and animals, and the very light weight of this plastic wastes enable them to quickly spread in different forms which convert them to relatively heavyweight [2].

The use of potable water is increasingly widespread in various sizes of plastic bottles. Consequently, huge amounts of this product are dumped in waste containers. Unfortunately, there are large amounts thrown in the streets, open areas, parks, forests, and rivers, from which reach to the seas [2].

The plastic is the most dangerous component of household waste for the following reasons;

1. Plastic is a non-biodegradable material and therefore may need plastic for hundreds of years before it decomposes completely.
2. Plastic waste is considered to be one of the lightest components of household waste, in addition to its fragmentation and breakage, which allows it to spread over vast distances away from the place where it was dumped by wind and water to very distant places
3. The plastic carries the effects of the materials that were packed in it and thus contributed to the spread of pollutants
4. The result of its fragmentation and fracture may turn into small pieces of marine and terrestrial organisms. Marine animals, especially birds, are most affected by plastic waste. Plastic waste kills 1,000,000 annual birds and 100,000 mammals per year.

The wrong procedures for the management of solid waste will lead to many problems includes accumulations of waste in the streets, public areas, and inside residual compounds, in which most Iraqi regions including Maysan province suffer from this problem as shown in Fig. (1-3). Thus, the development of an integrated waste management system is necessary to minimize the impact of these wastes on both people and the environment [1].

Fig. (1-3): Random accumulation of waste in Maysan province.

1.3: PLASTIC WASTE

Plastic has become everywhere around humanity. Whether used to store food scraps, save hospital equipment, or isolate homes, plastics are incomparable in their adaptability, endurance, and low costs. Given its seemingly limitless benefits, it is not surprising that plastics replace traditional materials in many sectors, for example, steel in automobiles, paper, and glass in packaging, and wood in furniture. As a result, the annual consumption of plastic has increased from 5 million tons in the 1950s to 280 million tons today [2].

Rapid population growth, urbanization, and industrial growth have led to the severe problem of waste generation in urban centers.

The waste quantities increased from 46 million ton in 2001 to 65 million ton in 2010 and said that per capita day production would increase to 0.7 kg in 2050. The characteristics of waste depend on various factors such as food habits, traditions, lifestyle, climate, etc. [2].

Almost half plastic products are designed for use once in short-term applications (less than six months) before disposal. Because most of these items are non-biodegradable or recyclable, plastic waste accumulates in a manner that has serious environmental consequences. Although governments have begun to impose new (and often rigid) regulatory restrictions on plastic waste management, for example, China banned light plastic shopping bags in 2008, but these restrictions are insufficient to address the growing plastic waste problem worldwide [2].

Moreover, most plastic products are made from so-called "thermoplastics manufactured from petroleum materials." Because a non-renewable resource forms the basis for the manufacture of many plastic products, most of which will not last for long, current plastic usage patterns are unsustainable [2].

There is a relationship between population capacity and weights of the annual solid waste have been developed to calculate the amount of waste generated by each person. According to the estimations of the Ministry of Planning and the Ministry of Municipalities and Public Works, the number of inhabitants of the Maysan province for 2016 was (515041 Capita) as previously mentioned for the amount of waste amounted to 234987 tons annually at a rate of product per person (456 kg /year). The relationship between population and weight of solid waste is presented in Table (1-2), according to estimations of Ministry of planning, in which the highest production of solid waste is recorded in 2011[1]. Solid waste in the Maysan province, one of the daily challenges facing the officials and workers in the municipality organization in which the daily collection of solid waste is 450 tons at a rate of 0.873 kg/person/day [1].

Table (1-2): The Relationship between the Number of Population and Annual Solid Waste Weights for the City of Amara [1]

Years	*City Population(people)*	*Quantity/Ton/Year*	*Average per capita/Kg/Year*
2010	440069	142956	325
2011	451569	346128	766
2012	464828	50899	109
2013	478437	139704	292
2014	492400	215671	432
2015	50444	228784	456
2016	515041	234987	456

Solid waste in Maysan province is consists of domestic waste, commercial, industrial, agricultural, medical and construction and demolition waste as well as plastic waste. Solid waste is divided by percent in the study area to 71% different types of waste and biodegradable materials and non-biodegradable wastes, debris at a rate of 25.9%, and scrap residues 3.1% [1] as shown in Fig. (1-4).

Solid wastes consist mainly of biodegradable with a percentage of 83% and non- biodegradable organic materials such as plastics, paper, and glass. Non-biodegradable materials are harmful to health and the environment because they require hundreds of years to decompose. The present study focused on reuse the plastic waste in the construction process in order to reduce the impact of this material, which represent the highest proportion of solid wastes by approximately 5% is not biodegradable by landfill health [1] as shown in Fig. (1-5).

Figure (1-5) presented that plastic waste is the highest percentage of inorganic solid waste, the plastic quantity in Amara is about 11749.35 Quantity /Ton / Year or 22.8 Capita/ Kg/ Year in 2016, as shown in Fig. (1-6)

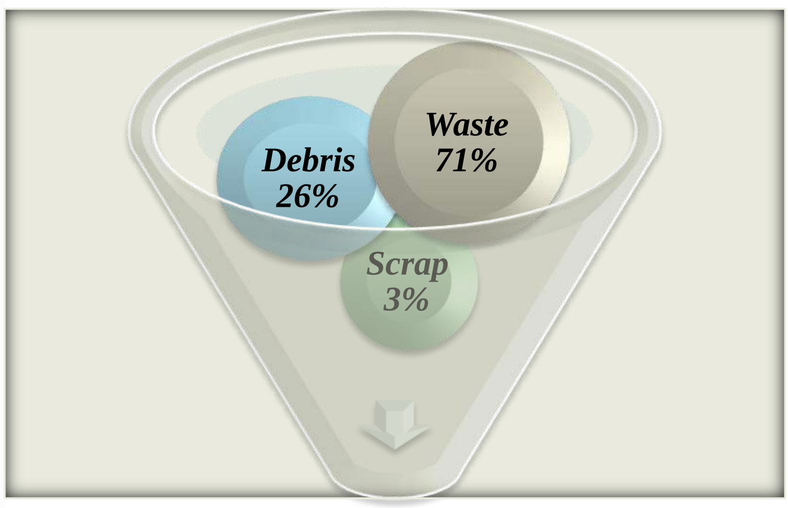


Fig. (1-4): Component of solid waste [1].

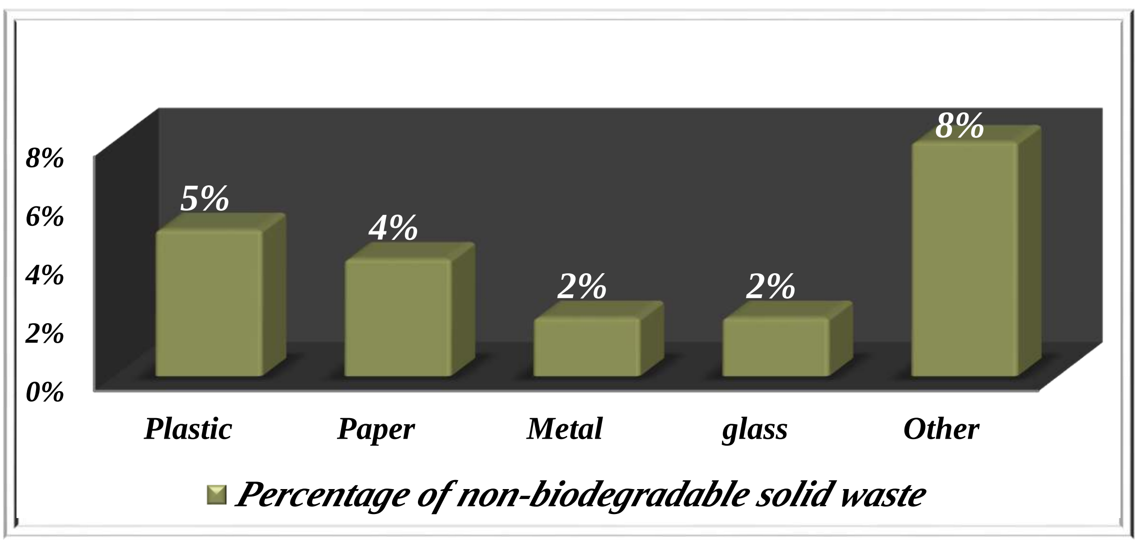


Fig. (1-5): Percentage of Component of Non-biodegradable Solid Waste for the City of Amara [1].

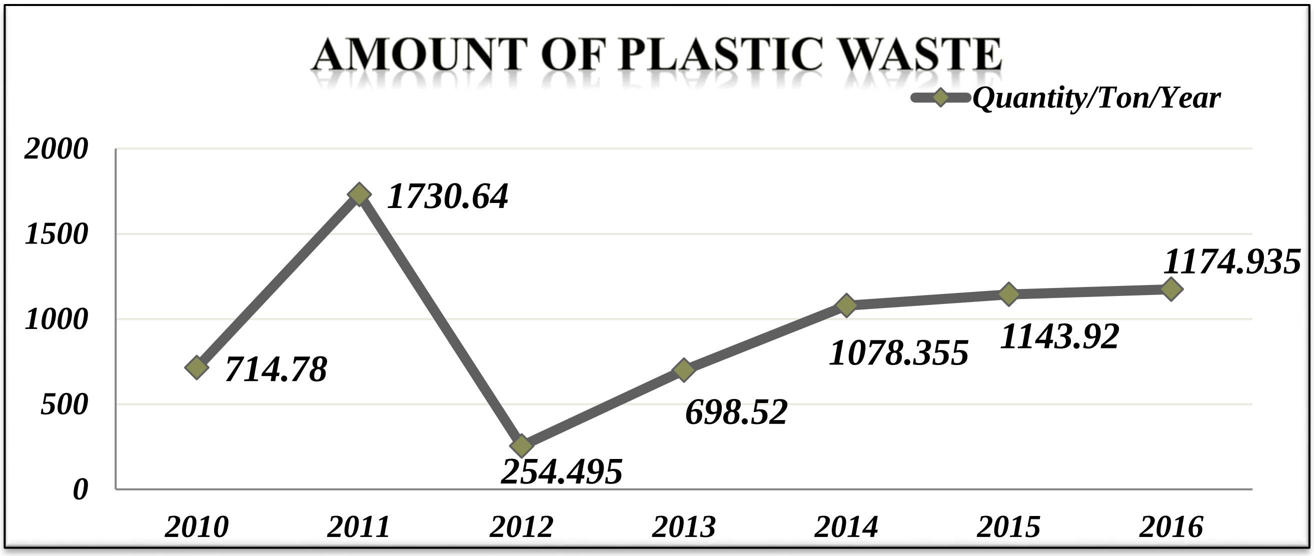


Fig. (1-6): Amount of Plastic Waste and Increase in Recent Years in Maysan Province [1].

1.3.1 Polyethylene Terephthalate (PET)

There are many kinds of plastic wastes reused in construction, but the most common type used by researchers is Polyethylene Terephthalate (PET), as will explain in the later chapter.

This type is used in cups and bottles of water and bottles of soda water and juices as shown in Fig. (1-7), thus huge amounts of PET plastic are consumed every day. These plastic bottles of PET are not recommended to be used more than once because this plastic porous and therefore lead to leakage of liquid in the bottle, which may cause the person using it to become poisoned [2].

Polyethylene Terephthalate (PET) is one of the most important and extensively used plastics in the world, especially for manufacturing beverage containers. The current worldwide production of PET exceeds 6.7 million tons/year and shows a dramatic increase in the Asian region due to recent increasing demands in China and India [3].

Fig. (1-7): Forms of Polyethylene Terephthalate (PET).

PET is a type of polyesters made of ethylene glycol. The composition of anaphylactic acid and its chemical name is polyethylene terephthalate or "PET." PET is one of the most used plastics in the manufacture of containers because of their high stability and their tolerance to high pressure and non-interaction with materials and the quality of large gas that can maintain the gas in a drink [4].

1.4: PLASTIC WASTES RECYCLED IN CONSTRUCTION MEMBERS

Plastic recycling is the process of recovering scrap or waste plastic and reprocessing the material into useful products sometimes wholly different in form from their original state.

One technique to reduce the plastic waste impact on the environment and reduce the cost of disposal is recycled it in the form of construction material as replacement of sand, or gravel or as fiber added to the concrete.

Concrete is extensively used as construction material in the world because of its excessive compressive strength, long service life, and low cost. However, concrete has an inherent disadvantage which is the low tensile strength and crack formulation. To enhance such weaknesses of the material, several types of research on fiber reinforced concrete have been accomplished [3]. There are many studies reviewed recycling the plastic waste with different types of these waste whether in the concrete mix or structural members. All these studies and their conclusions in details were explained in the next chapter.

1.6: RESEARCH OBJECTIVES

The present study deals with the use of three types of plastic waste available in Maysan province, namely Polyethylene Terephthalate PET, plastic boxes, and the waste of the plastic factory, Polyvinyl chloride PVC in various form in the concrete mix and structural members.

In addition to the improvement of concrete properties by adding these wastes, there is an economic benefit (reducing the cost of materials) and environmental benefit (solving some of the solid waste problems posed by plastics and save energy)

While the scientific objectives of this research are as follows:

- Investigate the effects of adding plastic waste pieces on the mechanical properties of concrete to improve its behavior, bring about new types of applications and enables saving sources of natural aggregate. There are many additives to evaluate the effect of size and shape of recycled PET, PVC, and boxes pieces on fresh and hardened properties such as investigating the effect of PVC and boxes as a partial replacement of sand or concrete mixture is reinforced with PET fiber to get the advantages of fiber reinforced concrete. Finally, this study is aimed to find out the optimum percentage of plastic waste used as aggregates and fiber in concrete.

- The development of a novel arrangement of reinforcement with continuous recycled PET fibers to enhance the mechanical properties of concrete beams

1.7: THESIS LAYOUT

The research includes five chapters and as follows:

- Chapter one presents an overview of the importance of concrete and the evolution of its industry during the time of the reinforcement concrete recycled fibers, as well as statistics on the number of population and solid waste types and quantities of its presence in the Maysan province and the number of the population and increasing over time, which led to an increase in plastic waste automatically.
- Chapter two includes an overview of the findings of the previous researches and studies on the impact of plastic waste on the concrete mixture, whether replaced with sand or gravel or fibers added to the mix and structural members of the two types of beams and slabs and use as reinforcement of these members.
- In chapter three, the specification of the materials used, their tests and the mixing percentages are presented. The work steps, the details of the samples, the method of preparation and processing, the tests carried out these samples and the equipment used in the research and tests on the concrete samples.
- Chapter four presented the results in this research with their forms, in addition to the discussion of these results.

- Chapter five explain the most important conclusions reached through the present study through the results of the tests, as well as a set of recommendations and proposals that document this study and achieve scientific benefit for future studies.

Chapter Two
Literature Review

CHAPTER TWO

LITERATURE REVIEW

2.1: GENERAL

In the past two decades, extensive research and studies have been conducted, which were aimed for understanding the behavior of the concrete members after strengthening them with Polyethylene terephthalate fibers and recycled fibers from different materials. This chapter summarizes the global experiences, recent developments and the most important findings of researchers in this field.

A number of topics will be covered in this chapter, including the most important types of plastic waste, where used as an alternative to specific percentages of one of the components of the concrete mixtures.

This chapter includes several studies related to plastic types and especially the waste Polyethylene terephthalate (PET) as the essential type of recycled plastic waste used for various construction purposes and those conducted on recycled concrete beams.

2.2: TYPES OF PLASTIC WASTE USED BY RESEARCHERS

Many kinds of plastic waste have been reused and invested in construction as shown in Fig. (2-1). Many researchers studied these types of waste that can be disposed by landfill and recycling in various shapes and sizes and incorporated in the concrete mixture as partial replacement of a specific part of the materials that fall into the concrete mixture or reuse in the structural members.

Polyethylene terephthalate (PET) was the most waste that has been re-used constructively and has been focused by researchers to knowing the effect of it in the properties of the mixture.

In this paragraph the studies in which the use of different types of these wastes and their impact on the properties of concrete were reviewed.

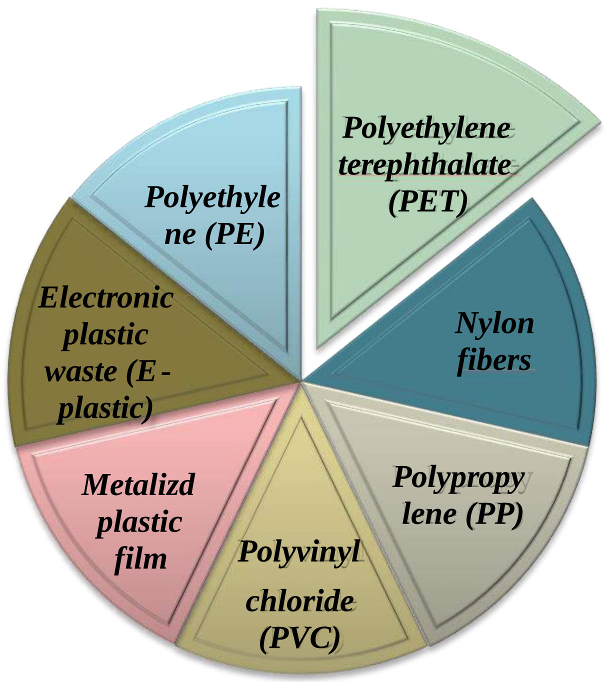


Fig. (2-1): Types of plastic waste.

2.2.1 Electronic Plastic Waste (E-plastic waste)

In 2014, Kumar et al. [5], used electronic plastic waste (computer waste) as a partial replacement of coarse aggregate in the concrete mixture in a percentage of (10, 20, 30, 40, 50) % by volume with a maximum size of these waste being 12.5 mm as shown in Fig. (2-2) with mixing proportion (1:2.14:3.08) and W/C of 0.49. The tests were carried out for fresh and hardened concrete at the ages of 7 and 28 days. They observed that the workability and dry and fresh density decreases as a plastic waste percentage increase. In addition, the compressive, split tensile, and flexural strength of the hardened concrete is reduced by increasing the proportion of the plastic waste used.

Fig. (2-2): Form of E- plastic waste after cutting.

In 2016, Manjunath et al.[6], added electronic plastic waste (The E-plastic waste consisted of discarded plastic waste from old computers, TVs, refrigerators, and radios) as a coarse aggregate in the concrete mixture in a percentage of (10 , 20, 30,)% by weight of cement in mixture with a maximum size of these waste being 20 mm, mixing proportion (1:1.4:2.4:0.5) and W/C is 0.5. The tests were carried out for fresh (slump test) and hardened concrete (compressive, split tensile, and flexural strength) at ages of 7, 14, and 28 days and observed that the workability, dry density, and fresh density decreases as a plastic waste percentage increase. In addition, the compressive, split tensile, and flexural strength of the hardened concrete are reduced by 52.98% when coarse aggregate replaced by 20% of the E- plastic waste used by 20 % at 28 days of curing ages, the split tensile strength is increased when coarse aggregate is replaced by 20% of E-plastic waste and the flexural strength is increased when coarse aggregate is replaced by 10% of E-plastic waste at 28 days.

2.2.2 Polypropylene (PP)

In 2011, Fraternali et al. [7], used two types of waste [polypropylene (PP) and Polyethylene Terephthalate (PET)] as a fiber with different lengths as shown in Fig. (2-3) added to the concrete mixture in a percentage of 1% by volume.

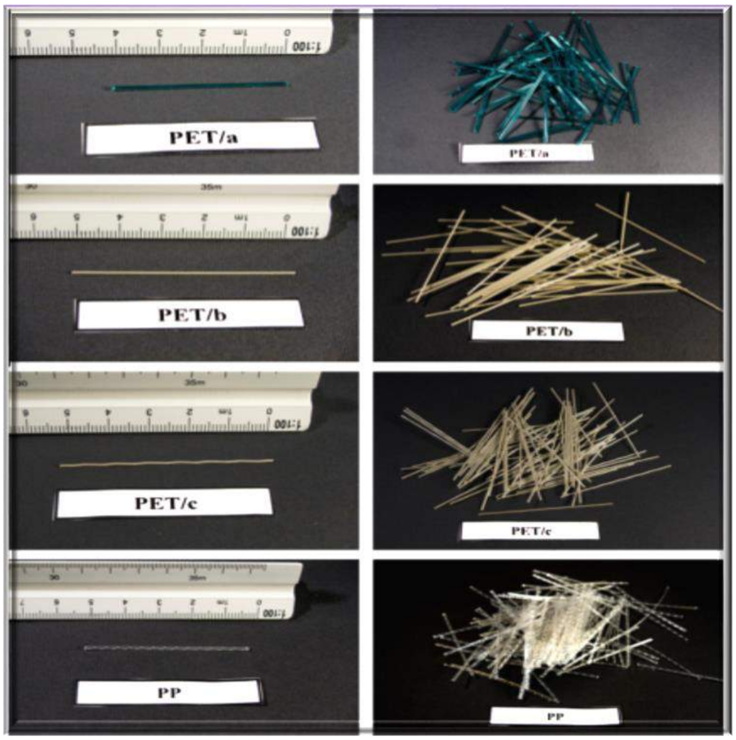


Fig. (2-3): Form of polypropylene (PP) and Polyethylene Terephthalate (PET) after cutting.

The thermal conductivity, compressive strength, first crack strength, and ductility indices tests were carried out. They observed that high strengths about 35%, 22%, and 0.03% of PET fibers (a, b, c) are able to produce significant increases in compressive strength and increases flexural strengths of recycled PET fiber reinforced concrete (RPETFRC), as compared to both unreinforced concrete (UNRC) and PP fibers reinforced concrete PPFRC.

In 2014, Patil et al. [8], used polypropylene (PP) and Polyethylene Terephthalate (PET) as coarse aggregate in the concrete mixture in a percentage of (10, 20, 30, 40, 50) % by volume of aggregate in the mix. The tests were carried out for hardened concrete (compressive and flexural strength) at ages of 7 and 28 days. They observed that the compressive strength decreases as a plastic waste percentage increase. In addition, the flexural strength of the hardened concrete is increased when coarse aggregate is replaced by 10% of polypropylene (PP) and Polyethylene Terephthalate (PET) at 7 and 28 days.

In 2014, Tapkire et al. [9], used polypropylene (PP) and polyethylene Terephthalate (PET) as alternative replacements of a part of the conventional aggregates (coarse aggregate) of concrete in a percentage of (10, 20, 30) % by weight of aggregates with size less than 10 mm, and mixing proportion (1:2.56:3.26) and W/C is 0.5.

The tests were carried out for fresh and hardened concrete at the ages of 14 and 28 days. They found that the optimum plastic percentage was 10% to 20% by weight of coarse aggregate for compressive strength.

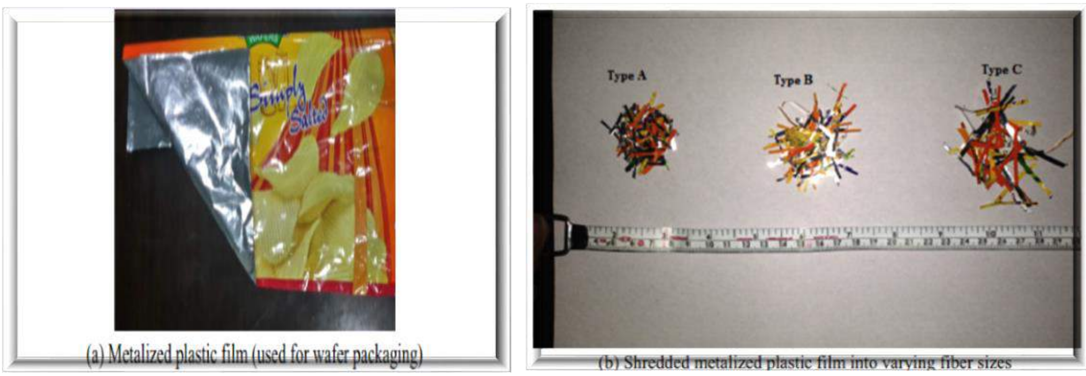
In 2015, Yang et al. [10], added polypropylene (PP) cut into short columns with lengths from 1.5 mm to 4 mm as shown in Fig. (2-4) like sand in the concrete mixture in a percentage of (10%, 15%, 20%, and 30%) of sand by volume in the mixture.

The tests were carried out for fresh and hardened concrete (compressive, split tensile, and flexural strength) at ages of 7 and 28 days and observed that the workability increases as a plastic waste percentage increase. In addition, dry density and elastic modulus decrease as a plastic waste percentage increase. The compressive, split tensile, and flexural strength of the hardened concrete are improved against increasing the proportion of the plastic waste used by 15 %.

Fig. (2-4): Form of* polypropylene (PP) *after cutting.

In 2017, Bhogayata et al. [11], used metalized plastic waste (MPW) (Low-density Polypropylene LDPE) as fiber added to the concrete mixture as shown in Fig. (2-5) in a percentage of (0-2) % by volume of in the mix. MPW was shredded into 5 mm, 10 mm and 20 mm long fibers at a constant 1 mm width and 0.08 mm thickness with mixing proportion (1:1.46:2.55) and W/C is 0.45.

Tests were carried out on fresh (slump test) and hardened concrete (compressive, split tensile, and flexural strength) and observed that the splitting tensile strength and ductility of concrete due to the addition of MPW fibers were improved, the workability, compressive strength and flexural strength showed a negligible reduction at 1% dosage of MPW fibers.



(a) Metalized plastic film (used for wafer packaging) (b) Shredded metalized plastic film into varying fiber sizes

Fig. (2-5): Form of Metalized Plastic Waste (MPW) Used for fiber Reinforcement.

2.2.3 Polyvinyl Chloride (PVC)

In 2014, Behl et al. [12], used polyvinyl chloride (PVC) pipe as a modifier up to a level of 3% and 5% of bitumen with size (2–4 mm) for paving application. The strength and stability were improved with the increase in the percentage of PVC pipe also increased resistance to permanent deformation.

In 2014, Köfteci et al. [13], used waste plastics (window, blinds and cable wastes) based on polyvinyl chloride (PVC) as a modifier for bitumen in a percentage of (1, 3, 5) % of bitumen weight in the powder form. They found that the optimum percentage of PVC as a modifier in bitumen were determined as in the amount of 3% window wastes.

2.2.4 Polyethylene (PE)

2.2.4.1 Low-Density Polyethylene (LDPE)

In 2016, Guendouz et al. [14], utilized two types of waste plastic

Polyethylene Terephthalate (PET) and Low-Density Polyethylene LDPE as a fiber and fine aggregates (powder) in sand concrete, where PET fibers with 40 mm of length and 0.5 of thickness and the LDPE powder with 2 mm maximum size as shown in Fig. (2-6) in a percentage of (10%,20%,30%, and 40%) were substituted by the same volume of plastic aggregates, and various amount of plastic fibers (0.5%, 1%, 1.5%,2%) were introduced by volume in sand concrete mixes with mixing proportion 350 kg/m3 of cement, 1200 kg/m3 of sand, 230 kg/m3 of fillers, 0.86 of water/cement ratio of and 1% of plasticizer .

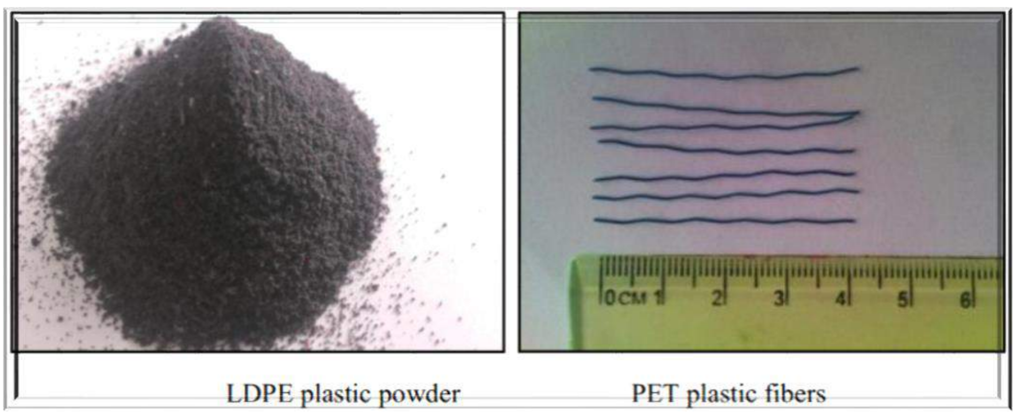


Fig. (2-6): Form of Polyethylene Terephthalate (PET) and Low-Density Polyethylene (LDPE) After Cutting.

The tests were carried out for fresh(slump) and hardened concrete (compressive and flexural strength) at ages of 7,28, and 90 days and observed that the level of substitution should be limited to 20% and 1.5% for plastic powder (LDPP) and plastic fibers (LPE) respectively.

2.2.4.2 High-Density Polyethylene (HDPE)

In 2011, Attaelmanan et al. [15], used High-Density polyethylene (HDPE) as modifier for asphalt paving materials with five asphalt percentages (4.0%, 4.5%, 5.0%, 5.5% and 6.0%) by weight of asphalt. The improvement of the performance of asphalt concrete mixtures is improved in the amount of 5% of HDPE.

2.2.5 Crushed Carbon Fiber Reinforced Plastic (CFRP) pieces

In 2005, Ogi et al. [16], added crushed carbon fiber reinforced plastic (CFRP) pieces as fibers in the concrete mixture in a percentage of (5, 7.5, 10) % by weight of CFRP with thickness varies ranging from 0.05 to 0.2 mm depending on their size as shown in Fig. (2-7).

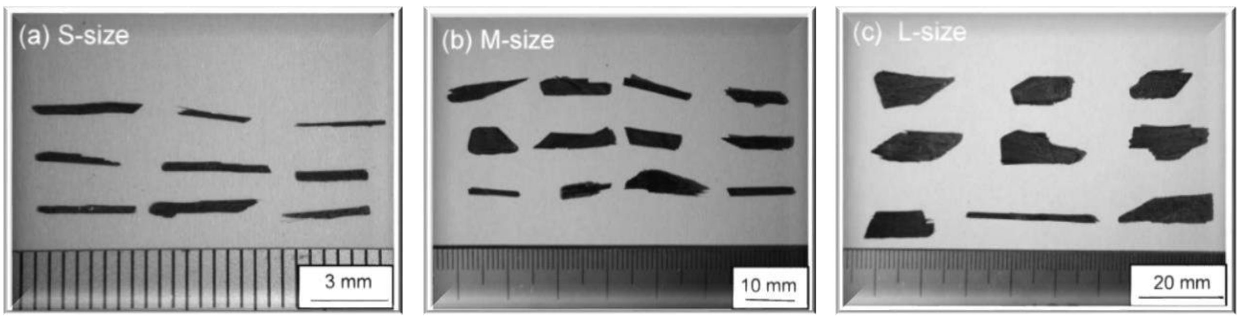


Fig. (2-7): Crushed CFRP Pieces Used for Reinforcement.

The compressive and flexural strength tests were performed, they observed that the compressive and flexural strength increased when replaced by 10% of CFRP with small pieces.

2.2.6 Plastic Bag Waste Fibers (PBWF)

In 2015, Ghernouti et al. [17], conducted a practical study for using plastic bag waste fibers (PBWF) as fiber in the concrete mixture (self - compacting concrete SCC) with different values of fiber content (1, 3, 5 and 7 kg/m^3) and lengths 2, 4, and 6 cm as shown in Fig. (2-8). The total amounts of cement, fillers, coarse aggregates, sand, water, and super plasticizer were all kept constant (430, 30, 350, 314, 174 and 6.6 kg/m3), respectively.

The slump, L-box, and stability sieve were performed for fresh concrete and the compressive, flexural, and split tensile strength tests were performed for hardened concrete. They observed that the properties of self- compacting concrete (SCC) in both fresh and hardened concrete were improved, where the amount of these waste effect on the properties of concrete without the effect of lengths of these fibers.

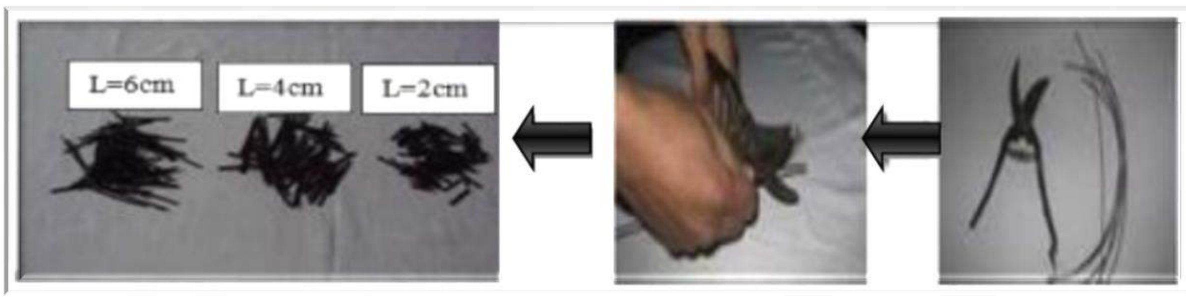


Fig. (2-8): Plastic Bag Waste Fibers (PBWF).

2.2.7 Nylon Fibers

In 2015, Spadea et al. [18], utilized nylon fiber as shown in Fig. (2-9) as tensile reinforcement of cement mortars in a percentage of (0.5, 1.0, 1.5) % by weight. The results showed that a higher percentage of fibers (1.5% rather than 1.0%) causes a less noticeable drop in the load after the peak value.

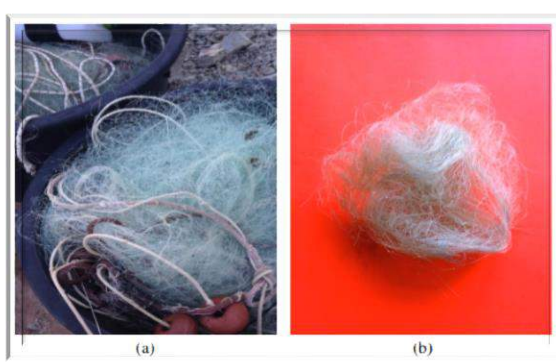


Fig. (2-9): Nylon fiber.

Table (2-1): Summary of Studies in which Researchers Used Different Types of Plastic Waste

Author	Type of Plastic	Usage and Dimension	Mixture proportion and percentage of uses	Remark
Ogi et al. 2005[16]	*crushed carbon fiber reinforced plastic (CFRP) pieces*	*Fiber with three lengths and widths (3.4*0.4, 9.9* 2.2 and 21* 7.7mm2) with thickness varies ranging from 0.05 to 0.2 mm*	*three percentage of (5,7.5,10) % by weight of CFRP*	*-The compressive and flexural strength increased when replaced by 10% of CFRP with small pieces*
Fraternali et al. 2011 [7]	*Polyethylene Terephthalate (PET)type (a, b, c) and polypropylene (PP)*	*Fiber*	*1:2.7:2.73 with w/c = 0.53*	*-High strength PET fibers (PET/a) are able to produce significative increases in compressive and flexural strengths of RPETFRC, as compared to both UNRC and PPFRC*
Attaelmanan et al. 2011[15]	*High density polyethylene (HDPE)*	*Modifier for asphalt paving materials*	*Five asphalt percentages (4,4.5,5,5.5,6) % by weight of asphalt*	*-The improvement of the performance of asphalt concrete mixtures is improved in the amount of 5% of HDPE.*
Kumar et al. 2014 [5]	*E-plastic waste*	*Coarse aggregate with max. size of 12.5 mm*	*1:2.14:3.08 and w/c = 0.49 with percentage of (10,20,30,40,50) % by volume of coarse aggregate*	*-The workability, fresh density and dry density of the mix were reduced against the increase in the percentage of E-plastic.* *- The compressive, split tensile, and flexural strength for the hardened concrete was reduced against the increase in the percentage of E-plastic.*

Table (2-1): Continued

Patil et al. 2014[8]	*(PP) and (PET)*	*Coarse aggregate*	*(10, 20, 30,40,50) % by volume of coarse aggregate*	*-The flexural strength of the hardened concrete is increased when coarse aggregate is replaced by 10% of polypropylene (PP) and Polyethylene Terephthalate (PET)*
Tapkire et al. 2014[9]	*(PP) and (PET)*	*Coarse aggregate with size less than 10 mm*	*1:2.56:3.26 with w/c ratio 0.5 with percentages (10, 20, 30) % by Weight of aggregates*	*-For compressive strength, the optimum plastic percentage was 10% to 20% by weight of coarse aggregate*
Köfteci et al. 2014[13]	*polyvinyl chloride (PVC)*	*modifier for bitumen*	*1%, 3%, and 5% of bitumen weight*	*-Only cable wastes in the amount of 5% improved performance of bitumen at low temperatures. -Optimum usage of the waste plastics as a modifier in bitumen were determined as in the amount of 3% window wastes*
Behl et al. 2014[12]	*PVC*	*used as a modifier*	*3% and 5% of bitumen*	*-PVC pipe waste can be used successfully in road construction. Strength and stability of the mix increased after the incorporation of PVC pipe waste also increased resistance to permanent deformation*
Manjunath et al. 2015[6]	*E-plastic waste*	*Coarse aggregate with a maximum size of 20mm.*	*1:1.4:2 with w/c = 0.5 and percentage of (0,10,20,30) % by weight of cement in mix.*	*-The workability and dry and fresh density decrease as a plastic waste percentage increase. -The split tensile strength and the flexural strength*

Table (2-1): Continued

				are increased when coarse aggregate is replaced by (20,10) %, respectively of E- plastic waste
Yang et al. 2015[10]	*PP*	*Sand ground into short columns with lengths from 1.5 mm to 4 mm*	*(10, 15, 20) % by volume of sand*	*-The workability increases as a plastic waste percentage increase. The compressive strength, splitting tensile strength and flexural tensile strength is increased with the replacement level up to 15%*
Guendou z et al. 2016[14]	*(PET) and (LDPE)*	*Fibers and fine aggregates (powder) in sand concrete where PET fibers with 40 mm of length and 0.5 of thickness and the LDPE powder with 2 mm maximum size*	*Various volume fractions of sand (10%,20%,30% and 40%) and various amount of plastic fibers (0.5%, 1%, 1.5%,2%) were introduced by volume in sand concrete mixes*	*-The level of substitution should be limited to 20% and 1.5% for plastic powder (LDPP) and plastic fibers (LPE) respectively*
Bhogayat a et al. 2017[11]	*metalized plastic waste (MPW) (LDPE)*	*Fiber shredded into 5 mm, 10 mm and 20 mm long fibers at a constant width 1mm width and 0.08 mm thickness*	*1:1.46 :2.55 and w/c = 0.45 with percentage of (0,0.5,1,1.5,2) % by volume of mix*	*-Splitting tensile strength and ductility of concrete due to the addition of MPW fibers were improved and the workability, compressive strength and flexural strength showed a negligible reduction at 1% dosage of MPW fibers*

2.3: RE-USE OF POLYETHYLENE TEREPHTHLATE (PET) FOR DIFFERENT STRUCTURAL PURPOSES

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

The researchers focused on PET usage in concrete mixtures by replacing a certain amount of weight of sand or gravel or adding by volume to the mixture, as well as PET used in structural members as reinforcement, as shown in Fig. (2-10)

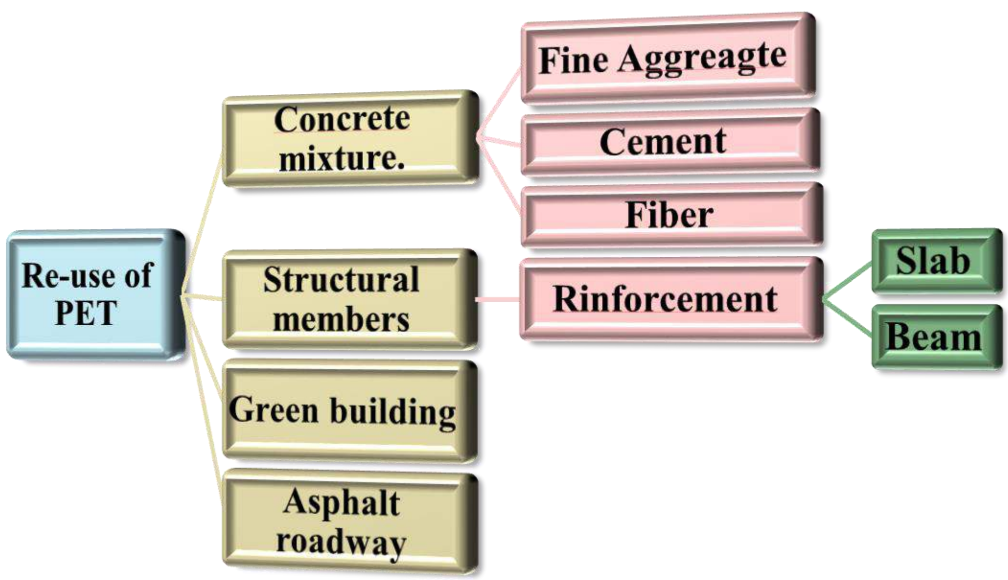


Fig. (2-10): Flowchart Illustrates the Various Purposes for Recycle PET in Concrete.

The trend to recycling plastic waste had increased in recent years and used for different purposes as shown in Fig. (2-11) and Fig. (2-12)

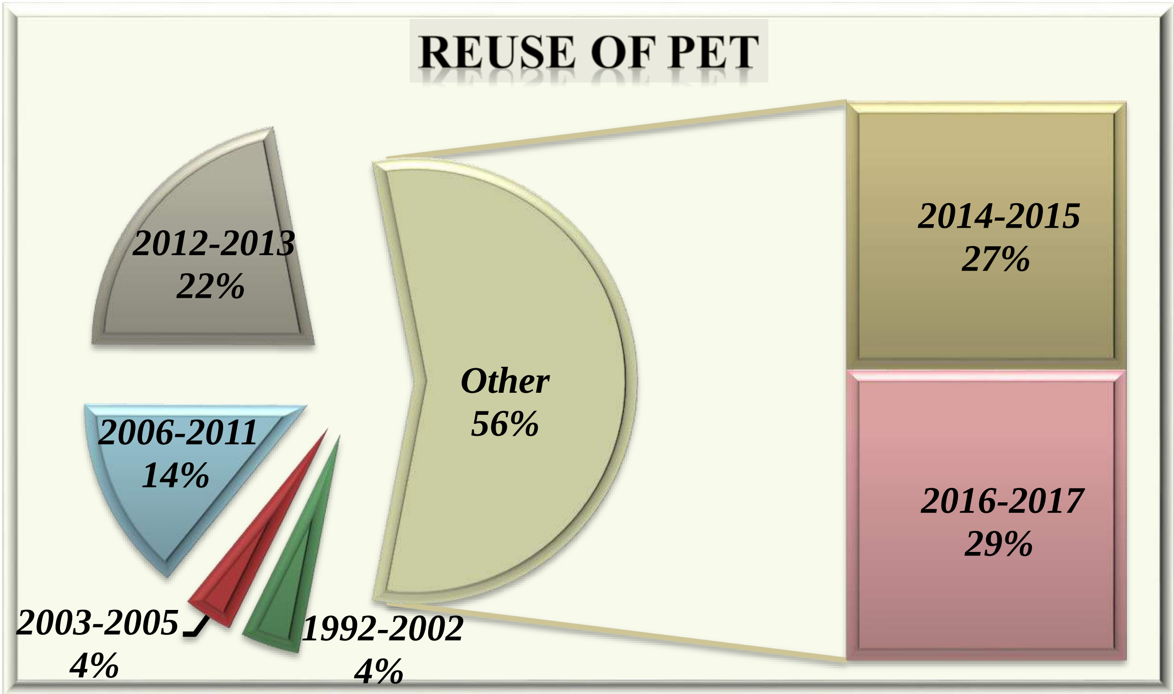


Fig. (2-11): Researches of Reuse PET per Year.

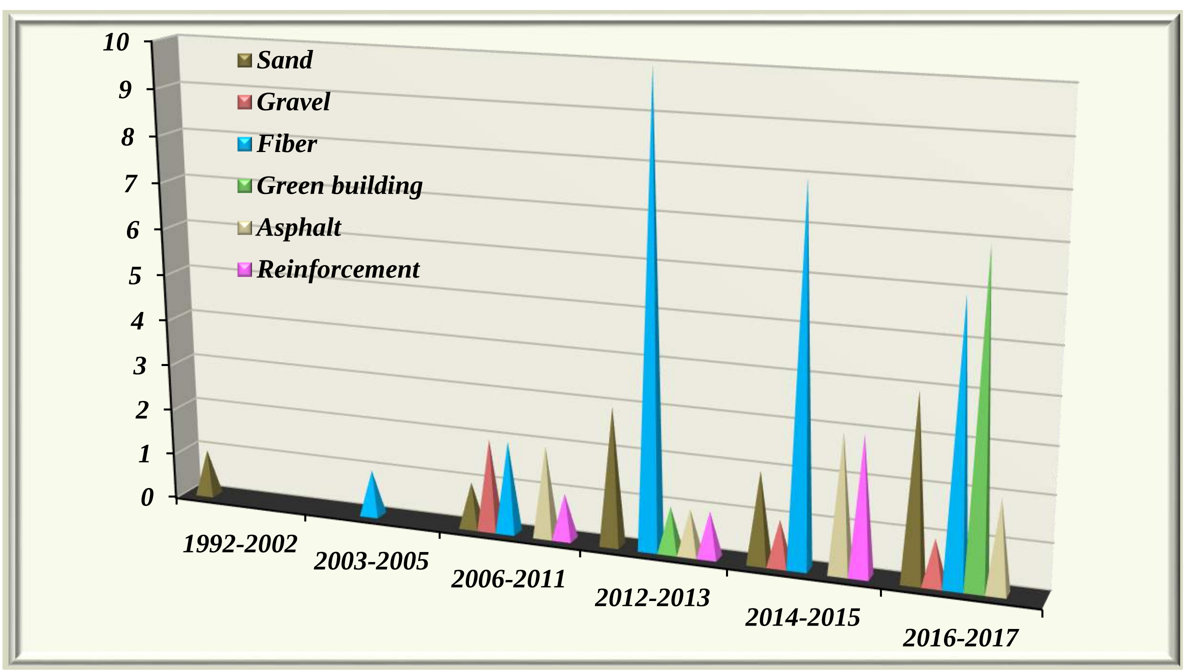


Fig. (2-12): Flowchart Illustrates the Evolution of Research Through the Years with Respect to the Type of Usage.

2.3.1 Re-use of PET in the concrete mixture

2.3.1.1 Re-use of PET as partial replacement of fine aggregate

In 2014, Prabhu et al. [19], used PET bottle as a partial replacement of fine aggregate in form of fiber in the concrete mixture in a percentage of (0.5,1.0,1.5) % by volume with three dimensions (50*3 mm, 100*3 mm, and 150*3 mm) with mixing proportion (1:1.48:2.54) and W/C is 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) gives the higher strength and 1.0 % replacement of sand by volume fraction was the optimum percentage for both compressive and tensile strength.

2.3.1.2 Re-Use of PET as a percentage of Cement

In 2013, Nibudey et al. [20], incorporated PET bottle as fiber to the concrete mixture in a percentage of (0.5, 1.0, 1.5, 2.0, 2.5, 3.0) % by weight of cement with dimensions (25 mm length and the breadth was 1 mm and 2 mm) with mixture proportion (1:1.42:3.55 and w/c = 0.48) with using super plasticizer 0.6% added by weight of cement. The workability (slump, compaction factor), compression, split tension and flexural tests were carried out for fresh and hardened concrete at ages of 28 days and observed that the workability and dry and fresh density decreases as a plastic waste percentage increase. In addition, the compressive, split tensile, and flexural strength of the hardened concrete in a percentage of 1% of PET fiber was increased.

2.3.1.3 Re-Use of PET as fibers

In 2017, Subramani et al. [21], added PET bottle as fiber to the concrete mixture in a percentage of (2,4,6) % by volume with dimensions (30 mm length, 5 mm width, and 0.6 mm thickness). The tests were carried out for fresh and hardened concrete at the ages of 7,14, and 28 days. They observed that 4 % of PET fiber by volume fraction was the optimum percentage for all tests.

2.3.2 Re-Use of PET in the Structural Members

2.3.2.1 Re-Use of PET for Reinforcement of Slab

In 2014 , Foti et al. [22], utilized PET as discrete long reinforcement of specimens in concrete in substitution of steel bars arranged as a grid for slab, where the technique for cutting of PET was removing the neck ,then longitudinally cutting a 5 cm-wide strip including the base of the bottle and ending on the opposite side, obtaining in this way a strip with a length of about 60 cm. Four 80 cm × 80 cm × 5.8 cm slabs have been prepared, two in non-reinforced concrete and two in concrete reinforced with PET grids as shown in Fig. (2-13).

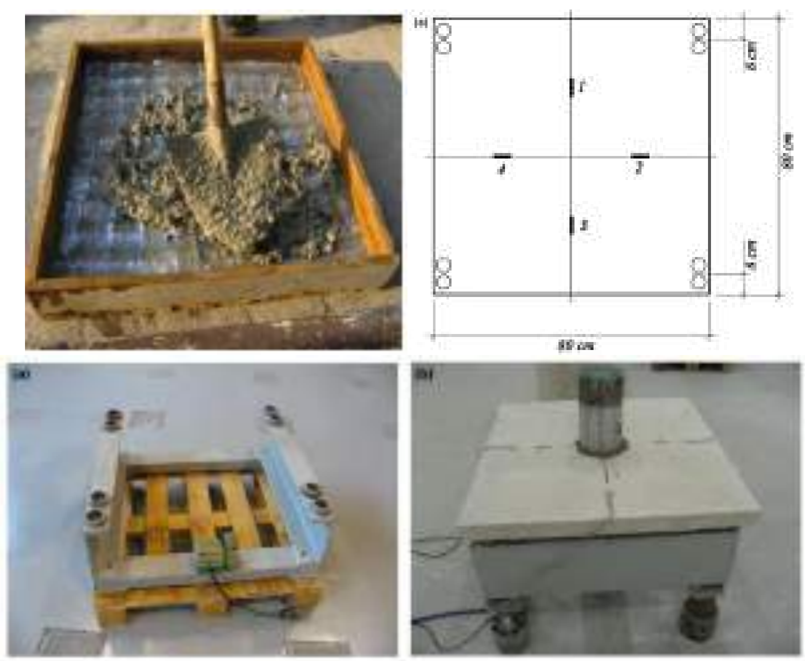


Fig. (2-13): Scheme of the Slab with the Position of the Strain Gauges and the Supports.

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

2.3.2.2 Re-use of PET for reinforcement of Beam

In 2014, Kumar et al. [23], used recycled PET fiber as reinforcement for the concrete beam in four parts of samples with steel bars, without steel bars, with PET reinforcement, and combined steel and PET reinforcement. Seven concrete beams were tested at 28 days for flexural strength with dimensions (100*100*500) mm and the beams used in seven types of control beams made with plain concrete without any reinforcement, the second type was beam reinforced with PET hollow bars of 48 cm long and 24 mm, 22.8 mm external diameter, internal diameter, the third and fourth types were beams with a single bar and two bars and length 48 cm in the tension zone , beam with combination of steel and PET reinforcement in the tension zone, beams with steel and PET long strips (strips dimensions were 8 cm long, 0.5 cm width, and 6.6 mm thickness), and the seventh type was beams with PET short strips were made which are prepared by replacing 1% fine aggregate with PET short strip (strips dimensions were 4 cm long, 0.4 cm width, and 0.6 mm thickness) as shown in Fig. (2-14) the results showed that the fiber reinforced concrete with different types that improved in flexural strength.

2.3.3 Re-Use of PET in Green building

In 2016, Raza et al. [24], used PET bottle as a brick for walls as shown in Fig. (2-15), where PET bottle filled with soil and tested for compressive strength that required 28 days curing time as shown in Fig. (2-16).

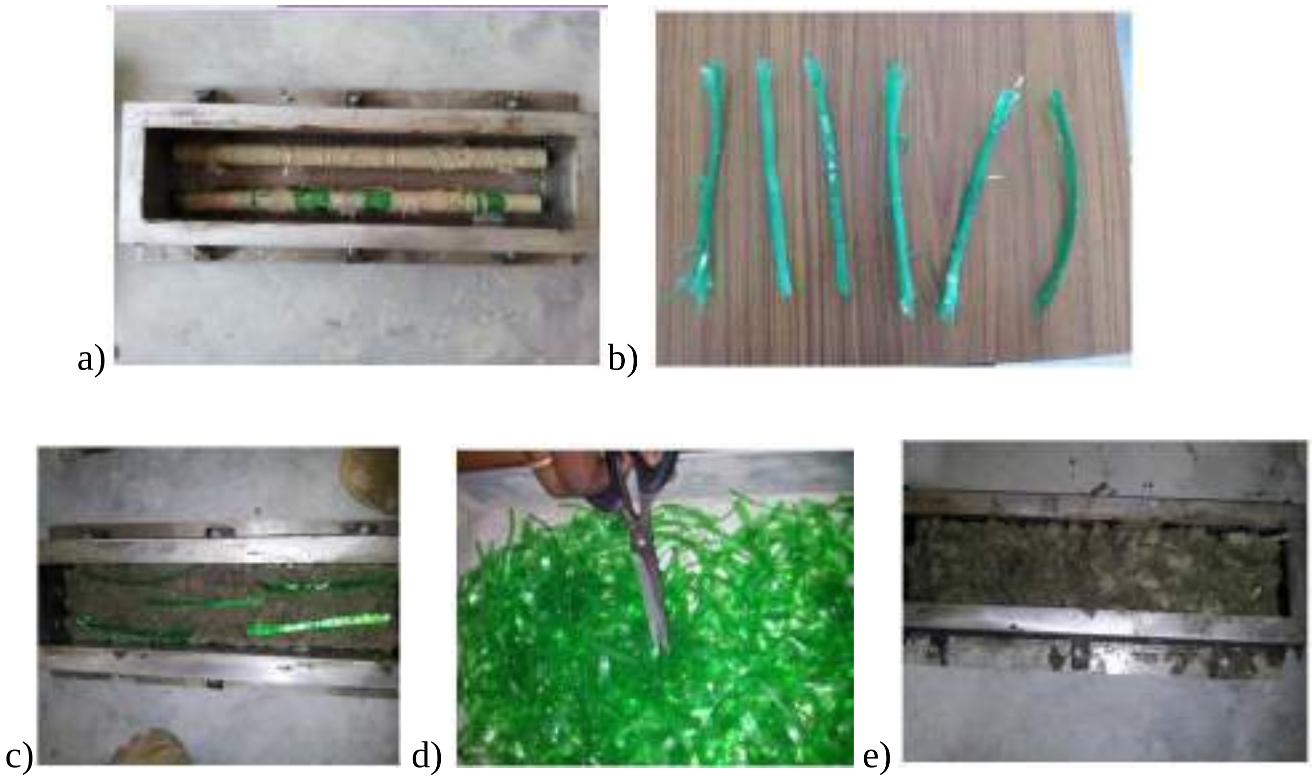


Fig. (2-14): a) PET Hollow Bars, b) PET Long strips, c) PET Long strips as reinforcement along with steel, d) PET Short strips, and e) Concrete with PET Short strips filled in beam mold.

2.3.4 Re-Use of PET in Asphalt roadway

In 2014, Gürü et al. [25], used PET bottle as asphalt roadway pavement material in a percentage of (1,2,3,5,10) % by asphalt mass

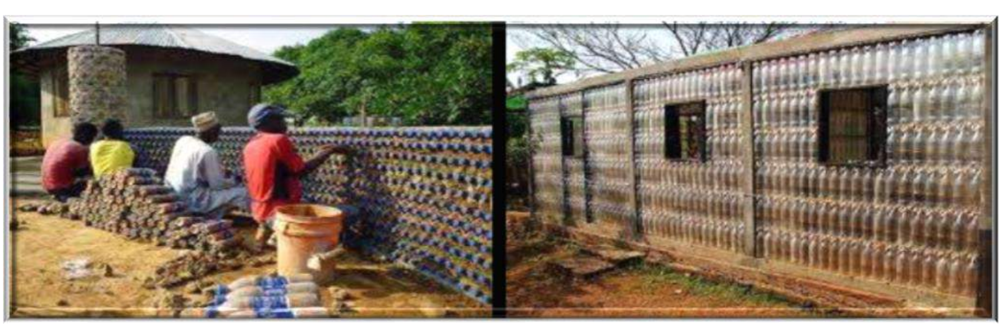
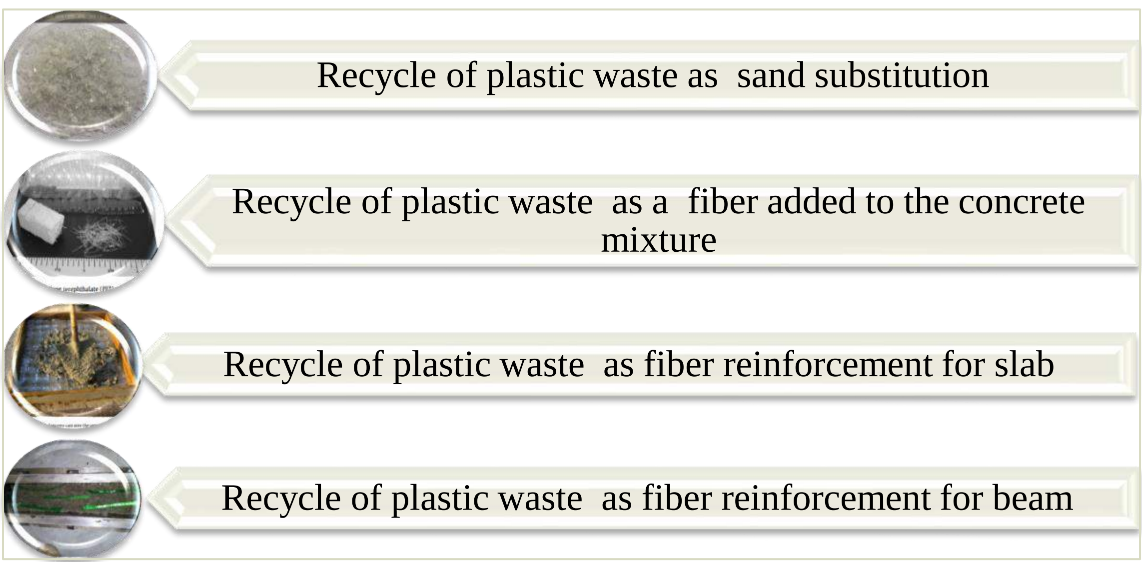


Fig. (2-15): Wall with PET bottle.

Fig. (2-16): Test applied on a waste PET bottles filled.
with soil and sealed tightly

2.4: IMPORTANT CASES STUDIED BY RESEARCHERS



2.4.1 Recycle of Plastic Waste as Sand Substitution

In 2008, Ismail et al. [26], used PET bottle as a partial replacement of fine aggregate in the concrete mixture in a percentage of (0,10,15,20) % by weight of sand with dimensions (0.15-12 mm length and 0.15-4 mm width) as shown in Fig. (2-17) with mixing proportion (380 kg/m^3 cement : 715 kg/m^3 sand : 1020 kg/m^3 gravel) and W/C is 0.53. The tests were carried out for fresh and hardened concrete at ages of 3, 7, 14, and 28 days and observed that the slump decreases sharply as a plastic waste percentage increase. In addition, the compressive, and flexural strength of the hardened concrete is reduced by increasing the proportion of the plastic waste used.

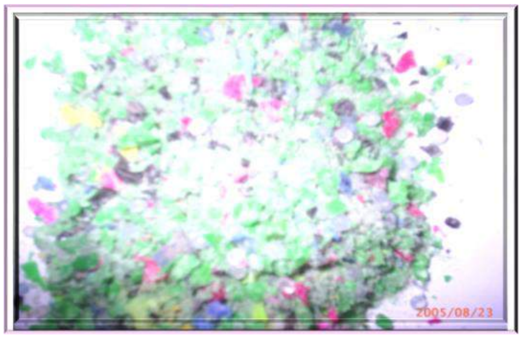


Fig. (2-17): Sample of plastic waste.

In 2013, Rahmani et al. [4], utilized PET bottle as a partial replacement of fine aggregate in the concrete mixture in a percentage of (5, 10, 15) % by volume with the maximum size of 7 mm as shown in Fig. (2-18) with two mixture. proportions as shown in Table (2-2). The tests were carried out for fresh and hardened concrete. They observed that the slump decreases as a plastic waste percentage increase. In addition, w/c = 0.42 gives larger strength and observed that 5% replacement of sand was the optimum percentage, but 10% replacement of sand had the same result of control specimens for compressive strength.

Fig. (2-18): Sample of plastic waste.

Table (2-2): Mixture proportion.

Component	Content (kg/m^3)							
	w/c = 0.42				w/c = 0.54			
	0% PET	5% PET	10% PET	15% PET	0% PET	5% PET	10% PET	15% PET
Cement	488.10	488.10	488.10	488.10	379.00	379.00	379.00	379.00
Water	209.90	209.90	209.90	209.90	210.20	210.20	210.20	210.20
Gravel	976.10	976.10	976.10	976.10	976.10	976.10	976.10	976.10
Sand	654.90	622.00	589.40	556.60	745.90	708.60	671.30	634.00
PET	–	8.80	17.60	26.40	–	10.00	20.00	30.00

In 2016, Azhdarpour et al. [27], used PET bottle as a partial replacement of fine aggregate in the concrete mixture in a percentage of (0, 15, 10, 15, 20, 25, 30) % with two sizes of plastic particles (2– 4.9 mm coarse plastic and 0.05 –2 mm fine plastic as shown in Fig. (2-19). The tests were carried out for fresh and hardened concrete at ages of 3,14, and 28 days. They observed that fresh and dry density decreases as PET particles increases. In addition, the compressive increases by 39% and 7.6% with replacing of 5 and 10% of PET particles.

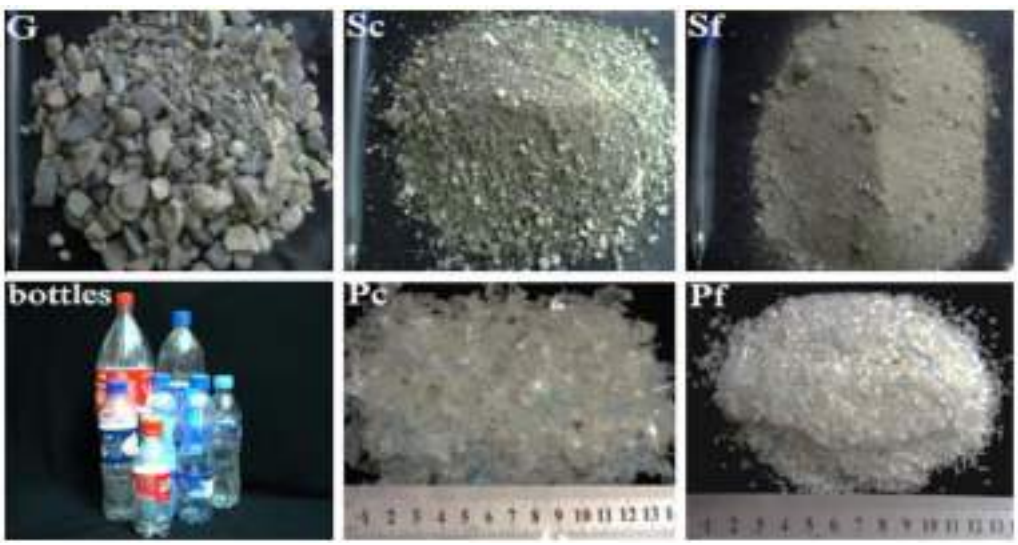


Fig. (2-19): Samples of materials and waste bottles used in the mix design; G (gravel), Sc (coarse sediment), Sf (fine sediment), Pc (coarse plastic particles) and Pf (fine plastic particles).

2.4.2 Recycle of Plastic Waste as Fiber s Added to the Concrete Mixture

In 2011, Oliveira et al. [28], added PET bottle as fiber to the concrete mixture in a percentage of (0,0.5,1.0,1.5) % by volume in mixture PET fiber was shredded into 35 mm length at a constant 2 mm width and 0.5 mm thickness as shown in Fig. (2-20).

Fig. (2-20): Form of PET Bottle Used for Fiber Reinforcement.

Compressive and flexural strength tests were performed at the ages of 7, 28, and 63 days. Their results showed that the incorporation of fibers in the mixture improved the properties of it and observed the percentage of 1.5% of fibers was the optimum percentage for the performance of mix.

2.4.3 Recycle of Plastic Waste as fiber Reinforcement for S lab

In 2015, Yin et al. [29], used PP (that produced through a melt spinning and hot drawing process) as reinforcement for the slab (the dimensions of the panel were 800 mm diameter and 75 mm thickness) with two indent types (Line & diamond) as shown in Fig. (2-21) with five percentage and mixture proportion as shown in Table (2-3).

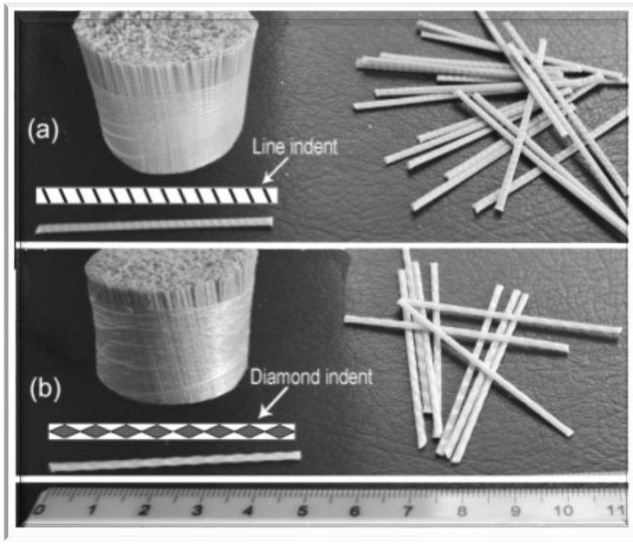


Fig. (2-21): (a) Line-Indent PP Fiber, and (b) Diamond-Indent PP Fiber.

Table (2-3): Mixture proportion and Details of PP fibers

Material	Plain concrete	Fibre reinforced concrete
0.6–4.75 mm Coarse Sand (kg/m^3)	350	350
6.7–9.5 mm Concrete Aggregate (kg/m^3)	950	950
0.3–5 mm Crusher Dust (kg/m^3)	220	220
0.075–0.3 mm Fine Sand (kg/m^3)	290	290
Fly Ash (kg/m^3)	130	130
Cement (kg/m^3)	256	256
Polyheed 8190 Admixture (ml/100 kg Cementitious Materials)	337	337
Water (l/m^3)	105	105
PP Fibre (kg/m^3)	0	4

Specimen	Indent type	Details
Virgin PP Fibre (Line)	Line	100% virgin PP
Recycled PP Fibre (Line)	Line	100% recycled PP
50:50 Virgin–Recycled PP Fibre (Line)	Line	Mixture of 50% of virgin PP and 50% recycled PP
Recycled PP Fibre (Diamond)	Diamond	100% recycled PP
5:95 HDPE–Recycled PP Fibre (Diamond)	Diamond	Mixture of 5% of HDPE and 95% recycled PP

2.4.4 Recycle of Plastic Waste as Fiber Reinforcement for Beam

In 2010, Kim et al. [3], compared between recycled PET fiber reinforced concrete and polypropylene PP fiber reinforced concrete that was utilized as reinforcement for a concrete beam with three fiber volume fractions of (0.5,1.0,1.5) %, where the technique for manufacturing of recycled PET fiber as shown in Fig. (2-22). Seven specimens were tested at 28 days for flexural strength with dimensions (2000*200*300) mm and details of reinforcement as shown in Fig. (2-23). Their results showed that the fiber reinforced concrete had better crack resistance and strain – hardening capacities than the specimens without fibers, and observed from load-deflection result that the maximum mid-span deflection was approximately 400% larger in the FRC than the specimens without fibers and the fibers enhanced tensile resistance and delayed macro-crack formation were showed and noticed that the ductility index and energy capacity beyond a volume fraction about 0.5% decreases as the fiber volume fraction increases.

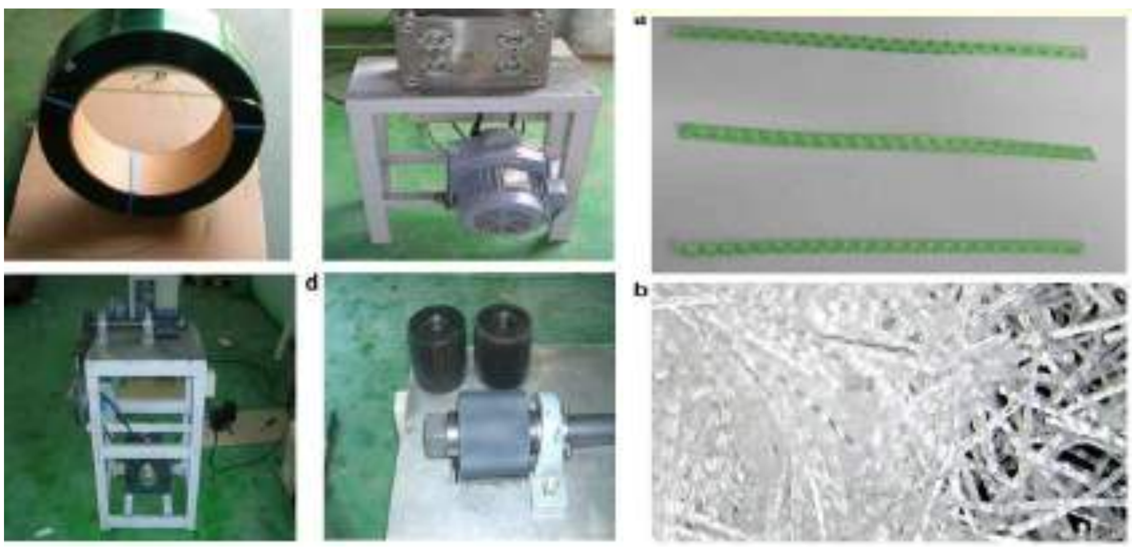


Fig. (2-22): Manufacturing System of Recycled PET Fibers and Geometry of the recycled PET Fibers and PP Fiber.

In 2013, Foti et al. [30], utilized PET fiber as discrete reinforcement of specimens added to the concrete in substitution of steel bars, where the fibers obtained by simply cutting the bottles, The PET bottle used with three forms in three tests one of them was the use of it in the circular form (Circular fibers) with 5mm width as shown in Fig. (2-24) used in percentages of (0.5, 0.75, 1.0) % by weight of concrete and the second form was concrete beams reinforced with long PET strips (half bottle) in a position similar to the reinforcement bars in the concrete beams and the third form was specimens in substitution of steel reinforcement as strips cutting from bottles with dimensions (45*0.2*300)mm. The second test used a prism. 100*100*400 mm for tensile stresses and four little beams with dimensions 100*200*110 mm for test 80 cm × 80 cm × 5.8 cm slabs have been prepared, the result showed that 1.0% is the best percentage of circular fibers.

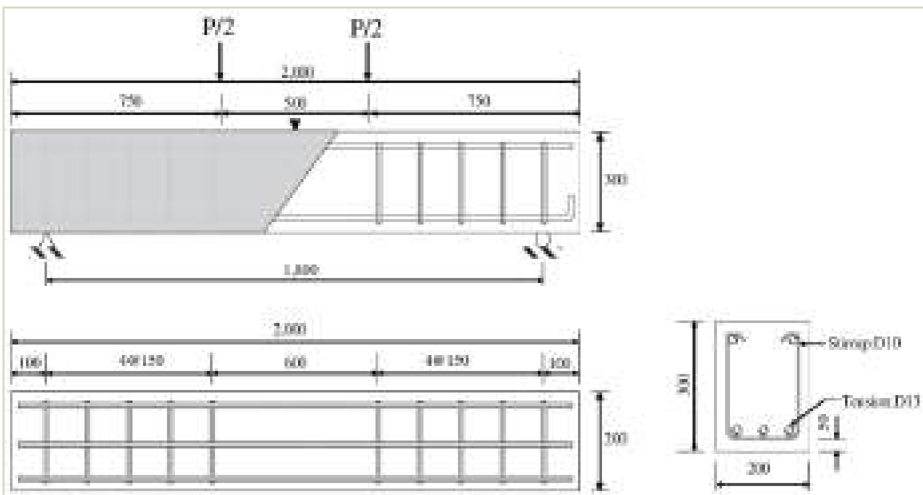


Fig. (2-23): Dimensions and Details of Reinforced Concrete Beam Specimen.

In 2014, Lopez et al. [31], utilized recycled PET fiber with dimensions of 4 mm width,0.34 thickness, and fibers with short and continuous length was 40mm,600mm cutting by the special device as shown in Fig. (2-25) as reinforcement for concrete beam with three fiber volume fractions of (0.00, 0.25, 0.5, 1.00) %. Seven concrete beams were tested after four weeks for flexural strength with dimensions (100*150*600) mm and the fibers placed in the mold with a separation between them of 15 mm as shown in Fig. (2-26) the results showed that the fiber reinforced concrete with both short and continuous fibers had better flexural strength, ductile behavior, and energy absorption capacity than the specimens without fibers.

Fig. (2-24): Forms of PET used (Circular fibers, half bottles, and strips).

Fig. (2-25): Device used to obtain recycled PET fibers.

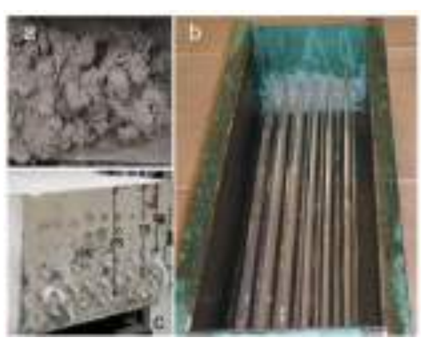


Fig. (2-26): Mold with short and continuous fiber respectively.

2.5: SUMMARY

From researchers, it noticed that they focused on:

- From literature, using 1.5% of PET fiber and 5% of PET particles as partial replacement of sand were the optimum percentages.

  In the present study, PET fiber with new shapes and different sizes are used.

- Limited researches related to use PVC and box wastes in concrete mixture found in the literature review.

- From literature, using PET bar as reinforcement in different patterns. In the present study, the same way to use these PET bars in additional new patterns is tried

Chapter Three
Experimental Work

CHAPTER THREE

EXPERIMENTAL WORK

3.1: GENERAL

The evaluation of the properties of materials used in the production of the concrete mixture is included in this chapter. The details of the materials used, the physical and chemical properties, and their proportion in each concrete mixture are presented. Then the nature of using plastic waste for knowing the difference between concrete mixture with or without this waste is investigated. Also, details of beams samples with different percentages and cross sections included these wastes were explained. Then tests on the specimens and the curing ages were showed. All tests are done in the laboratory of Material and Construction - College of Engineering /Misan University.

3.2: PROGRAM OF WORK

This chapter is divided into two parts; the first part includes a description of different types of the plastic wastes for different uses within the concrete mixture with various percentages and the second part includes the description of using the PET bottle waste as reinforcement in the beam are presented.

In the present study, the plastic wastes are used in various forms as shown in Fig. (3-1). The plastic wastes are used into concrete mixture either as a replacement for sand or added as fiber. In addition, some plastic wastes are formed to be used as reinforcement into structural members.

3.3: MATERIALS

In this research, the locally available materials are used. Ordinary Portland cement, tap water, fine aggregate, coarse aggregate, and plastic waste are used. The chemical additives are used to improve the workability.

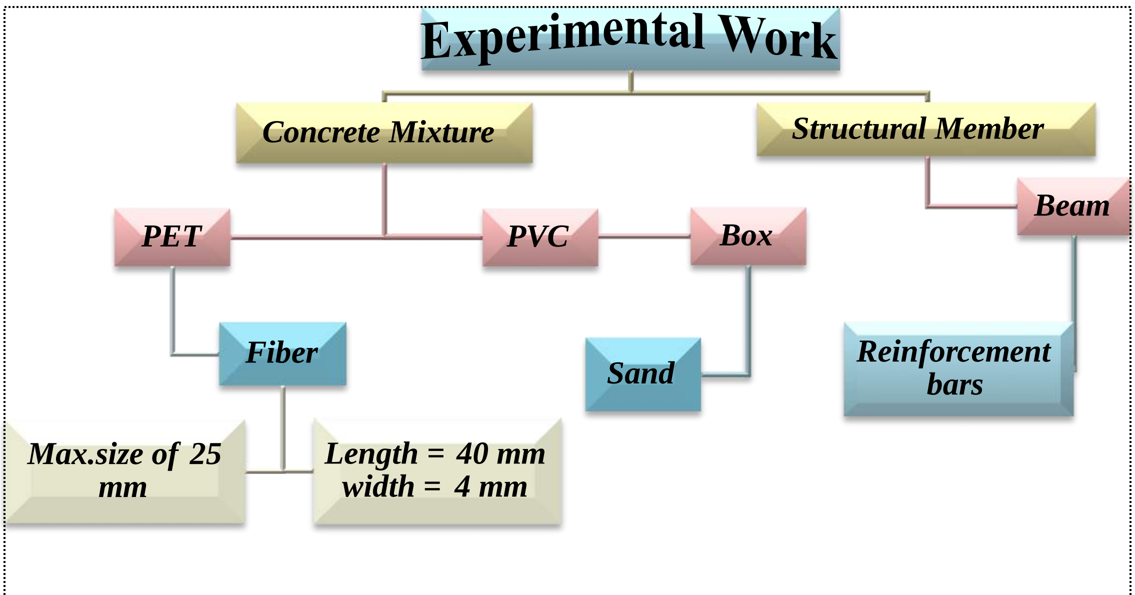


Fig. (3-1): Flowchart for Experimental work.

3.3.1 Cement

Ordinary Portland cement (Type 1) produced by Lafarge company (Kresta Trade name) is used in this study. It was placed in a dry place to keep the properties of cement from the impact of moisture. The chemical composition and physical properties of the cement are shown in Tables (3-1) and (3-2), respectively. The tests are done in the laboratory of Material and Construction – Technical Institute/Misan University according to the Iraqi Specification No.5/1984[32].

Table (3-1): Chemical Composition of Cement

Oxide composition	***Abbreviation***	***Content (percent) By weight***	***Limit of Iraqi specification No.5/1984[32]***
Lime	CaO	63.96	---
Silica	SiO_2	21.32	---
Alumina	AL_2O_3	4.58	---
Iron Oxide	Fe_2O_3	3.25	---
Sulphate	SO_3	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	C_3S	50.69	---
Di Calcium Silicate	C_2S	18.28	---
Tri Calcium Aluminate	C_3A	8.14	---
Tetra Calcium Alumina Ferrite	C_4AF	9.89	---

Table (3-2): Physical Properties of the Cement

Physical properties	***Test result***	***Limits of Iraqi Specification NO.5/1984[32]***
Fineness Using Blain Air Permeability Apparatus (m^2/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

Natural sand from the Basra region in the south of Iraq utilized in this study. The properties of the sand are shown in Table (3-3), Fig. (3-2) and Table (3-4), which included, the grading, the specific gravity, sulfate content, and absorption, respectively according to the Iraqi Specification No. 45/1984[33]

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

Sieve size (mm)	***Percent passing %***	***Cumulative passing % Limits of Iraqi specification No.45/1984 [33]***
10	100	100
4.75	95.6	90-100
2.36	87.73	75-100
1.18	76.04	55-90
0.60	50.25	35-59
0.3	11.75	8-30
0.15	2.4	0-10

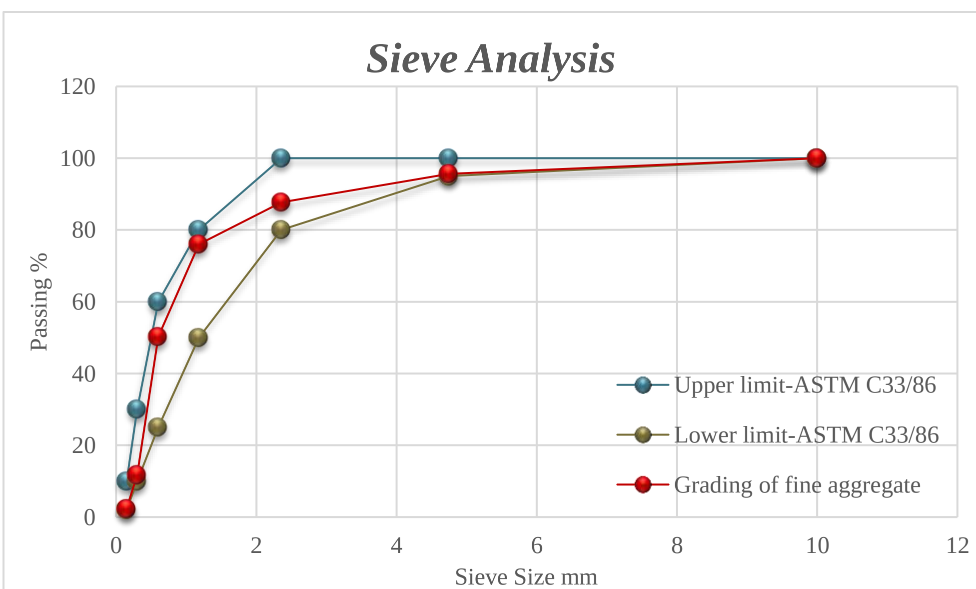


Fig. (3-2): Grading Curve for Original Fine Aggregate.

Table (3-4): Physical Properties of Fine Aggregate

Physical properties	*Test results*	*Limits of Iraqi specification No.45/1984 [33]*
Specific gravity	2.56	-
Sulfate content %	0.13	≤0.5%
Absorption %	0.75	-

3.3.3 Coarse Aggregate

The coarse aggregate used in this study is naturally available in Chilat region eastern Amarah. Gravel with a maximum size of (20 mm). The grading of coarse aggregate according to the Iraqi Specification No. 45/1984 [33] is shown in Table (3-5).

Table (3-5): Grading of Coarse Aggregate

NO	*Sieve size*	*%Passing*	
		% Coarse Aggregate	*Iraqi specification No. 45/1984[33]*
1	37.5 mm	100	100
2	20 mm	95	95-100
3	10 mm	39.83	30-60
4	5 mm	1.145	0-10

3.3.4 Mixing Water

The Osmosis recycled (R.O) water was utilized for casting and curing all the specimens.

3.3.5 Admixture

Super plasticizer admixture utilized in this study to increase the workability of the fresh concrete because of the presence of plastic. The liquid Type PC 260 is used, and it is conforming with ASTM C494-99 Types A and G [34]. It is a technical specification according to the international specifications shown in Table (3-6).

3.3.6 Steel Reinforcement

The deformed steel bars of 12.7 mm diameter were employed as tension reinforcement and 9.5 mm diameter for shear reinforcement and for anchored top bars to fix the stirrups. Table (3-7) shows the properties of reinforcing bars.

Table (3-6): Technical Description of Flocrete PC 260

Chemical Base	***Modified polycarxylates based polymer***
Appearance/colors	Light yellow liquid
Freezing point	-7^{0} C approximately
Specific gravity @ 25^{0} C	1.1±0.02
Air entrainment	Typically less than 2 % additional air is entrained above control mix at normal dosages
Dosage	0.5 to 4.0 liter per 100 kg of binder
Storage condition/Shelf Life	12 months if stored at temperatures between 2^{0} C and 50^{0} C

Table (3-7): Properties of Steel Reinforcement

Bar type	*Bar diameter (mm)*	*Bar area (mm^2)*	*Yield strength fy (MPa)*	*Tensile strength fu (MPa)*	*Yield strain*
Longitudinal steel bars	6	28.26	533	631	0.00267
Longitudinal steel bars *Steel stirrups*	10	78.5	515	624	0.00258
Longitudinal steel bars	12	113.04	493	583	0.00247

3.3.7 Plastic

Three types of plastic were used in the present study:

3.3.7.1 Plastic waste Type 1:

Polyvinyl chloride (PVC) waste from the plastic factory in Maysan province with a maximum size of 10 mm. This type had an irregular shape (not spherical), and its color is white as shown in Fig. (3-3), the grading of PVC is closer to the grading of sand according to the Iraqi specification No.45/1984[33] of Zone 1, but it does not achieve the gradient of all the sieves as shown in Table (3-8).

Table (3-8): Grading of Plastic Waste Type 1 (PVC).

Sieve size	*Cumulative % passing*
12.7 mm	100
9.5mm	94.74
4.75 mm	52.63
1.18 mm	32.105
0.6 mm	26.654
0.3 mm	22.331
Pan	11.8

Fig. (3- 3): Plastic Waste Type 1 (PVC).

3.3.7.2 Plastic waste Type 2:

Plastic box from the waste container in Maysan province with a maximum size equal to 12.7 mm. This type had irregular shape too, and it had many colors (black, blue, and green) as shown in Fig. (3-4), the grading of this type of plastic waste is closer to the grading of sand according to the Iraqi specification No.45/1984[33] of Zone 1, but it does not achieve the gradient of all the sieves as shown in Table (3- 9).

Fig. (3-4): Plastic Waste Type 2(Plastic box).

Table (3-9): Grading of Plastic Waste Type 2 (plastic box)

Sieve size	*Cumulative % passing*
19 mm	100
12.7 mm	98.315
9.5 mm	87.39
4.75 mm	13.05
1.18 mm	1.488
Pan	0

3.3.7.3 Plastic waste Type 3:

Polyethylene Terephthalate PET from the waste container in Maysan province. This type used in two types large and small PET bottle. Large PET bottle cut with a random shape and it had two colors (white and green) as shown in Fig. (3-5), the grading of a large PET bottle is not closer to the grading of sand or gravel according to the Iraqi specification No.45/1984[33] as shown in Table (3-10), while small PET bottle was approximately rectangular with average length (40 mm) and width (4mm).

a)  b) 

Fig. (3-5): Plastic Type (3), a) Large PET bottle particles b) Small PET bottle particles.

Table (3-10): Grading of Plastic Waste Type 3 (large PET)

Sieve size	*Cumulative % passing*
38.5 mm	100
25.4 mm	97.7
19 mm	80.55
12.7 mm	45.08
9.5 mm	24.485
4.75 mm	10.755
1.18 mm	8.467

Table (3-11): Properties of PET bottle (small) Used in this Work [35].

Property	*Type a*
Bulk Density Kg/m^3	447
Specific gravity	1.258
Water Absorption (24 hr)	0%
Thickness	(0.14-1) mm
Tensile (Young's Modulus) MPa	1700-2510
Melting temperature Tm	255
Yield strain ε % (Tensile)	60
Tensile yield stress (MPa)	60

Table (3-12): Properties of PET bottle (large) Used in this Work [36].

Property	*Type b*
Density (kg/m^3)	1410
Specific gravity	1.38
Thickness	0.2 mm
Water Absorption (24 hr)	0.5
Tensile (Young's Modulus) MPa	1700
Melting temperature Tm	538
Ultimate strain ε %	180
Flexural modulus (rigidity) E-MPa, (3-point –Flexure	2000
Yield strain ε % (Tensile)	4
Breaking strength σB- MPa, (Tensile)	50

3.4: MIXTURE USED

The reference mixture designed according to ACI Recommended Practice 211.1 and checked by trial batches. The procedure is as follows:

1. The slump chosen after trial batches according to mixes from previous studies, So the slump chosen for the case of the beam was 200 mm.
2. The maximum size of the aggregate was 20 mm.
3. Water content from ACI 211.1-91 for the case of a slump is equal to 200 mm, and the maximum size of aggregate is 20 mm, then the water content = 203 kg/m^3.
4. Water to cement ratio chosen in this study for the sake of analysis are 0.41 and 0.53
5. Cement content is chosen based on the relationship:

$$\text{The weight of cement} = \frac{\textbf{Weight of water}}{\mathbf{w/c}} \quad \text{………..….Eq. (3-1)}$$

$$= \frac{\mathbf{203}}{\mathbf{0.41}} = 495.12 \text{ kg/m}^3$$

6. The coarse aggregate estimated based on the maximum size of aggregate = 20 mm and on the grading of fine aggregate = 2.6, the bulk volume was 0.64, so the coarse aggregate is equal to the bulk density of coarse aggregate multiplied by the bulk volume
   Coarse aggregate content = 0.64 * 1600 = 1024 kg/m^3
7. The fine aggregate estimated by using the so-called absolute volume method as follow;

$$\frac{W}{1000} + \frac{C}{1000\,Pc} + \frac{F.A}{1000\,Pf.A} + \frac{C.A}{1000\,P\,c.A} = \mathbf{1} \quad \text{………. …Eq. (3-2)}$$

$$\frac{\mathbf{203}}{\mathbf{1000}} + \frac{\mathbf{495.12}}{\mathbf{1000*3.15}} + \frac{F.A}{\mathbf{1000*2.58}} + \frac{\mathbf{1024}}{\mathbf{1000*2.64}} = \mathbf{1}$$

So, the fine aggregate = 649.64 kg/m^3

- The final mixtures are shown in Fig. (3-6):

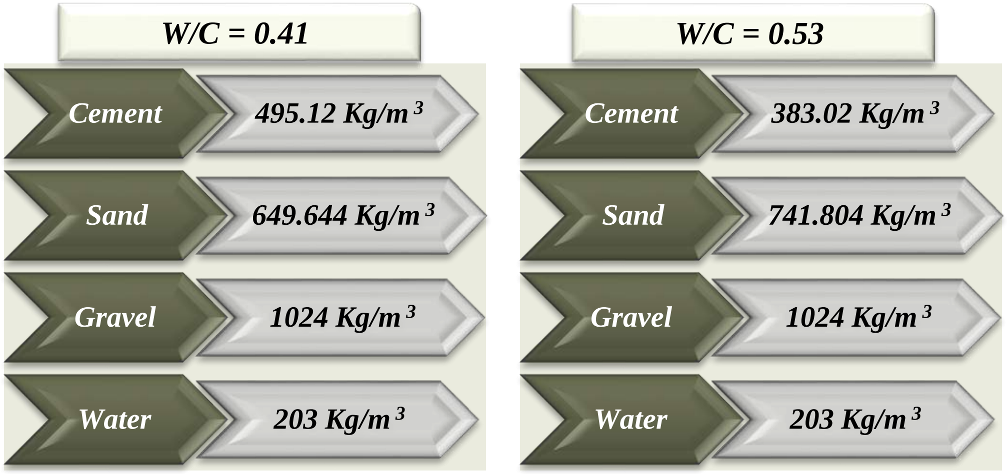


Fig. (3-6): Mixtures designed with two w/c.

Super plasticizer is added to the mixture by weight of cement with a percentage of 0.8% from the equation below;

$$SP\ (\%) = \frac{(w/c)_{old} - (w/c)_{SP}}{(w/c)_{old}} \quad \text{.........Eq. (3-3)}$$

$$0.8\% = \frac{0.41 - (w/c)_{SP}}{0.41} \rightarrow (w/c)_{SP} = 0.40672$$

$$(w/c)_{SP} = \frac{\text{Weight of water}}{\text{Weight of cement}} \rightarrow 0.40672 = \frac{\text{Weight of water}}{495.12}$$

∴ Weight of water = 201.37kg/m^3

3.5: EXPERIMENTAL WORK

The experimental program included many of mixes to study the effect of waste plastic percentages on the concrete properties, three types of these wastes with different proportions were used to select the best percentage from each type by comparison with the reference mix. Then the selected mixes are used in structural beam specimens in different forms to investigate its effect on beam behavior. Thus, the experimental work was divided into two primary phases:

- Phase I: Focused on the impact of plastic waste on the mechanical properties of concrete. Six cubes with dimensions of (100*100*100) mm, six cylinders with dimensions of (100*200) mm, and six prisms with dimensions of (100*100*500) mm were casting for each percentage of waste to calculate compressive, split tensile, and flexural strengths.
- Phase II: focused on the effect of plastic waste on the structural behavior of beam specimens. Many patterns for using waste plastic in beams are used, namely as a sand replacement, as fiber, or as reinforcement bars. Nineteen concrete beams with various mixes and reinforcement were cast and compared with the reference beam.

3.5.1 Concrete Mixture

As mentioned previously there are three types of mixtures with plastic waste namely, PVC, boxes, and PET.

Accordingly, this section is divided into three parts, each part focused on one type of plastic wastes, via mixture proportion, percentages that used in the mix as shown in Figures (3-7) and (3-8). A super plasticizer is added to all mixes with 0.8% by weight of cement since it is found that plastic reduces the homogeneous of the mix. A slump test is accomplished for each batch. The plastic wastes of boxes and PET are cutting by a special machine manufactured for the research purposes as shown in Fig. (3-9). This machine has weight equal to almost 200kg, dimensions of (116cm Length, 45cm width, and 150cm Height), and with a capacity up to 20 bottles to cut. Also, it contains a rear motor with a diameter of 16cm approximately. At the top there is a small door opens to insert the bottles to be cut, where contain inside the sharp blades to the bottles and the bottom is a filter with openings can be changed to the required size through which bottles are extracted from the bottom.

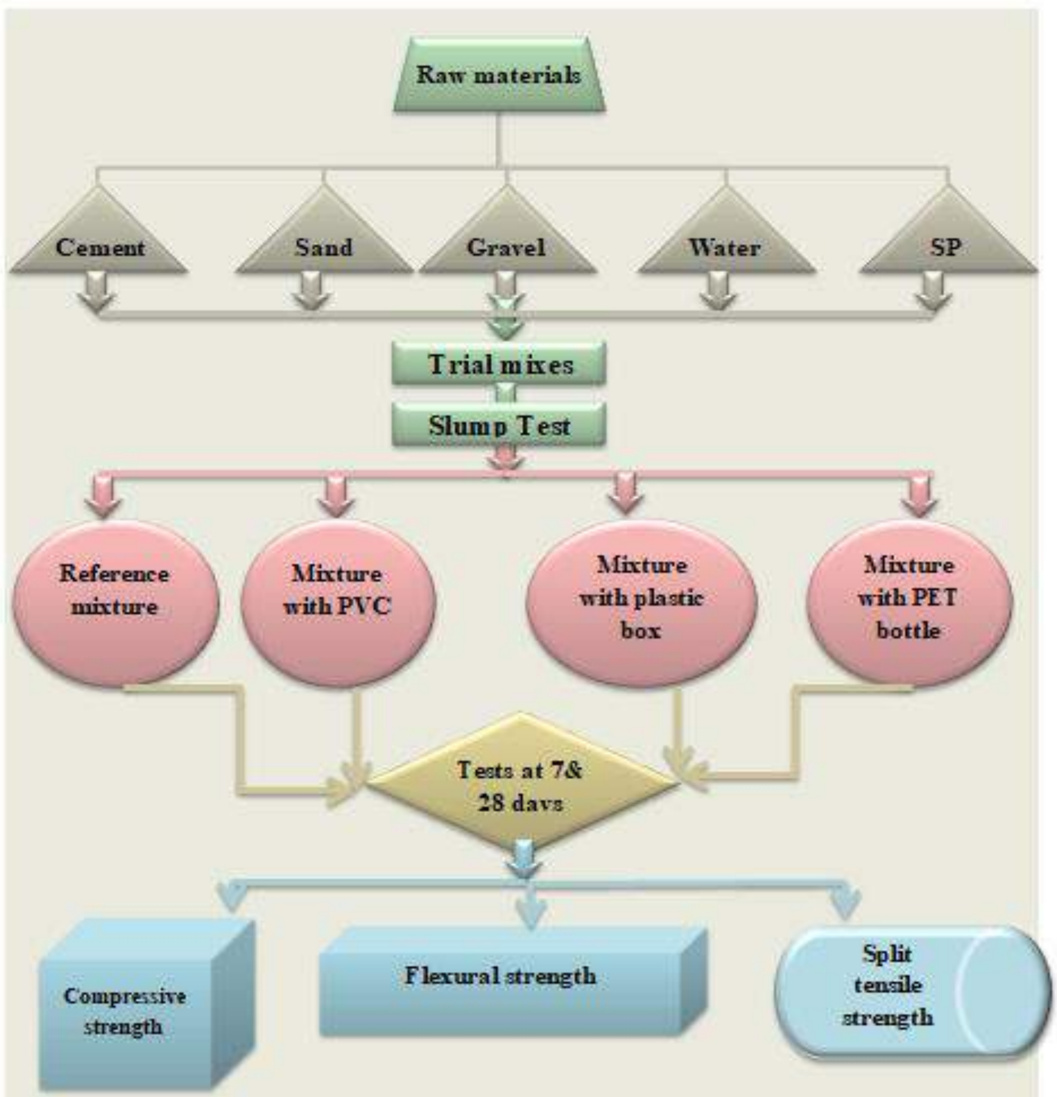


Fig. (3-7): Flowchart for the experimental work for the concrete mixture.

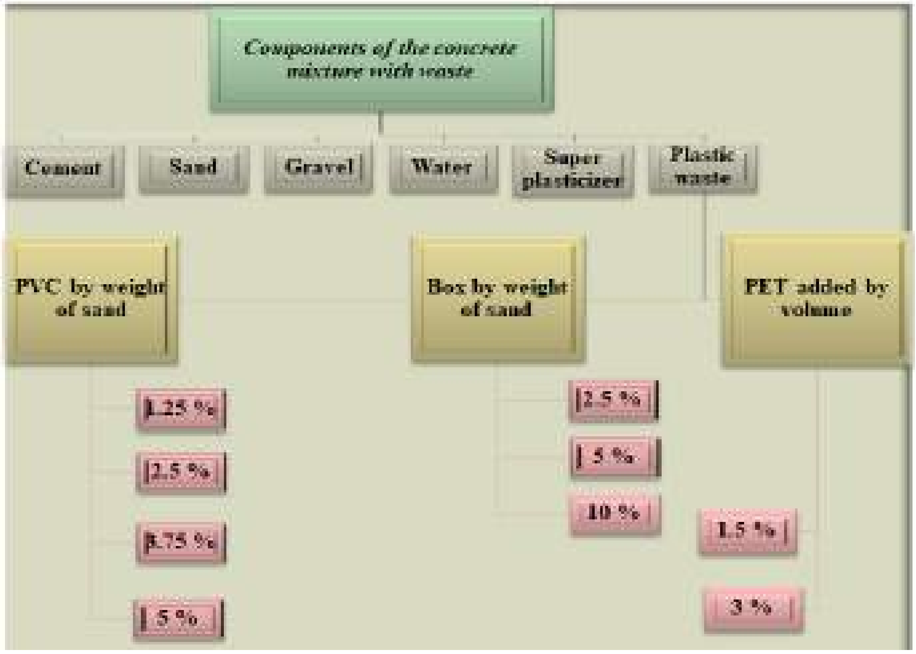


Fig. (3-8): Concrete mixture with plastic waste.

a)

b)


Fig. (3-9): Machine used to cut plastic waste a) Side view b) Internal composition of the machine.

c) *d)* *e)* *f)*

Fig. (3-9): Continued

c) Cutting blades d) Side view of blades e) Side view of the machine shows the motor of machine f) Inclined view of the machine.

Type I: Polyvinyl chloride (PVC) used as a particular replacement of sand

Polyvinyl chloride (PVC) waste are obtained from Plastic Factory in Amarah City, the center of Maysan Province. These wastes are side effect during the process of production PVC pipes in this factory. PVC waste is used directly without any treatment or resize, the maximum size of particles obtained is 9.5 mm and used in the concrete mixture with different percentages as replacement of sand by weight, in which two (w/c) were used namely 0.41 and 0.53 as shown in Table (3-13). Four percentages of PVC waste are used in the present study, namely,1.25 %, 2.5 %, 3.75 %, and 5 %.

Table (3- 13): Concrete mixture proportion with PVC

	Case I		**W/C = 0.41**		
Material (Kg/m^3)	**0%**	**1.25%**	**2.5%**	**3.75%**	**5%**
Cement	495.12	495.12	495.12	495.12	495.12
Sand	649.644	641.523	633.403	625.282	617.164
Gravel	1024	1024	1024	1024	1024
Water	201.38	201.38	201.38	201.38	201.38
PVC	-	8.121	16.2411	24.352	32.48
SP	3.961	3.961	3.961	3.961	3.961
	Case II		**W/C = 0.53**		
Material (Kg/m^3)	**0%**	**1.25%**	**2.5%**	**3.75%**	**5%**
Cement	383.02	383.02	383.02	383.02	383.02
Sand	741.804	732.53	723.259	713.98	704.7138
Gravel	1024	1024	1024	1024	1024
Water	201.38	201.38	201.38	201.38	201.38
PVC	-	9.272	18.545	27.817	37.0902
SP	3.064	3.064	3.064	3.064	3.064

Type II: Plastic Boxes used as a particular replacement of sand

Plastic boxes are collected from waste containers in Maysan province and used in the concrete mixture as a sand replacement by weight. Three percentages of Plastic box waste are used in the present study, namely 2.5 %, 5 %, and 10 % with single w/c of 0.41 as shown in Table (3-14). The waste cutting using a machine to get on maximum size 0f 12.7 mm as shown in Fig. (3-10).

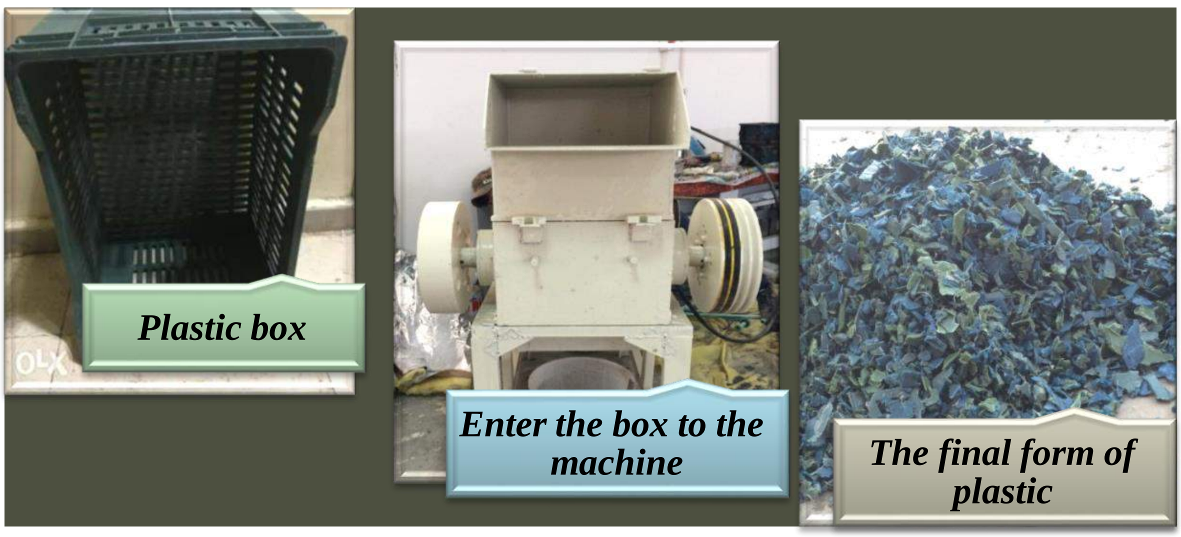


Fig. (3-10): Steps to prepare the particles of the plastic box.

Table (3-14): Concrete mixture Proportion with plastic box

Material (Kg/m^3)	***0%***	***2.5%***	***5%***	***10%***
Cement	495.12	495.12	495.12	495.12
Sand	649.644	633.4029	617.1618	584.6796
Gravel	1024	1024	1024	1024
Water	201.38	201.38	201.38	201.38
PL	-	16.2411	32.4822	64.9644
SP	3.961	3.961	3.961	3.961

Type III: Polyethylene Terephthalate PET used as fiber

Polyethylene Terephthalate PET used in the present study are collected from waste containers in Maysan province in which there are two sizes commonly available small and large bottles as shown in Fig. (3-11). PET is added as fibers to the concrete mixture by volume of the mix using two shapes of fibers as shown in Table (3-15) with two percentages 1.5 % & 3 %. The first shape was irregular fiber cutting using a special machine with a maximum size of 25.4 mm as shown in Fig. (3-12), while the second shape was regular fiber cutting manually with 40 mm length and 4 mm width as shown in Fig. (3-13)

Table (3-15): Concrete mixture with PET bottle

Material (Kg/m^3)	Plastic Type	Regular hand fiber		Irregular machine fiber	
	0%	1.5%	3%	1.5%	3%
Cement	495.12	495.12	495.12	495.12	495.12
Sand	649.64	649.64	649.64	649.64	649.64
Gravel	1024	1024	1024	1024	1024
Water	201.38	201.38	201.38	201.38	201.38
PL	-	6.705*	13.41*	21.15#	42.3#
SP	3.961	3.961	3.961	3.961	3.961

*** (**Percentage of PET * Density of small PET)

(Percentage of PET * Density of large PET)

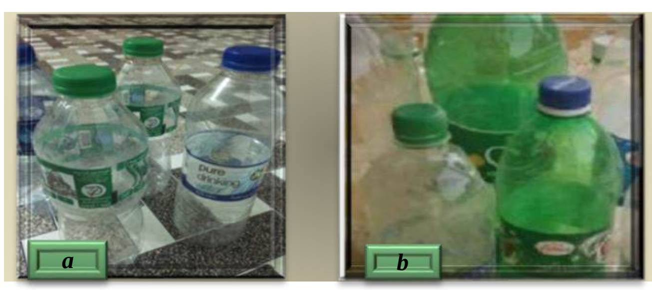


Fig. (3- 11): Types of PET bottle a) small PET b) large PET.

Fig. (3- 12): Steps to prepare the particles of regular hand PET fiber.

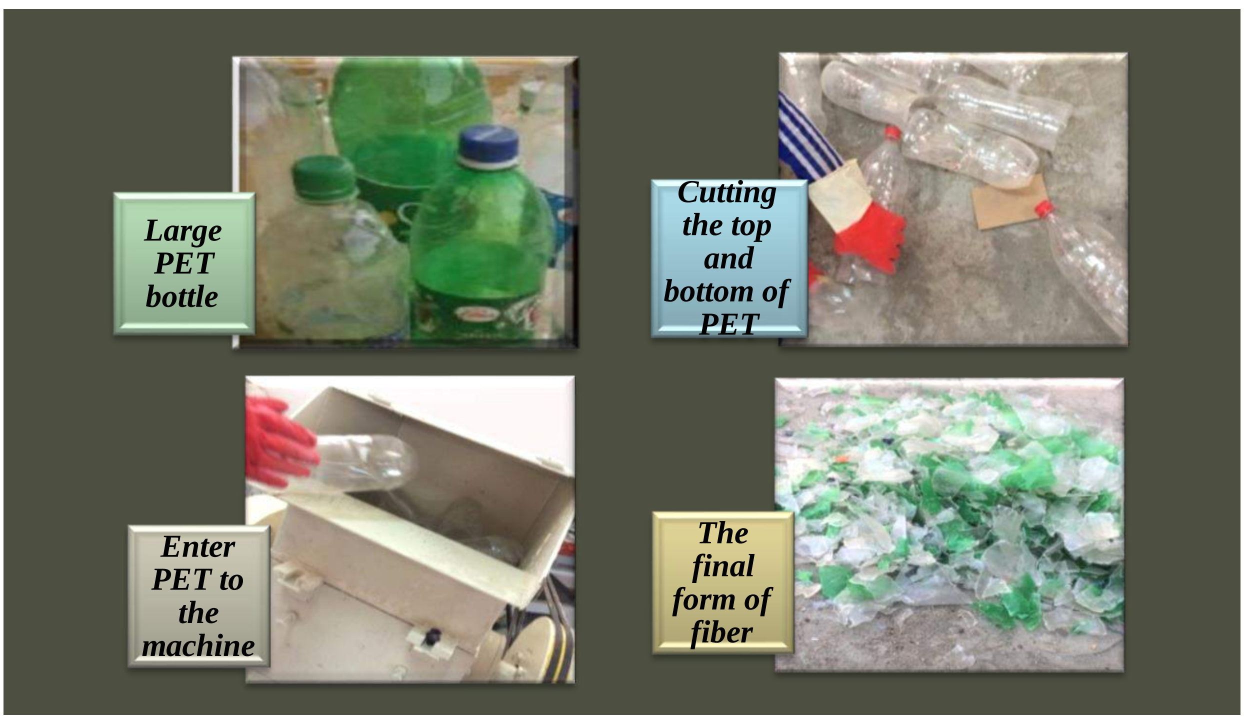


Fig. (3-13): Steps to prepare the particles of irregular machine PET fiber.

3.5.2 Structural Member

3.5.2.1 Beam Molds

Wooden molds are utilized for casting all concrete beams, as shown in Fig. (3-14). All molds consist of a wooden base and four moving sides that connect and with the base by bolts and screws. The beam is simply supported with span length 1400 mm, and the cross section is rectangular (b×h=150×200mm).

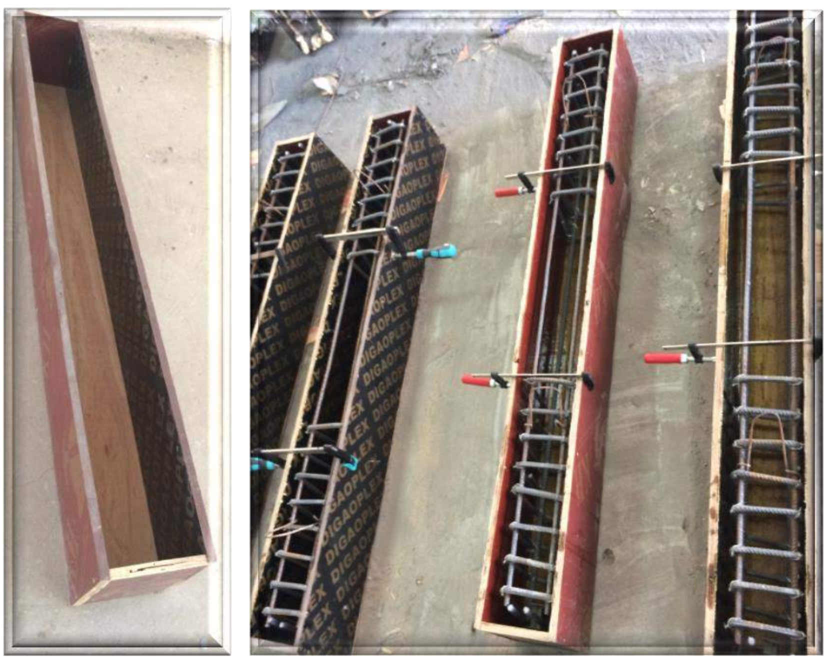


Fig. (3-14): Beam Molds and Reinforcement.

3.5.2.2 Details of Concrete Beams

Nineteen concrete beams are cast in this study, with different arrangements of reinforcement. Some beams are reinforced with deformed rebar, as shown in Fig. (3-15), which include two bars of 12.7 mm diameter as tension reinforcement, stirrups reinforcement of 9.5 mm diameter at 60 mm c/c and two bars of 9.5 mm as anchorage bars to fix the stirrups. Other beams were reinforced with PET bottle as partial or fully reinforcement.

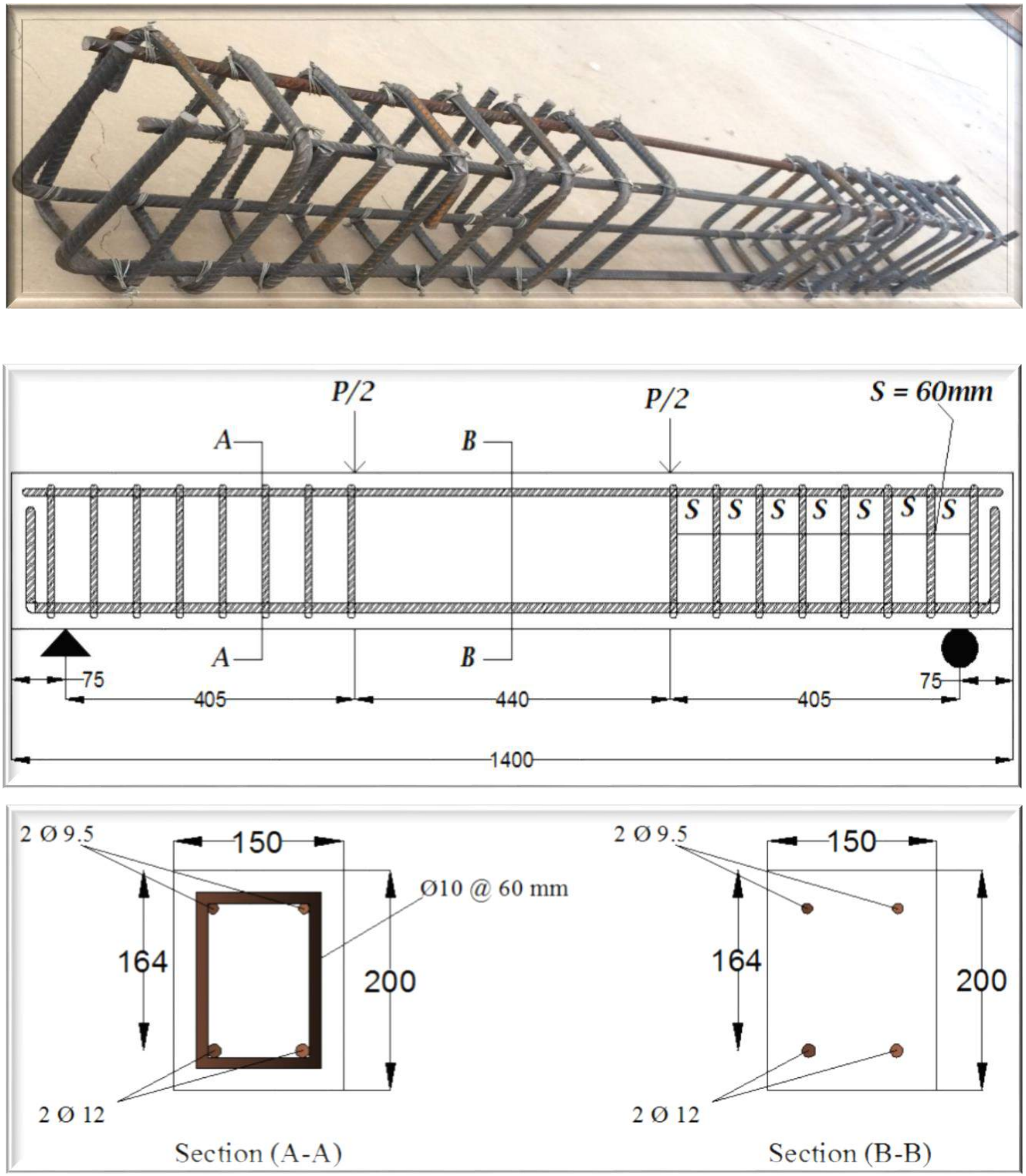


Fig. (3-15): Dimensions and Details of Beam Specimen.

3.5.2.3 Flexural Reinforcement

The flexural reinforcement of beam is designed to ensure that, the compression part of the beam and the section fails in flexure with tension controlled failure. All beams are designed according to ACI 318-95 Code [37]. The steps of analysis of the reference beam are shown in the Appendix.

3.5.2.4 Shear Reinforcement

The shear reinforcement of beam is designed according to ACI 318-95[37] to ensure that, the section withstand the shear force. The steps to calculate the shear load to ensure that the section fails in flexure with sufficient shear resistance are shown in the Appendix.

3.5.2.5 Test Variables

Nineteen beams with various variables are tested in the present study. Test variables include the type of plastic waste added to the mixture, the percentage of plastic waste, reinforcement type, and hybrid cross section of beams as shown in Tables (3-16), (3-17) and Fig. (3-16), respectively.

Table (3-16): Beams Variables

No.	***Beam Designation***	***Waste type***	***Cross section***	***Percentage of plastic waste***	***Tension reinforcement***	***Waste replacement***
1	*B1-0-ho-0%-S*	*Normal concrete*	*Homogenous*	*0 %*	*Steel Rebar*	*-*
2	*B2-0-ho-0%*	*Normal concrete*	*Homogenous*	*0 %*	*No reinforcement*	*-*
3	*B3-1-ho-1.25%-S*	*PVC, Type 1*	*Homogenous*	*1.25 %*	*Steel Rebar*	*Sand replacement*

Table (3-16): Continued.

4	*B4-2-ho-5%-S*	*Boxes, Type 2*	*Homogenous*	*5 %*	*Steel Rebar*	*Sand replacement*
5	*B5-3ai-ho-1.5%-S*	*PET, irregular Type 3a*	*Homogenous*	*1.5 %*	*Steel Rebar*	*Fiber by volume of mix*
6	*B6-3ar-ho-1.5%-S*	*PET, regular Type 3a*	*Homogenous*	*1.5 %*	*Steel Rebar*	*Fiber by volume of mix*
7	*B7-1-hy-1.25% 10%-S*	*PVC, Type 1*	*Hybrid*	*1.25% in com 10% in Ten.*	*Steel Rebar*	*Sand replacement*
8	*B8-2-hy-5% 10%-S*	*Boxes, Type 2*	*Hybrid*	*5% in com. 10% in Ten.*	*Steel Rebar*	*Sand replacement*
9	*B9-3-hy-1.5%bi 3%ar-S*	*PET, Type3*	*Hybrid*	*1.5% in com. 3% in Ten.*	*Steel Rebar*	*Fiber by volume of mix*
10	*B10-0-ho-0%-P1*	*Normal concrete*	*Homogenous*	*0 %*	*Plastic rebar Type 1*	-
11	*B11-0-ho-0%-P2*	*Normal concrete*	*Homogenous*	*0 %*	*Plastic rebar Type 2*	-
12	*B12-0-ho-0%-P3*	*Normal concrete*	*Homogenous*	*0 %*	*Plastic rebar Type 3*	-
13	*B13-0-ho-0%-P4*	*Normal concrete*	*Homogenous*	*0 %*	*Plastic rebar Type 4*	-
14	*B14-0-ho-0%-P5*	*Normal concrete*	*Homogenous*	*0 %*	*Plastic rebar Type 5*	-
15	*B15-0-ho-0%-P6*	*Normal concrete*	*Homogenous*	*0 %*	*Plastic rebar Type 6+steel bar*	-
16	*B16-0-ho-0%-P7*	*Normal concrete*	*Homogenous*	*0 %*	*Plastic rebar Type 7+steel bar*	-
17	*B17-0-ho-0%-P8*	*Normal concrete*	*Homogenous*	*0 %*	*Plastic rebar Type 8+steel bar*	-
18	*B18-0-ho-0%-P9*	*Normal concrete*	*Homogenous*	*0 %*	*Plastic rebar Type 9+steel bar*	-
19	*B19-0-ho-0%-P10*	*Normal concrete*	*Homogenous*	*0 %*	*Plastic rebar Type 10*	-

Where, the symbols used in naming the beams as follows:

Bi-j- ho, hy-%-S, P

Where;

Symbol	The symbol's meaning	Symbol	The symbol's meaning
i	1,2,3, 4, …	S	steel reinforcement
j	0,1,2,3ai,3ar,3bi	P1	plastic reinforcement Type 1
0	normal concrete	P2	plastic reinforcement Type 2
1	PVC, Type 1	P3	plastic reinforcement Type 3
2	Boxes, Type 2	P4	plastic reinforcement Type 4
3ai	irregular PET, Type 3a	P5	plastic reinforcement Type 5
3ar	regular PET, Type 3a	P6	plastic reinforcement Type 6
3bi	irregular PET, Type 3 b	P7	plastic reinforcement Type 7
ho	homogenous	P8	plastic reinforcement Type 8
hy	hybrid	P9	plastic reinforcement Type 9
%	waste percentage	P10	plastic reinforcement Type 10

Table (3-17): Beams details

Beam Name	Constituent	A form of plastic and reinforcement used
Normal Mixture with different reinforcement		
B1-0-ho-0%-S	*Reference beam with normal mixture and reinforcement*	
B2-0-ho-0%	*Plain concrete beam*	

Table (3-17): Continued.

Different Mixture		
B3-1-ho-1.25%-S	*Beam with an optimum* mixture of PVC that equal to 1.25 % by weight of sand and normal reinforcement*	 
B4-2-ho-5%-S	*Beam with an optimum* mixture of a plastic box that equal to 5 % by weight of sand and normal reinforcement*	 
B5-3ai-ho-1.5%-S	*Beam with an optimum* mixture of small PET bottle pieces that equal to 1.5 % by volume of mix and normal reinforcement*	 

**1.25%, 5%, and 1.5% are the optimum percentages of PVC, plastic boxes, and PET, respectively, as shown in Chapter four, Section 4.3.2.1*

Table (3-17): Continued.

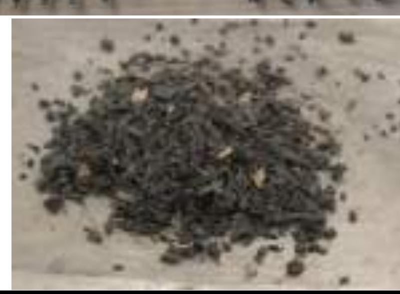
B6-3ar-ho-1.5%-S	*Beam with an optimum* mixture of small PET bottle fiber that equal to 1.5 % by volume of mix and normal reinforcement*	 
	Hybrid Mixture	
B7-1-hy-1.25% 10%-S	*Beam with two mixtures (Hybrid PVC) one of them in the compression part that consists of 1.25 % PVC and the other in the tension part consists of 10 % PVC and normal reinforcement*	 
B8-2-hy-5% 10%-S	*Beam with two mixtures (Hybrid plastic box) one of them in the compression part that consists of 5 % Plastic box and the other in the tension part consists of 10 % Plastic box and normal reinforcement*	 

Table (3-17): Continued.

B9-3-hy-1.5%bi 3%ar-S	*Beam with two mixtures (Hybrid PET bottle) one of them in the compression part that consists of 1.5 % large PET bottle and the other in the tension part consists of 3 % small PET fiber and normal reinforcement*	  
	Different Reinforcement	
B10-0-ho-0%-P1	*Beam with the normal mixture and tension reinforcement with bar consists of large PET bottle rolled and fixed with each other by small PET bottle and neck of the bottle and filled with plastic box*	 
B11-0-ho-0%-P2	*Beam with the normal mixture and tension reinforcement with bar consists of large PET bottle and put inside them small PET bottle*	 

Table (3-17): Continued.

B12-0-ho-0%-P3	*Beam with the normal mixture and tension reinforcement with bar consists of large PET bottle rolled and put inside them small PET bottle rolled too and contacted with each other with the neck of the bottle*	
B13-0-ho-0%-P4	*Beam with the normal mixture and tension reinforcement with bar consists of small PET bottle rolled and covered in the middle with the neck of the bottle and filled with PVC*	
B14-0-ho-0%-P5	*Beam with the normal mixture and tension reinforcement with two layers of large PET bottle cut into two parts and connected with stirrups and top reinforcement*	

Table (3-17): Continued.

Hybrid reinforcement		
B15-0-ho-0%-P6	*Beam with the normal mixture and normal reinforcement with the addition of one layer of large PET bottle cut into two parts and connected with stirrups*	
B16-0-ho-0%-P7	*Beam with the normal mixture and tension reinforcement with bar consists of large PET bottle rolled around steel reinforcement*	
B17-0-ho-0%-P8	*Beam with the normal mixture and tension reinforcement with bar consists of large PET bottle rolled around Small PET bottle that rolled too that rolled around steel reinforcement*	
B18-0-ho-0%-P9	*Beam with the normal mixture and tension reinforcement with bar consists of small PET bottle rolled around steel reinforcement*	
B19-0-ho-0%-P10	*Beam with the normal mixture and fully reinforcement with PET bottle*	

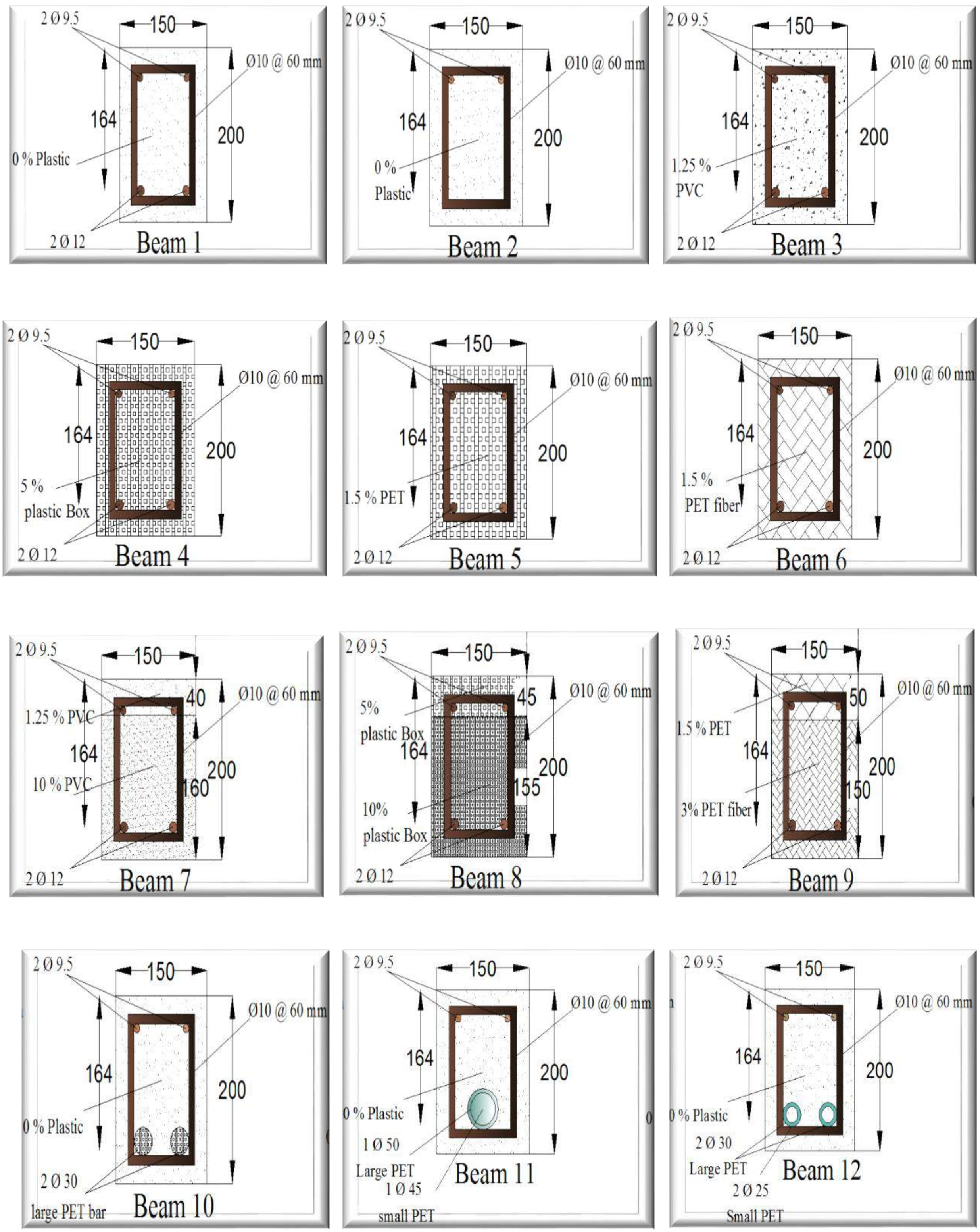


Fig. (3-16): Beams details.

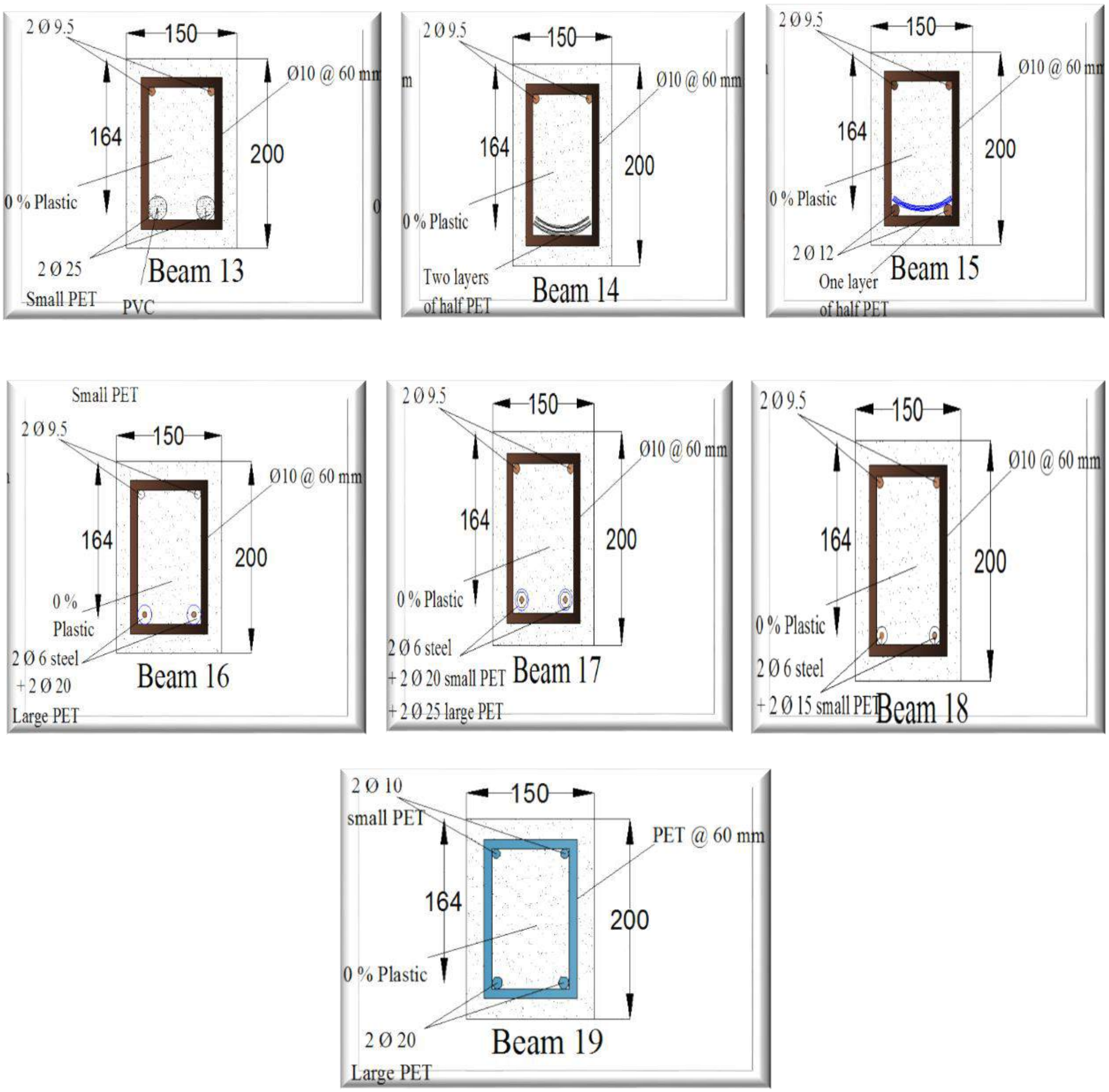


Fig. (3-16): Continued.

3.6: MIXING PROCEDURE

Mixes are batching in the structural lab at college of Engineering, Misan university according to the following procedure:

1- All materials required for each mixture are weighed and placed in a clean area.

2- Gravel and sand are washed with clean water and left to dry before mixing.
3- The mixing process started with mixing sand to the gravel, then the cement and the plastic waste are added to the mixture. Finally, the water and super plasticizer are added to the mix gradually with the continuous mixing, see Fig. (3-17).

Fig. (3-17): Method of mixing.

One of the problems encountered during the mixing is the difficulty of mixing due to the presence of plastic waste which reduces the workability of the mixture. Therefore, super plasticizer was used to overcome this problem, especially PVC waste because its nature is like dust or soil so that the components of the mixture are separated from each other. The other problem is the segregation that occurs when the mixture is shaken using the vibrator, so manual shaking was used to overcome it, see Fig. (3-17)

3.7: CASTING AND CURING PROCEDURE

Initially, the molds are prepared to grease the inner sides, and the reinforcement cages are installed into the mold. Then concrete is casting into the mold by three layers with compaction using a vibrator. Finally, the top concrete surface for each mold is leveled as shown in Fig. (3-18)

Fig. (3-18): Casting and curing of beams.

All beams de-molded after one day and covered with a sheet and watered from time to time to keep the humidity during the curing time that finished after 28 days to prepare the beams for testing.

3.8: TESTS ON CONCRETE MIXTURE

3.8.1 Fresh Concrete Tests

3.8.1.1 Slump Test

Workability is one of the important properties defining the fresh properties of concrete and Concrete is said to be workable when it had appropriate consistency, handled without segregation, cast without loss inhomogeneity and compacted with less effort. This test is prescribed according to ASTM C143[38] as shown in Fig. (3-19).

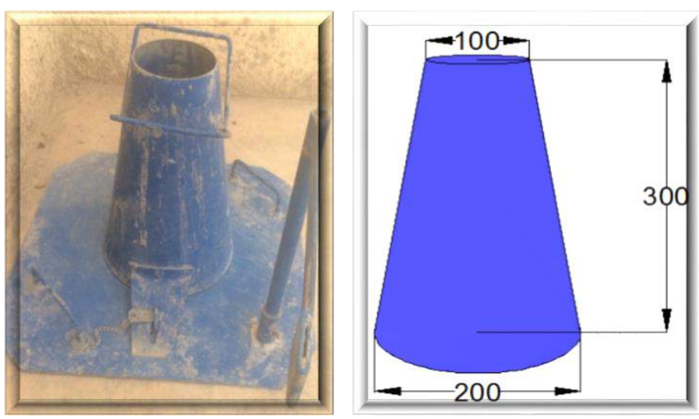


Fig. (3-19): The slump cone used in the slump test.

3.8.2 Hardened Mechanical Tests

3.8.2.1 Compressive Strength Test

The British standards BS1881: Part 16:1983[39] was adopted to examine the compressive strength of concrete using cubical (100*100*100) mm specimens for testing. This test was done in the College of Engineering, Misan University, using a compression machine with a capacity of (2000 kN) as shown in Fig. (3-20)

Fig. (3-20): Compressive Strength Test.

3.8.2 Splitting Tensile Strength

The ASTM- C496[40] was adopted to examine the split tensile strength of concrete using cylindrical (100*200) mm specimens for testing. This test was done in the College of Engineering, Misan University, using Compression machine with a capacity of (2000 kN) as shown in Fig. (3-21).

Fig. (3-21): Split tensile strength Test.

3.8.3 Flexural Strength Test

The ASTM- C78[41] was adopted to examine the flexural strength of concrete using prism (100*100*500) mm specimens for testing. This test was done in the College of Engineering, Misan University, using Flexural machine with a capacity of (50 kN) as shown in Fig. (3-22).

The following equation is utilized to calculate the flexural strength:

$$fr = \frac{3PL}{2bd^2} \quad \text{……………………………………………. Eq. (3-4)}$$

where:

fr: modulus of rupture (MPa)

P: maximum applied load (N)

L: span length (mm)

b: average width of the specimen (mm)

d: average depth of specimen (mm)

Fig. (3-22): Flexural strength Test.

3.9: TESTING OF CONCRETE BEAMS

3.9.1 Testing Machine

In the structural laboratory of Misan University, a hydraulic manual jack machine was used. The testing set up machine showed in Fig. (3-23), consists of two basic parts. Two points loads and supports. This machine with dimensions of (300cm Length, 200cm width, and 200cm Height),

The distance between the two points loads was 440 mm. The loads are applied in successive increments of (5kN) until reaching to the failure load. At each load increment, observations were recorded such as the deflection and first crack and draw crack patterns.

3.9.2 Deflection Reading

Dial gauge was used to calculate the deflections for all beams at every load stage. The dial gauge was placed under the mid-span of the beam and had an accuracy of (0.01 mm) with a maximum reading of 5 cm as shown in Fig. (3-24).

Fig. (3-24): Dial gauge.

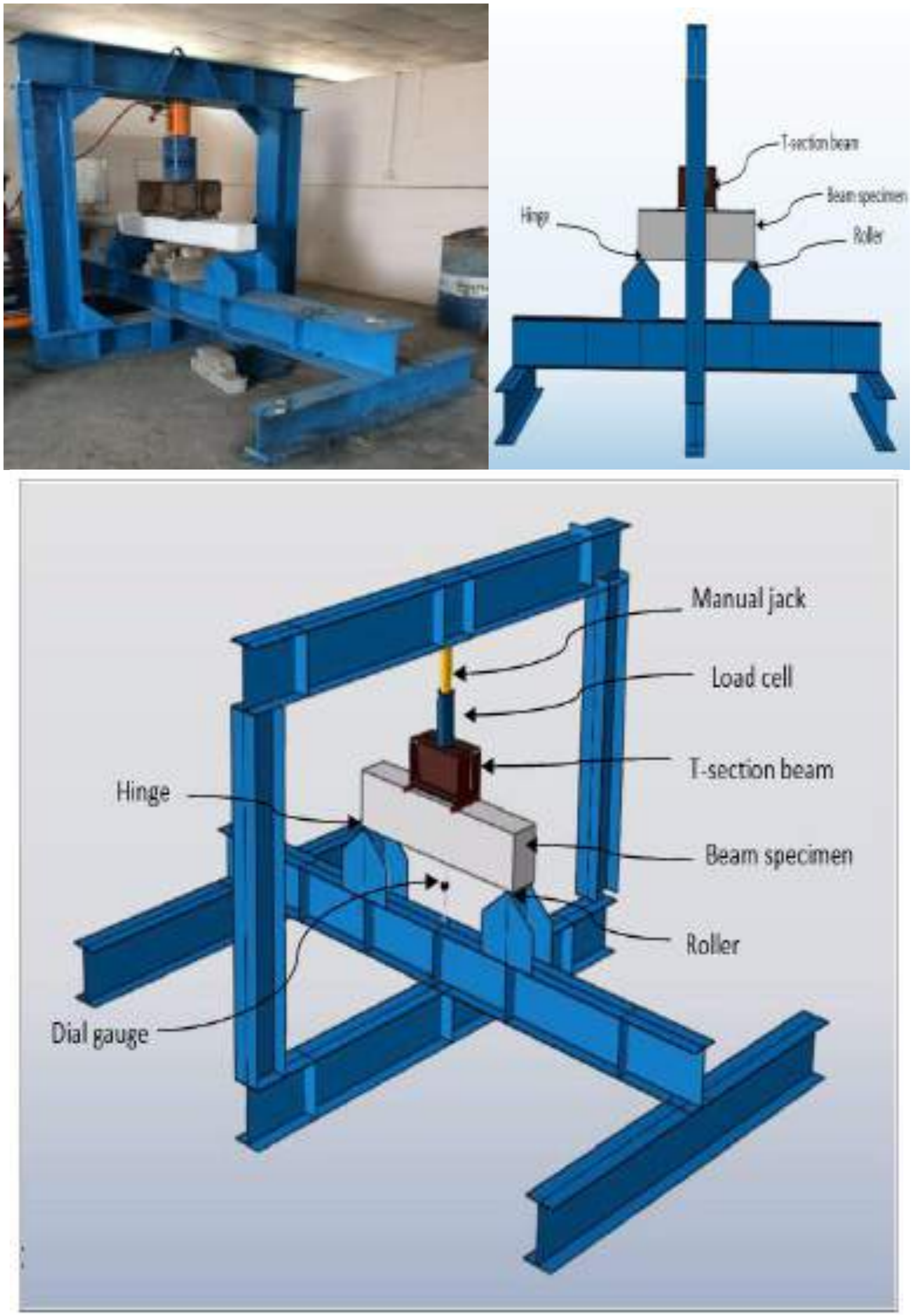


Fig. (3-23): Testing machine with front and side view.

Chapter Four
Results And Discussion

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1: GENERAL

In this chapter, results of tests for the experimental program that explained in the previous chapter are presented and discussed

4.2: TESTS OF SPECIMENS

Results are divided into two sections. The first section is related to the concrete mixture as shown in Fig. (4-1), and the other section is related to the beams tested as shown in Fig. (4-2).

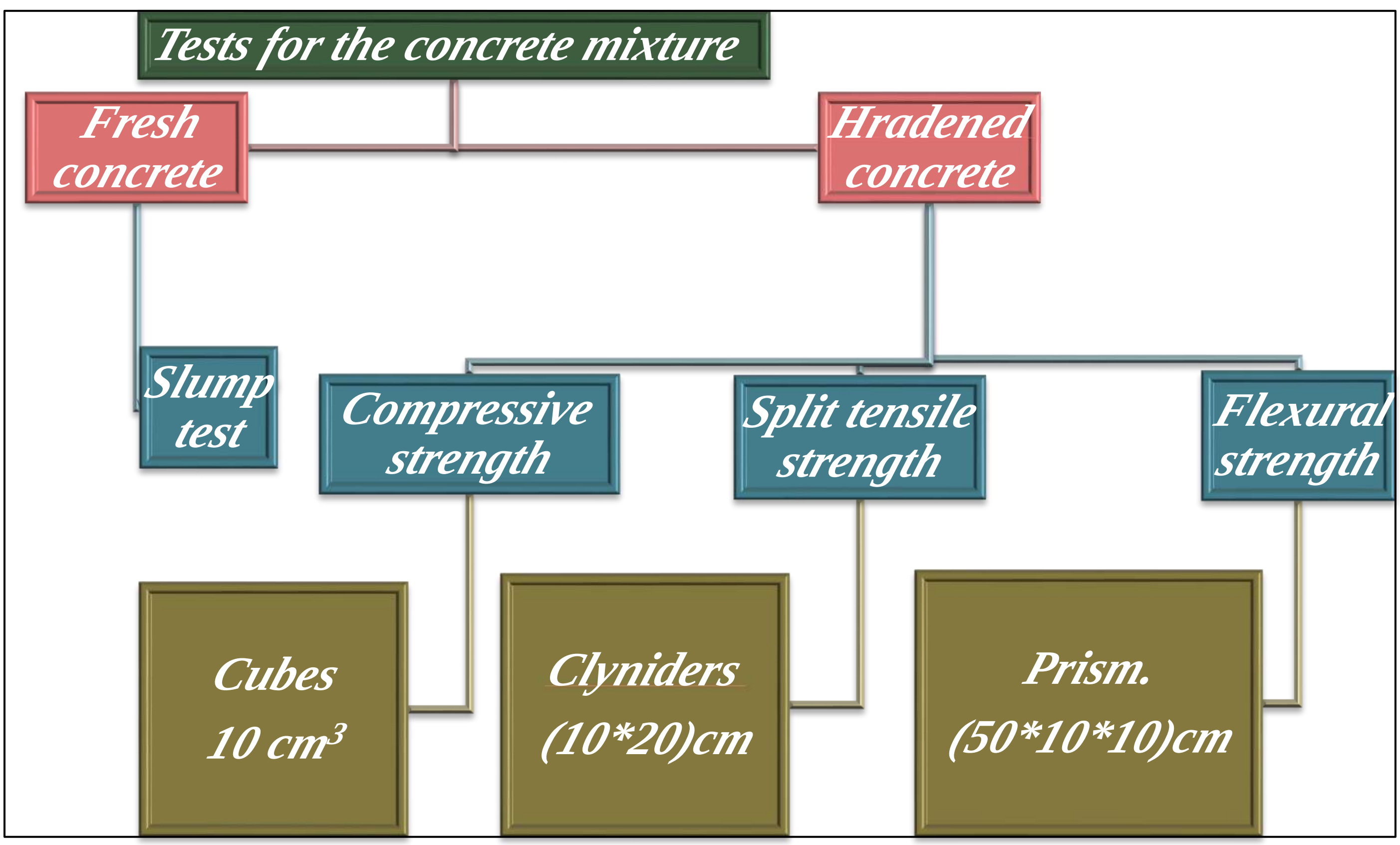


Fig. (4-1): Flowchart for Tests of Concrete Mixture.

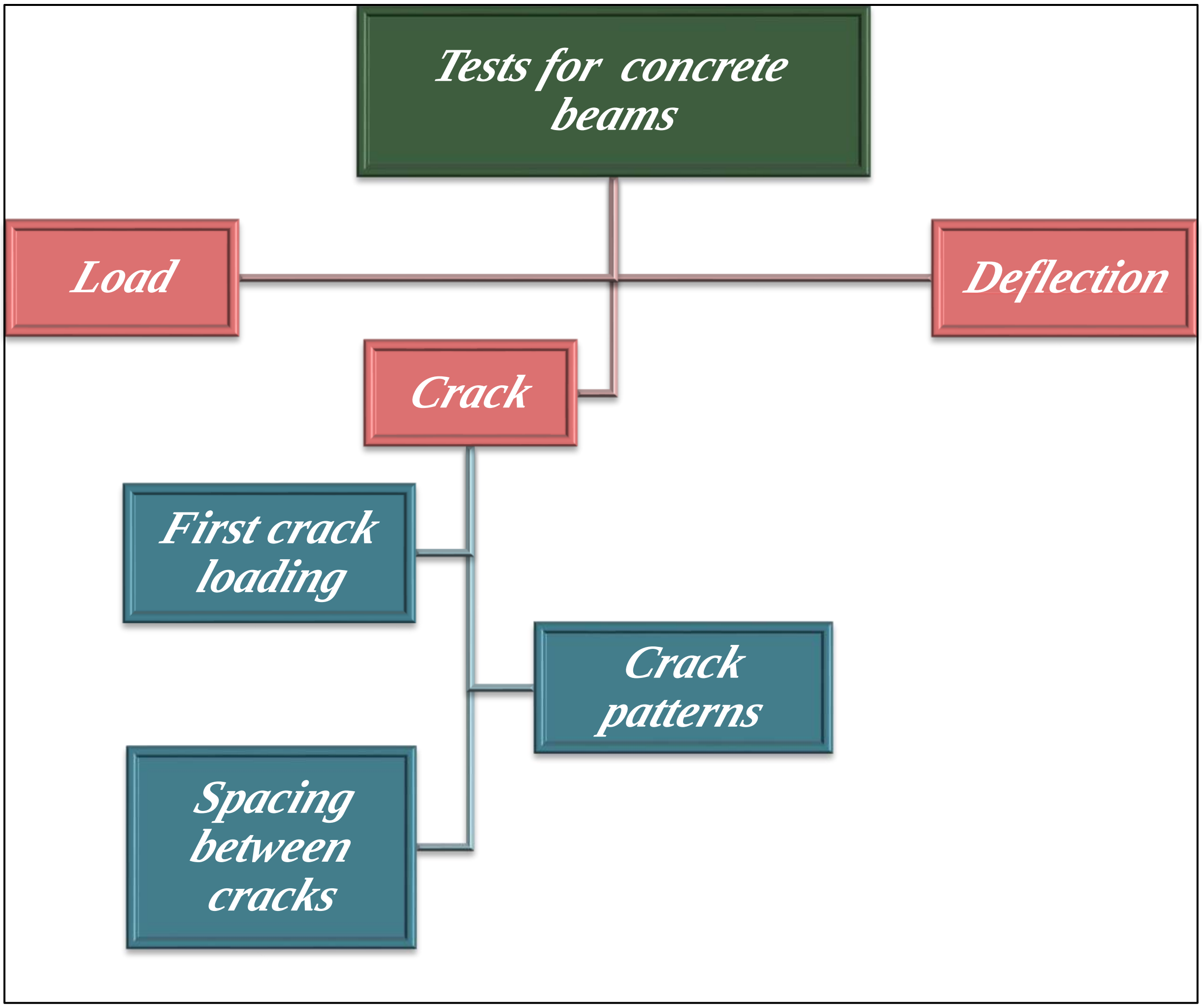


Fig. (4-2): Flowchart for Tests of Beams.

4.3: TEST RESULTS FOR CONCRETE MIXTURE

This section dealing with fresh and hardened properties of concrete with different types of plastic waste used in the concrete mixture at the ages of 7 and 28 days, which include:

a. Workability of mixes.
b. Compressive strength.
c. Splitting tensile strength.
d. Flexural strength.

4.3.1 Fresh concrete test

4.3.1.1 Slump Test

After preparing the mixes with the mixture proportions for each type of wastes, slump test was taken immediately after mixing process to ensure that mixes meet workability requirements with two (w/c) ratios 0.41 and 0.53. Slump Cone test was adopted for each mix that contains different dosages of plastic waste.

The results demonstrated that as the percent of plastic wastes for all types are increased as the slump is decreased as shown in Table (4-1) and Fig. (4-3). This indicates that the presence of plastic wastes as a sand replacement or as the fiber reduces the fresh concrete effect on workability. Thus, to face this problem, the workability should be improved either by adding additional water to the mix (which reduce the concrete performance) or added super plasticizer admixture. In the present study, super plasticizer admixture is used to improve fresh concrete workability.

The reduction of a slump for each waste type is shown in Fig. (4-3), as a result, the mixtures that contain on 1.25% PVC, 2.5% plastic boxes, and 1.5% PET are the optimum percentages for knowing the workability. In all mixtures, the best mixture that has the higher workability is the mixture that contains on 2.5% of plastic boxes.

From Fig. (4-3), the linear equations, which represent the relationship between the slump and the plastic percentage for each type of additive are shown as follows;

- For PVC waste:

  Slump = -30.4 (% PVC) + 212……………………….……….....Eq. (4-1)

  $R^2 = 0.9678$

- For plastic box waste:

  Slump = -2.9714(% Box) + 198……………………….…………Eq. (4-2)

  $R^2 = 0.9657$

- For PET waste:

  a. Hand fiber PET

  Slump = -26.667 (% PET) + 205………………..…...…Eq. (4-3)

  $R^2 = 0.9552$

  b. Machine fiber PET

  Slump = -28.333(% PET) + 204.83…………….…….…Eq. (4-4)

  $R^2 = 0.9626$

Table (4-1): Result of Slump test for all types of plastic waste

Plastic waste type		W/C	Plastic Percentage (%)	Slump Test mm	Workability classification	Limit of ENV 206 [42]	Reduction in Slump %
PVC		0.41	0	200	S4: High workability	>160 mm	----
			1.25	180	S4: High workability	>160 mm	10
			2.5	150	S3: Medium workability	100-150 mm	25
			3.75	100	S3: Medium workability	100-150 mm	50
			5	50	S2: Low workability	50-90 mm	75
Plastic box		0.41	2.5	190	S4: High workability	>160 mm	5
			5	180	S4: High workability	>160 mm	10
			10	170	S4: High workability	>160 mm	15
PET	Hand fiber	0.41	1.5	175	S4: High workability	>160 mm	12.5
			3	120	S3: Medium workability	100-150 mm	40
	Machine fiber		1.5	172	S4: High workability	>160 mm	14
			3	115	S3: Medium workability	100-150 mm	42.5

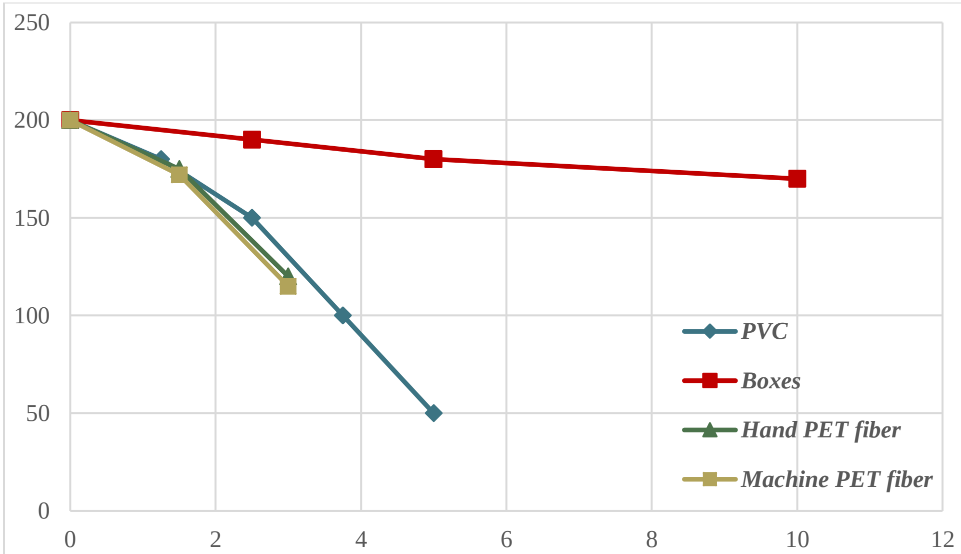


Fig. (4-3): Result of slump test for each type of plastic waste.

This decreasing in slump related to many causes such as the shape of plastic waste which is usually sharp edge and irregular which increase the surface area of particles, and the other cause that the presence of the plastic waste particles is separate the components of mixes from each other which reduce the homogeneity of mixes, this effect is minimized using super plasticizer.

4.3.2 Hardened concrete tests

4.3.2.1 Compressive strength

Compressive strength is the ability of concrete to resist the compressive forces axially, and when reaching the limits of compressive strength, the concrete is completely crushed. Compressive strength considers one of the most important properties of concrete which reflect the performance of the concrete. Six cubes (100*100*100) mm were adopted (three cubes for seven days and three cubes for twenty eight days) for each percentage of plastic waste types. The results of compressive strength are shown in Table (4-2) and Figures (4-4), (4-5), and (4-6).

It is observed from Table (4-2) and Fig. (4-4), that all samples which contain PVC particles with dosages ranged from 1.25% to 5 % show an increase in compressive strength for both w/c ratios 0.41 and 0.53. The mix that contains on 1.25% of PVC particles as replacement of sand is the optimum percentage which gave a compressive strength of 49.9MPa and 34.7MPa for water /cement ratio of 0.41 and 0.53, respectively, but all other percentages of PVC replacement gave strength higher than reference mixture (the mixture without PVC particles). As a result, the compressive strength increases with the increase of PVC particles content compared to the reference mixture for all mixes of w/c = 0.41 and 0.53 and both 7 and 28 days.

The effect of plastic boxes particles on concrete compressive strength for water to cement ratio 0.41 is shown in Table (4-2) and Fig. (4-5). It’s observed that the samples contain plastic boxes waste particle with dosages of 2.5% and 5% showed an increase in compressive strength. While dose 10% of plastic box particles gave less compressive strength than reference mixture by about 3.03%.

Thus, for Plastic boxes waste particles the dose of 5% is the optimum percentage as a sand replacement, therefore 10% replacement yield compressive strength close to that of reference mixture, which encourages to recycle many amounts of Plastic boxes in concrete construction without affecting the compressive strength of the concrete.

Table (4-2): Results of compressive strength for all types of plastic waste

Plastic waste type	W/C	Plastic Percentage (%)	Compressive strength (fcu) MPa 7 Days	28 Days	Average 28 Days	Changing in Compressive strength (%)	$\frac{7}{28}$ ratio
PVC	0.41	0	26.4	40.9 36.4 36.4	37.9	----	0.69
		1.25	44.8	51.4 49.4 48.9	49.9	+31.7	0.89
		2.5	31.07	42 42.3 41.5	41.9	+10.7	0.74
		3.75	34.4	42.1 44.2 40	42.1	+11.1	0.82
		5	38.7	50.4 44.5 43.6	46.2	+21.82	0.84
	0.53	0	22.4	27.55 27 25	26.5	----	0.84
		1.25	32.6	35.3 35 33.7	34.7	+31.2	0.94
		2.5	26.33	34 34.8 34.4	34.4	+30.1	0.76
		3.75	23	32.2 22.7 30.2	28.37	+7.25	0.81
		5	28.45	28.1 25.8 26.9	26.95	+1.9	1.06
Plastic box	0.41	2.5	37.6	31.1 44.6 41	38.95	+2.8	0.96
		5	42.9	41.4 46.4 60.2	49.333	+30.2	0.87

Table (4-2): Continued.

PET	Machine fiber	0.41	10	35.97	41.6 31.9 36.8	36.75	-3.03	0.97
			1.5	28.93	44.3 33.1 38.6	38.7	+2.11	0.75
			3	35.2	39.3 38.1 38	38.47	+1.5	0.91
	Hand fiber		1.5	----	49.6 58.1 54	53.9	+42.08	----
			3	----	35.6 32.1 25.8	31.17	-17.8	----

Also, it is observed from Table (4-2) and Fig. (4-6), that the samples that contain machine PET fiber show a slight increase in compressive strength for both dosages 1.5% and 3%. This yield that PET particles can be recycled into concrete construction with 3% without affecting the compressive strength of concrete. While the samples that contain hand PET fiber show an increase in compressive strength in the mixes that contain on 1.5 %, while 3% of hand PET fiber led to drop in compressive strength by 17.75% in strength.

Thus, the shape of PET as fiber has an important impact on concrete compressive strength. Thus, regular fiber assists in recycling much amount in PET waste into concrete construction at the same time improve its performance.

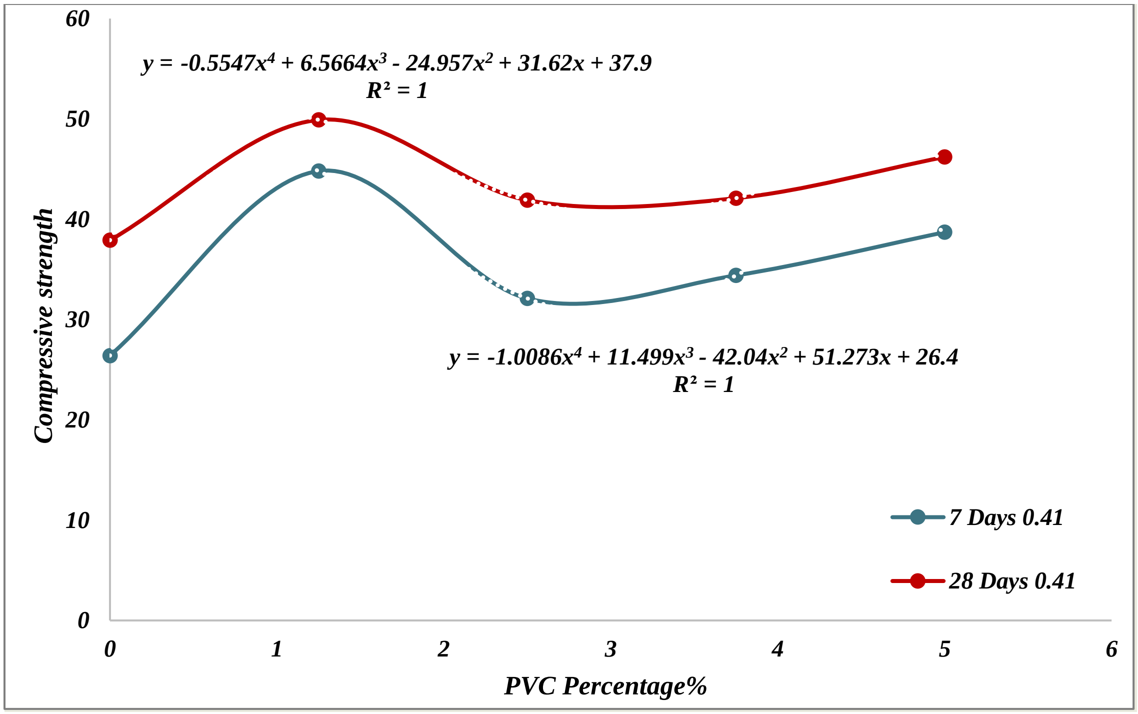


Fig. (4-4): Result of compressive strength for PVC type.

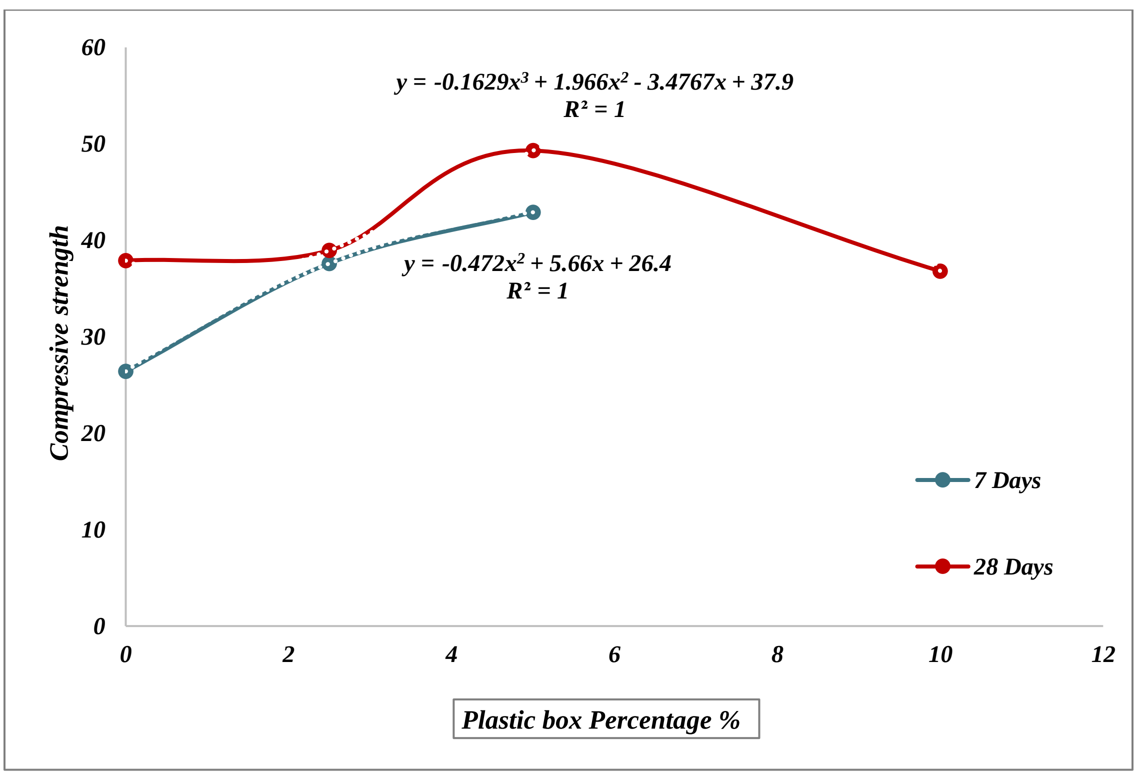


Fig. (4-5): Result of compressive strength for Plastic box type.

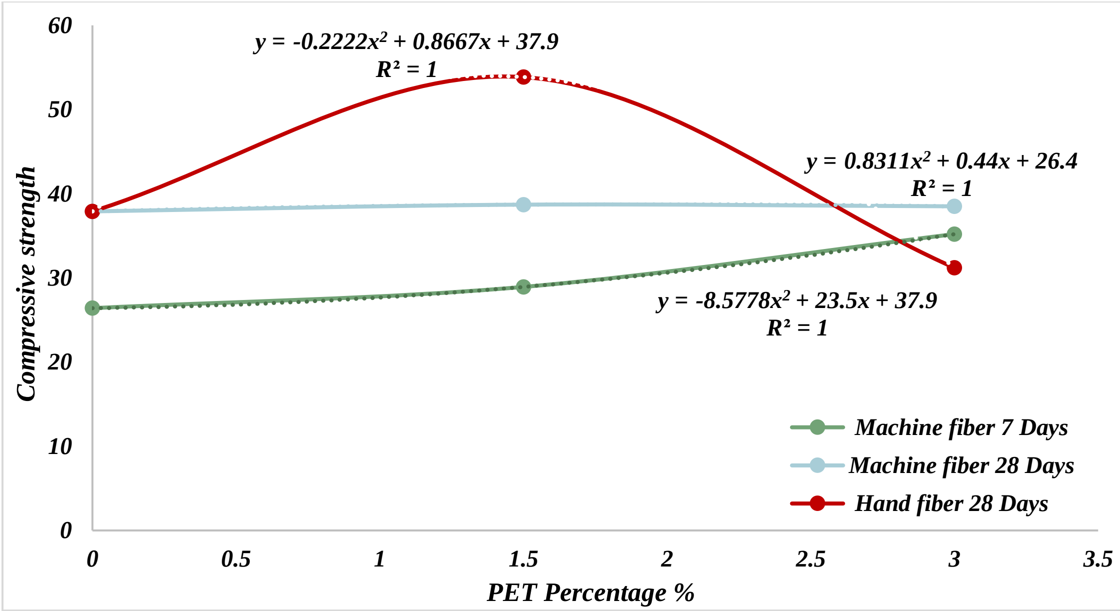


Fig. (4-6): Result of compressive strength for PET type.

As a result, the polynomial equations, which represent the relationship between the compressive strength at 7 days and 28 days for each type of additive are shown as follows;

- For PVC waste:

  $y = 0.0007x^3 - 0.0735x^2 + 3.1308x - 6.4091$……………….Eq. (4-5)

  $R^2 = 0.9773$

- For plastic box waste:

  $y = 0.1156x^2 - 7.3163x + 150.48$………………..……….. Eq. (4-6)

  $R^2 = 0.9997$

- For Machine PET waste:

  $y = -0.0401x^2 + 2.535x - 1.075$…………………………….Eq. (4-7)

  $R^2 = 1$

y: Compressive strength at 28 days

x: Compressive strength at 7days.

The failure mode of all cubes that contain different types of plastic waste showed that cubes are not crushed suddenly as for reference mix, and after failure, the cubes are not fractured as pieces but kept its shape with surface cracks; this shows the ductility provided by the presence of plastic waste. Fig. (4-7) showed the failure mode of cubes with PVC waste.

a)0% ***b)2.5%*** ***c)5%***

Fig. (4-7): Failure Modes of Concrete Cubes with Percentage of (0, 2.5, 5)%PVC, respectively.

4.3.2.2 Split Tensile Strength

Six cylinders (100*200) mm were adopted to measure the tensile strength of concrete by split tensile test three cylinders for 7 days and three cylinders for 28 days for each percentage. The results are shown in Table (4-3) and Fig. (4-8). It is observed from Table (4-3) and Fig. (4-8), that the samples that contain PVC particles show a slightly increase in split tensile strength by about 6.45% and 5.77% for both w/c ratios 0.41and 0.53, respectively for particles dosage of 1.25 % and drop for 2.5%, 3.75%, and 5%, respectively.

Thus 1.25% is considered the optimum percentage for split tensile strength. Therefore, PVC particles improve both compressive and tensile strength of concrete.

It is observed from Table (4-3) and Fig. (4-8), that the samples which contain plastic boxes particles show decreases in split tensile strength for all percentages. The decreasing of split tensile strength of plastic box for percentage of 2.5%, 5%, and 10% are 12.9%, 24.19% and 24.84%, respectively. Thus, Plastic boxes improve compressive strength, in contrast, it reduces the tensile strength of concrete.

Table (4-3): Result of Split Tensile Strength for all Types of Plastic waste

Plastic waste type	***W/C***	***Plastic Percentage (%)***	***fs***		***$\frac{7}{28}$ ratio***	***f\`c***	***γ*** ***$fs=\gamma\sqrt{f`c}$***
			7 Days	***28 Days***			
PVC	0.41	0	2.7	3.1	0.87	30.3	0.56
		1.25	3.2	3.3	0.96	39.9	0.52
		2.5	2.7	3.05	0.88	33.5	0.53
		3.75	2.6	3.07	0.85	33.7	0.53
		5	2.7	3.1	0.87	36.9	0.51
	0.53	0	2.43	2.6	0.93	21.2	0.56
		1.25	2.3	2.75	0.84	27.8	0.52
		2.5	2.25	2.3	0.97	27.7	0.44
		3.75	2.1	2.2	0.95	22.7	0.46
		5	2.3	2.4	0.96	21.6	0.52
Plastic box	0.41	2.5	2.55	2.7	0.94	31.2	0.48
		5	2.3	2.35	0.98	39.5	0.37
		10	2.65	2.33	1.14	29.4	0.43

The failure mode of the reference mixture is suddenly crushed and completely divided into two parts, while there is no plastic separation in the cylindrical samples that contain plastic wastes, but there are cracking development and spreading on the sample surface as shown in Fig. (4-9), which indicate that ductility provided by plastic wastes for concrete.

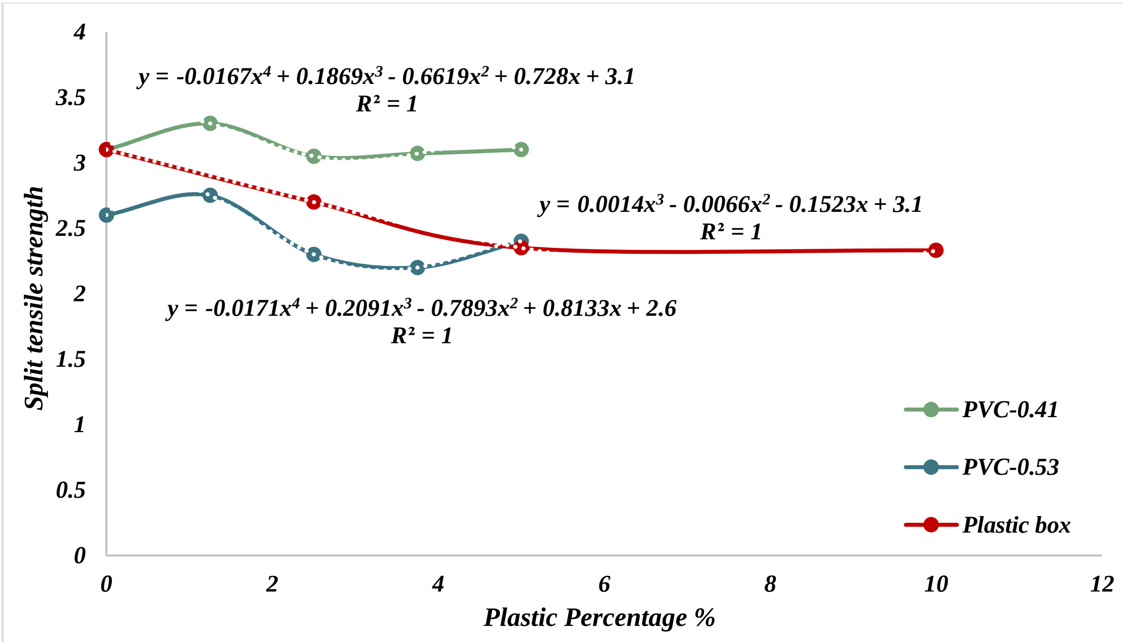


Fig. (4-8): Result of Split Tensile Strength for plastic waste

a)0% *b)2.5%* *c)5%*

Fig. (4-9): Failure Modes of Concrete Cylinders with Percentage of (0, 2.5, 5) %PVC, respectively.

So, the polynomial equations, which represent the relationship between the tensile strength at 7 days and 28 days for each type of additive are shown as follows;

- For PVC waste:
  $y = 0.5x^2 - 2.5167x + 6.2333$……………….……………….Eq. (4-8)
  $R^2 = 0.9589$
- For plastic box waste:
  $y = 354.76x^3 - 2675.3x^2 + 6712.3x - 5600.1$….……………Eq. (4-9)
  $R^2 = 1$

y: Split tensile strength at 28 days

x: Split tensile strength at 7days.

As a result, the polynomial equations, which represent the relationship between the compressive strength (fcu) and split tensile strength (fs) for each type of additive are shown as follows;

- For PVC waste:
  $fcu = 1644.9fs^3 – 15400fs^2 + 48048fs - 49920$……….…..Eq. (4-10)
  $R^2 = 0.5903$
- For plastic box waste:
  $fcu = 2359.3fs^3 – 19192fs^2 + 51692fs - 46058$…….……..Eq. (4-11)
  $R^2 = 1$

4.3.2.3 Flexural Strength

Six prisms (100*100*500) mm to estimation the flexural strength was adopted three prisms for seven days and three prisms for twenty eight days for each percentage of mixes that contain different proportions of plastic wastes and the results are shown in Table (4-4) and Fig. (4-10).

It is observed from Table (4-4) and Fig. (4-10), that all samples that contain PVC particles showed an increase in flexural strength due to PVC waste for w/c = 0.41. While for w/c of 0.53 only dosage 1.25% yield higher flexural strength than reference mix.

Thus, 1.25% sand replacement with PVC waste particles is the optimum dose for both w/c ratios.

It is observed from Table (4-4) and Fig. (4-10), that plastic boxes particles with 2.5% sand replacement increase the flexural strength. While for higher dosages, namely 5%, and 10%, there is a drop in flexural strength. Thus 2.5% sand replacement by plastic boxes waste particles is the optimum dose for w/c = 0.41.

Also, observed from Table (4-4) and Fig. (4-10), that the samples that contain machine PET fiber show a slight decrease in flexural strength in all the mixes, while the samples that contain hand PET fiber show a slight increase in flexural strength in the mixes that contain on 1.5 % PET fiber and drop for 3% PET fiber. Thus, PET in both shapes has slightly effect on the flexural strength.

So, the polynomial equations, which represent the relationship between the flexural strength at 7 days and 28 days for each type of additive are shown as follows;

- For PVC waste:
  $y = 0.5x^2 - 2.5167x + 6.2333$……………………………Eq. (4-12)
  $R^2 = 0.9589$
- For plastic box waste:

$y = -10.611x^2 + 80.863x - 149.14$………………...............Eq. (4-13)

$R^2 = 1$

- For PET waste:
  a. Hand fiber PET

     $y = 1.7079x^2 - 12.278x + 26.316$…………………...Eq. (4-14)

     $R^2 = 1$

  b. Machine fiber PET

     $y = 0.5112x^2 - 3.3441x + 9.7271$…………………...Eq. (4-15)

     $R^2 = 1$

y: Flexural strength at 28 days

x: Flexural strength at 7days.

As a result, the polynomial equations, which represent the relationship between the compressive strength (fcu) and flexural strength (fr) for each type of additive are shown as follows;

- For PVC waste:

  $fcu = -1991.2fr^4 + 34990fr^3 – 228551fr^2 + 658505fr –$ 706775.......Eq. (4-16) $R^2 = 1$
- For plastic box waste:

  $fcu = 25.031fr^3 - 314.24fr^2 + 1295.9fr - 1710.7$…………..Eq. (4-17)

  $R^2 = 1$
- For PET waste:
  a. Hand fiber PET

     $fcu = 17.722fr^2 - 125.19fr + 241.34$………………...Eq. (4-18)

     $R^2 = 1$

b. Machine fiber PET

$fcu = -0.9419fr^2 + 5.4125fr + 32.709$……………. Eq. (4-19)

$R^2 = 1$

Also, the polynomial equations, which represent the relationship between the flexural strength (fr) and tensile strength (fs) for each type of additive are shown as follows;

- For PVC waste:

  $fr = -2715.1fs^3 + 25760fs^2 – 81421fs + 85744$…………......Eq. (4-20)

  $R^2 = 0.9906$

- For plastic box waste:

  $fr = 94.395fs^3 - 774.7fs^2 + 2107fs - 1894.4$………………..Eq. (4-21)

  $R^2 = 1$

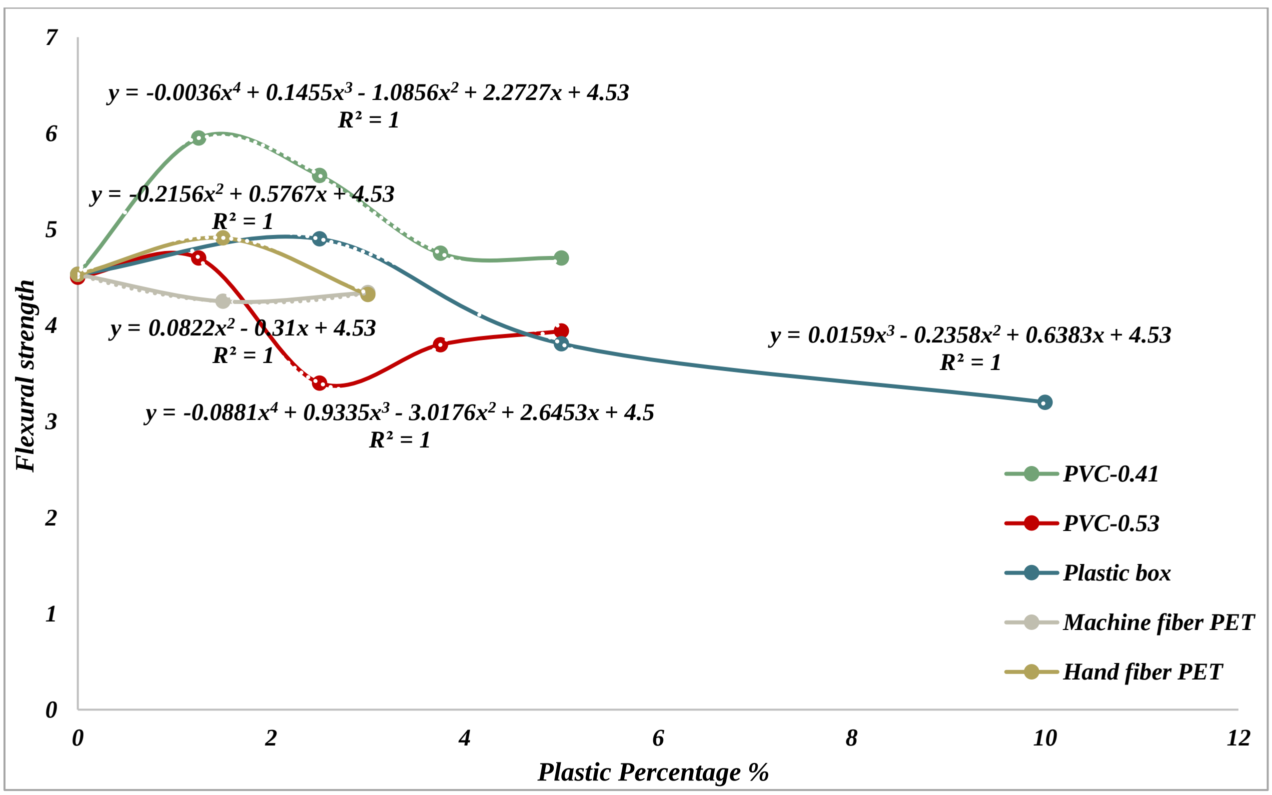


Fig. (4-10): Result of Flexural strength for plastic waste.

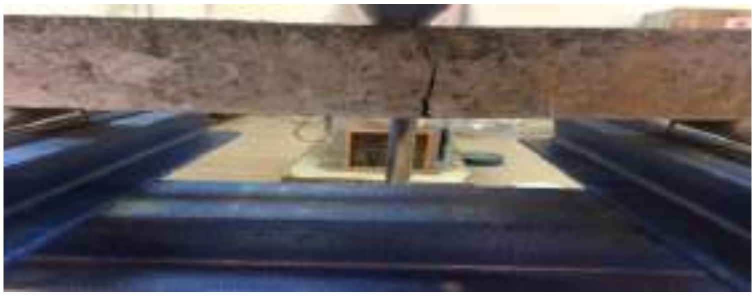
Table (4-4): Result of Flexural Strength for all Types of Plastic Waste

Plastic waste type		***W/C***	***Plastic Percentage (%)***	***Flexural strength fr MPa***		***7/28 ratio***	***f\`c***	***α*** ***fr=α√f\`c***
				7 Days	***28 Days***			
PVC		0.41	0	4	4.53	0.88	30.3	0.82
			1.25	5.6	5.945	0.94	39.9	0.94
			2.5	3.97	5.56	0.71	33.5	0.96
			3.75	3.797	4.746	0.8	33.7	0.82
			5	4.22	4.7	0.89	36.9	0.77
		0.53	0	3.735	4.46	0.84	21.2	0.96
			1.25	3.82	4.7233	0.81	27.8	0.89
			2.5	2.63	3.401	0.77	27.7	0.65
			3.75	3.137	3.797	0.83	22.7	0.79
			5	3.031	3.935	0.77	21.6	0.85
Plastic box		0.41	2.5	3.776	4.9	0.771	31.2	0.88
			5	3.488	3.81	0.92	39.5	0.61
			10	3.405	3.17	1.07	29.4	0.58
PET	Machine fiber	0.41	1.5	3.617	4.25	0.85	30.96	0.76
			3	3.82	4.336	0.88	30.8	0.78
	Hand fiber		1.5	4.4	4.91	0.89	43.12	0.75
			3	3.61	4.317	0.84	24.94	0.86

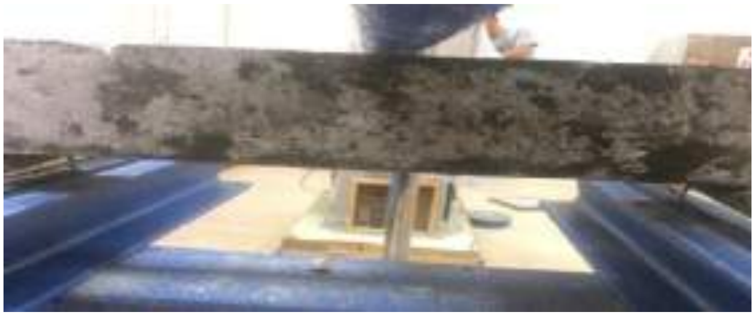
The failure modes of prisms are shown in Fig. (4-11), in which for reference samples (no wastes added) the flexural failure led to complete fracture of the samples and divided it into two separate pieces, which for samples contain plastic waste although the samples are failed there is no movement in fracture path and the samples still appear as one unit. This is a significant impact of waste on flexural behavior of beams, due to they reduce the development and spreading of cracks which very important property to protect the reinforcement and minimize cracks width.

a)0 %

b)1.25%



c)2.5%



d)3.75%

e)5%

Fig. (4-11): Failure modes of concrete prisms with PVC.

4.4: STRUCTURAL BEHAVIOR OF BEAMS

The flexural behavior of the concrete beams via the ultimate load, the deflection at mid span, ductility, and the crack pattern is investigating. One reference beam with plain concrete and eleven specimens with different types of bars are tested.

For each load increment, the deflection at mid-span is measured and the crack pattern of beams is modifying based on crack path growth.

4.4.1 Beam Ultimate Load

The ultimate loads for all concrete beams are recording and presenting in Table (4-5). The reference beam (***B1-0-ho-0%-S***) is a homogeneous section of normal concrete reinforced with steel rebar; it has ultimate failure load is 82.5kN. The water to cement ratio used of the concrete mixture for all beams is 0.41.

The beams (***B3-1-ho-1.25%-S and B4-2-ho-5%-S***) which have a homogenous section of concrete with 1.25% PVC plastic waste and 5% Plastic boxes waste as a sand replacement, respectively, reinforced with steel rebar, showed higher ultimate failure load than reference beam by about 6.06% and 1.81%, respectively. These results coincide with trial mixes showed that 1.25% PVC waste and 5% plastic boxes waste are the optimum percentages and gave higher compressive and tensile stresses.

While the concrete beams (***B5-3ai-ho-1.5%-S & B6-3ar-ho-1.5%-S***) with two shapes of fiber (irregular and regular) with percentages of 1.5% by volume of the mix, the decrease in load was (9.09%&12.12%), respectively. Thus, PET fibers slightly reduced the ultimate load and might be used for the objective of reducing the impact of plastic waste on the environment management element without affecting the performance of beams.

To use as much as possible of plastic wastes within concrete beams, hybrid-section of concrete beams is investigated. The upper part of beam section above natural axis (Compression Zone) the concrete mixes with optimum percentages of plastic wastes are used, namely 1.25% and 5% for PVC and Plastic boxes waste as a sand replacement, respectively, and 1.5% of PET fiber. While in the lower part of beam section below neutral axis (Tension Zone) the concrete mixes with the largest percentage of plastic wastes are used, namely 10% for both PVC and plastic boxes wastes as a sand replacement and 3% for PET fiber.

The use of hybrid section beams yields ultimate loads of about 85%-89% of the reference beam, namely acceptable results taking into account the number of plastic wastes that recycled into concrete beams.

The beams (***B7-1-hy-1.25% 10%-S*** and ***B8-2-hy-5% 10%-S)*** which have hybrid section of concrete beam with 1.25% PVC plastic wastes and 5% Plastic boxes waste as sand replacement in compression zone, respectively and 10% sand replaced with PVC and Plastic boxes in tension zone, showed relatively small reduction in ultimate load by 14.5 % and 10.3 %, respectively.

While for the beam (***B9-3-hy-1.5%bi 3%ar-S***) which have 1.5% and 3% of PET fiber in compression and tension zones, respectively showed a reduction in the ultimate load of 14.5%. Thus, the best hybrid section with plastic wastes in which only about 10% reduction in ultimate load.

In the present study it's tried to use PET as tension reinforcement in different shapes and configurations listed in Chapter 4, but all presented plastic bars are failed except one case in which the deformed steel bar is used with additional layer of PET bottle cut into two parts, namely beam (***B15-0-ho-0%-P6***) in which the ultimate load reached to 85 kN, i.e. 3.03 % larger than reference beam.

Table (4-5): Ultimate Load of Tested Beams

Beam designation	***Waste plastic type***	***fcu***	***fc`***	***Pu(kN)***	***Pu/Pu(Reference beam) %***	***Change in ultimate load %***
B1-0-ho-0%-S	----	35.8	30.4	82.5	100	----
B2-0-ho-0%	----	35.8	30.4	30	36.36	- 63.63
B3-1-ho-1.25%-S	PVC	47.2	40.1	87.5	106.06	+ 6.06
B4-2-ho-5%-S	Plastic boxes	41.5	35.3	84	101.8	+ 1.8
B5-3ai-ho-1.5%-S	PET	39.5	33.6	75	90.9	- 9.09
B6-3ar-ho-1.5%-S	PET	43.1	36.6	72.5	87.87	- 12.12
B7-1-hy-1.25% 10%-S	PVC	29.9	25.4	70.5	85.45	- 14.5
B8-2-hy-5% 10%-S	Plastic boxes	26.4	22.4	74	89.69	- 10.3
B9-3-hy-1.5%bi 3%ar-S	PET	25.4	21.6	70.5	85.45	- 14.5
B10-0-ho-0%-P1	PET	35.8	30.4	12.5	15.15	- 84.84
B11-0-ho-0%-P2	PET	35.8	30.4	15	18.18	- 81.81
B12-0-ho-0%-P3	PET	35.8	30.4	15	18.18	- 81.81
B13-0-ho-0%-P4	PET	35.8	30.4	20	24.24	- 75.75
B14-0-ho-0%-P5	PET	35.8	30.4	20	24.24	- 75.75
B15-0-ho-0%-P6	PET	35.8	30.4	85	103.03	+ 3.03
B16-0-ho-0%-P7	PET	35.8	30.4	25	30.3	- 69.69
B17-0-ho-0%-P8	PET	35.8	30.4	30	36.36	- 63.63
B18-0-ho-0%-P9	PET	35.8	30.4	30	36.36	- 63.63
B19-0-ho-0%-P10	PET	35.8	30.4	15	18.18	- 81.81

4.4.2 Load-Deflections Behavior

The deflection for all concrete beams was presented in Table (4-6).

Load-deflection curves were recorded for all beams at mid-span as shown in Figures (4-12), (4-13), (4-14), (4-15), and (4-16).

As shown in Table (4-6), the reference beam (***B1-0-ho-0%-S***), had the ultimate deflection (12.65 mm) lower than all beams that contained on the plastic waste within the concrete mixture.

Table (4-6): Maximum deflection of Tested Beam

Beam designation	***Ultimate Load Pu(kN)***	***Maximum deflection Δu (mm)***	***Δu/Δu(Reference beam) %***	***Changing in deflection %***
B1-0-ho-0%-S	82.5	12.65	100	-----
B2-0-ho-0%	30	4.05	32.01	- 67.98
B3-1-ho-1.25%-S	87.5	25.55	201.97	+ 101.97
B4-2-ho-5%-S	84	27.05	213.83	+ 113.83
B5-3ai-ho-1.5%-S	75	20.05	158.49	+ 58.49
B6-3ar-ho-1.5%-S	72.5	15.05	118.97	+ 18.97
B7-1-hy-1.25% 10%-S	70.5	30.05	237.55	+ 137.55
B8-2-hy-5% 10%-S	74	25.05	198.023	+ 98.023
B9-3-hy-1.5%bi 3%ar-S	70.5	25.05	198.023	+ 98.023
B10-0-ho-0%-P1	12.5	16.05	126.87	+ 26.87
B11-0-ho-0%-P2	15	17.05	134.8	+ 34.8
B12-0-ho-0%-P3	15	17.05	134.8	+ 34.8
B13-0-ho-0%-P4	20	20.05	158	+ 58
B14-0-ho-0%-P5	20	16.05	126	+ 26
B15-0-ho-0%-P6	85	27.05	213.83	+ 113.83
B16-0-ho-0%-P7	25	30.05	237.55	+ 137.55
B17-0-ho-0%-P8	30	29.05	229	+ 129
B18-0-ho-0%-P9	30	28.05	222	+ 122
B19-0-ho-0%-P10	15	16.05	126.8	+ 26.8

Also, using PET layers in addition to steel reinforcement in tension zone, considerably increase the maximum deflection. Thus for ***(B15-0-ho-0%-P6)***, the maximum deflections is 27.05 mm which greater than that of the reference beam by about 113.83%. Thus, the PET layer improves the beam ductility without any reduction in its strength. Also, all beams which contain PET bars as tension reinforcement led to an increase in ultimate deflection by about (26 %-137 %).

As shown in Figures (4-12), (4-13), and(4-14), the beams (***B3-1-ho-1.25%-S***, ***B4-2-ho-5%-S, B5-3ai-ho-1.5%-S***, ***B6-3ar-ho-1.5%-S***, ***B7-1-hy-1.25% 10%-S***, ***B8-2-hy-5% 10%-S***, ***B9-3-hy-1.5%bi 3%ar-S***) with plastic waste within the mixture were approximately similar and equal in curves which means had quivalent stiffness, and theses curves were similar to that of reference beam (***B1-0-ho-0%-S)*** and the beam (***B15-0-ho-0%-P6***)with layers of PET bottle in the tension zone .

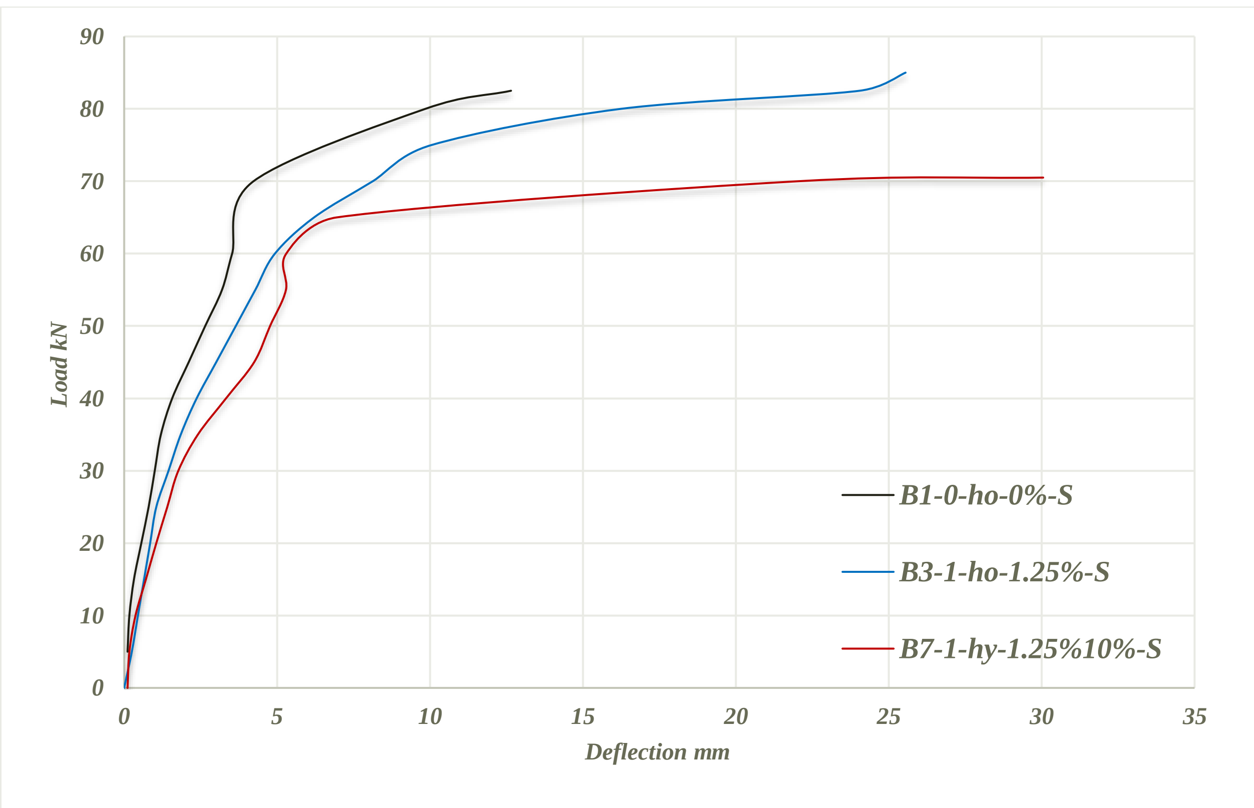


Fig. (4-12): Load Deflection curves for beams with PVC waste.

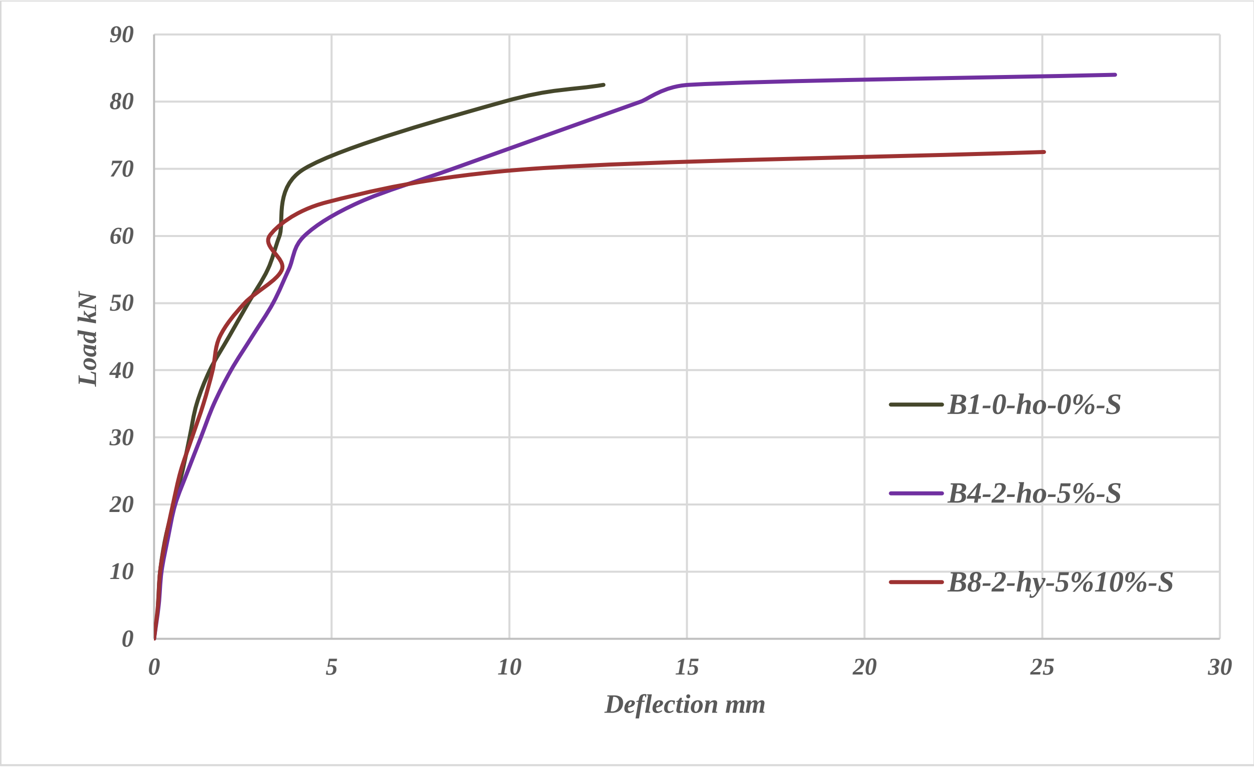


Fig. (4-13): Load Deflection curves for beams with plastic boxes waste.

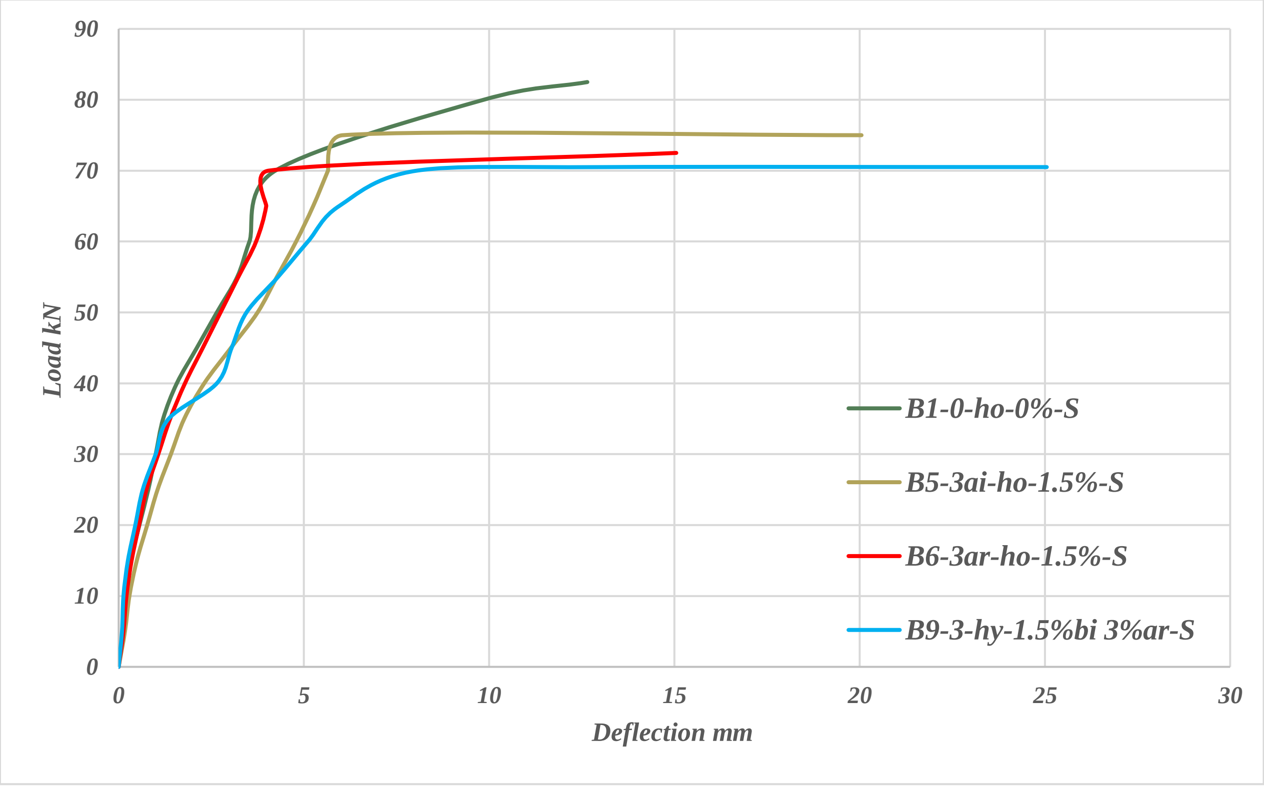


Fig. (4-14): Load Deflection curves for beams with PET bottle waste.

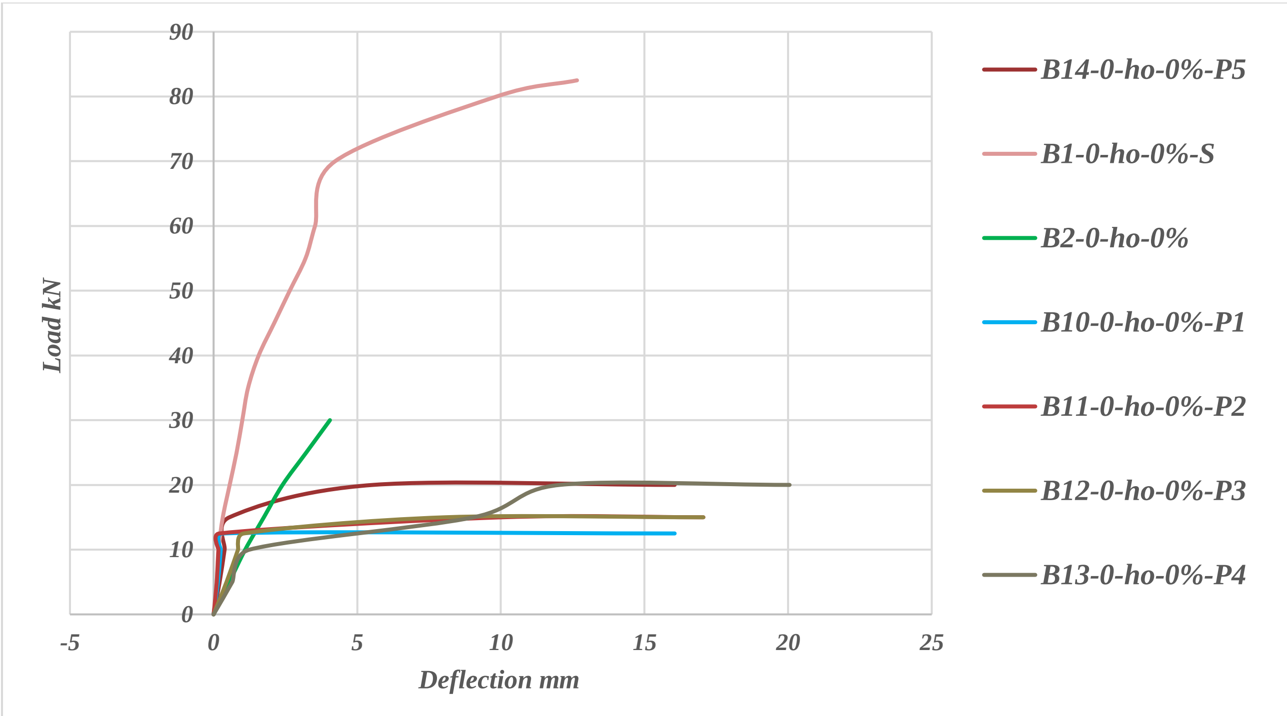


Fig. (4-15): Load Deflection curves for beams with PET bar reinforcement.

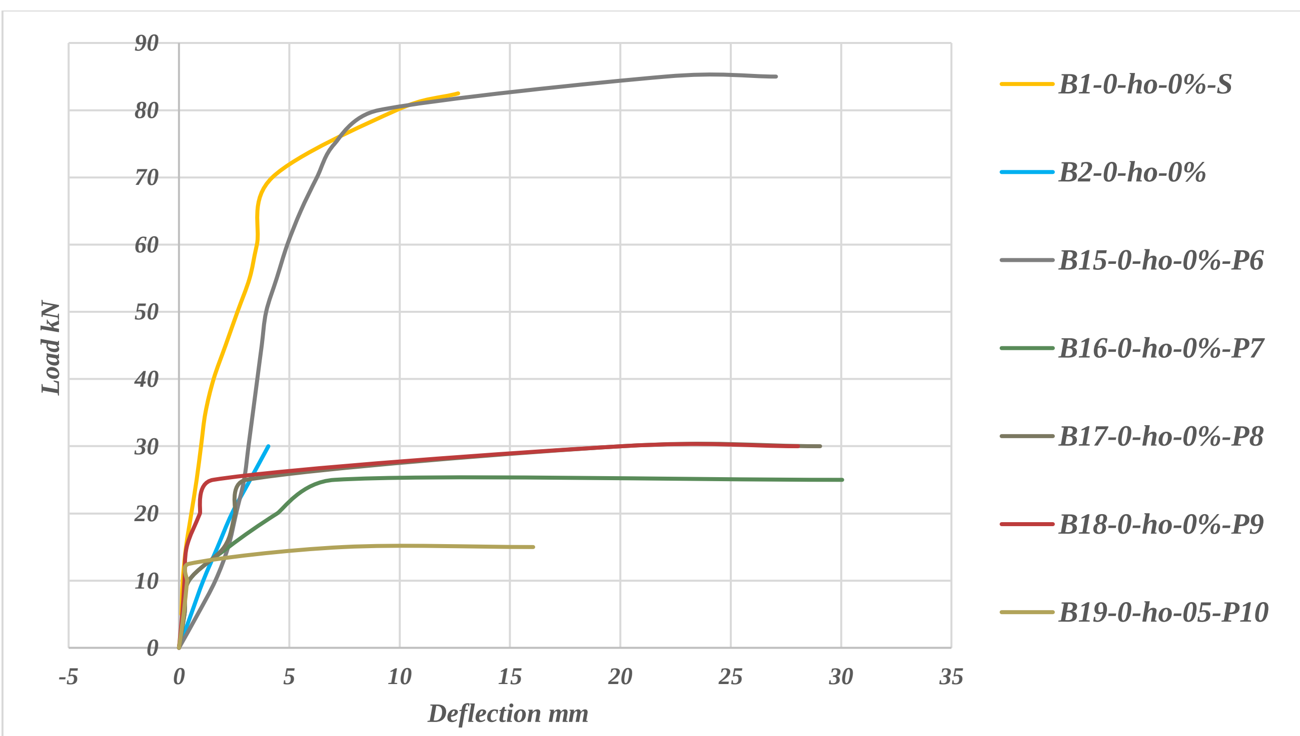


Fig. (4-16): Load Deflection curves for beams with PET bar hybrid reinforcement.

Ductility is the structural member's ability to undergo inelastic deformations beyond yield deformation without a significant load in its load-carrying capacity. The ductility index (μ) can be obtained from the load-deflection curve by dividing the maximum deflection (Δu) on the yield deflection (Δy). The ductility for all concrete beams was presented in Table (4-7) and Fig. (4-17).

Table (4-7): Ductility of Tested Beam

Beam designation	***Ultimate Load Pu (kN)***	***Maximum deflection Δu (mm)***	***Yield deflection Δy (mm)***	***Ductility index***	***Changing in ductility***
B1-0-ho-0%-S	82.5	12.65	4.23	2.9	----
B2-0-ho-0%	30	4.05	2.4	1.68	-42.07
B3-1-ho-1.25%-S	87.5	25.55	8.13	3.14	+8.27
B4-2-ho-5%-S	84	27.05	4.23	6.5	+124.14
B5-3ai-ho-1.5%-S	75	20.05	5.65	3.55	+22.4
B6-3ar-ho-1.5%-S	72.5	15.05	4.05	3.72	+28.27
B7-1-hy-1.25% 10%-S	70.5	30.05	5.3	5.66	+95.17
B8-2-hy-5% 10%-S	74	25.05	3.6	6.98	+140.7
B9-3-hy-1.5%bi 3%ar-S	70.5	25.05	5.95	4.21	+45.17
B10-0-ho-0%-P1	12.5	16.05	0.3	53.5	+1744.83
B11-0-ho-0%-P2	15	17.05	0.2	85.25	+2839.66
B12-0-ho-0%-P3	15	17.05	1.05	16.23	+459.66
B13-0-ho-0%-P4	20	20.05	9.05	2.21	-23.8
B14-0-ho-0%-P5	20	16.05	0.55	29.2	+906.9
B15-0-ho-0%-P6	85	27.05	9.05	2.99	+3.1
B16-0-ho-0%-P7	25	30.05	4.45	6.753	+132.9
B17-0-ho-0%-P8	30	29.05	3.05	9.52	+228.3
B18-0-ho-0%-P9	30	28.05	1.55	18.1	+524.14
B19-0-ho-0%-P10	15	16.05	0.45	35.7	+1131.03

As shown Table (4-7), the hybrid section beams (B7-1-hy-1.25% 10%-S, B8-2-hy-5%10%-S, and B9-3-hy-1.5%bi 3%ar-S) which contain on plastic waste within the concrete mixture have a relative ductility index of 5.66, 6.98, and 4.21, respectively which are approximately 2–3 times greater than that of the reference specimen without plastic particles. Also, the beams with homogenous section (B3-1-ho-1.25%-S, B4-2-ho-5%-S, B5-3ai-ho-1.5%-S, and B6-3ar-ho-1.5%-S) have approximately 1–3 times greater than that of the reference beam. Notably, the hybrid beam with plastic boxes had the largest ductility index results; this ductility behavior showed in Figures (4-12), (4-13), and (4-14).

In the present study it's tried to use PET as tension reinforcement in different shapes and configurations, and all presented beams with plastic bars gave the higher values of ductility as compared with others beams that contain on the plastic waste within the concrete mixture as shown in Table (4-7), Figures (4-15) and (4-16).

Thus, the inclusion of any type of plastic wastes in any shape much improves the beam ductility.

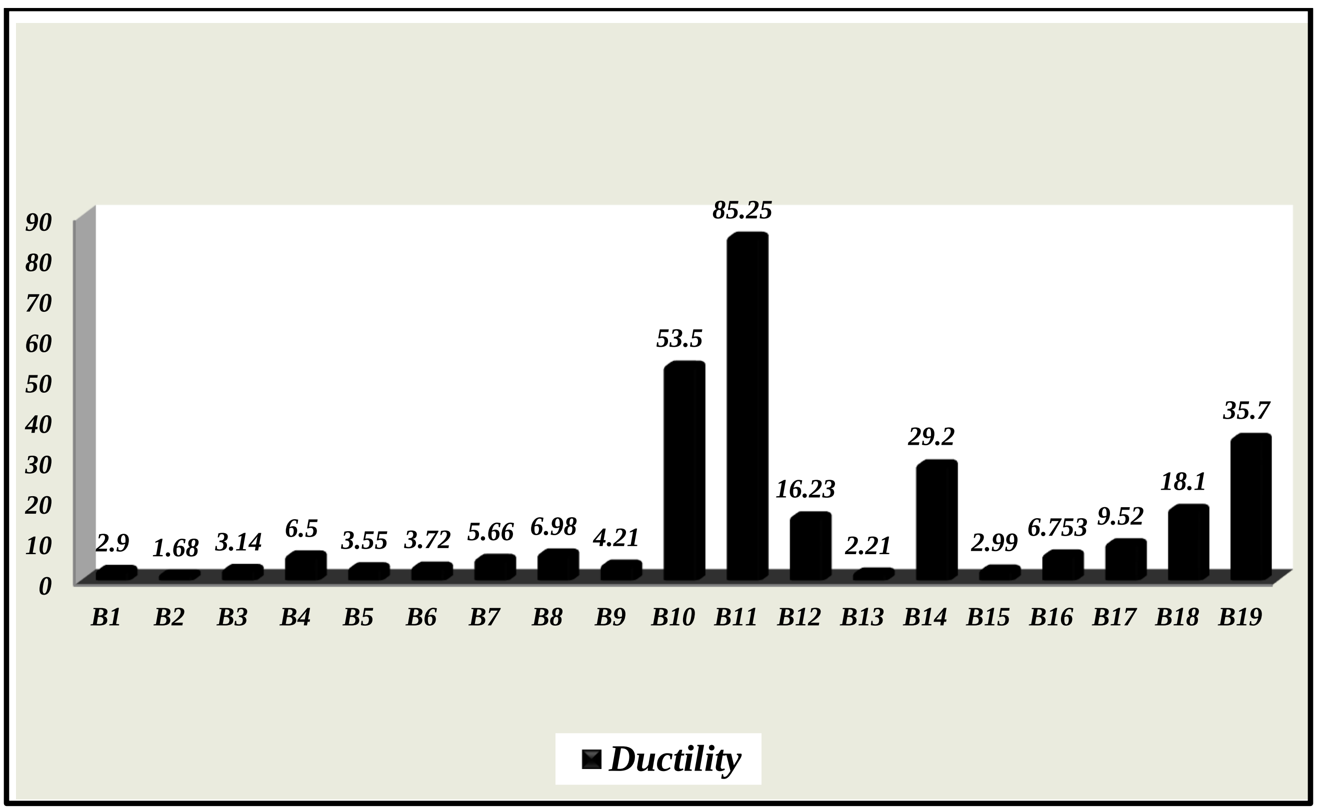


Fig. (4-17): Ductility of tested beams.

4.4.3 Cracking

The cracking is development in concrete when applied tensile stress exceeding the tensile strength of concrete. The cracking of all beams specimens is investigated as shown in Fig. (4-18). The cracking investigation is accomplished via the following topics:

1. First cracking load.
2. Crack pattern.
3. The spacing between the cracks.

4.4.3.1 First Cracking Load (p_{cr}) for Concrete beam

The first crack loads for all concrete beams were recorded and presented in Table (4-8), and the figures of all beams are shown in Fig. (4-18).

As shown in Table (4-8), the reference beam (***B1-0-ho-0%-S)*** revealed the first crack at a load of 35kN, while in case of the concrete maximum that contains plastic waste, the first crack load depends on the type and amount of plastic within tension zone.

For concrete with PVC waste, the cracking load is decreased as the percentage of waste increased in tension zone, in which for 1.25% ***(B3-1-ho-1.25%-S)*** and 10% ***(B7-1-hy-1.25% 10%-S)***, the cracking loads are 35kN and 30kN, respectively, namely with reduction percent of 0% and 14.3%. Thus, PVC reduces the cracking capacity and increase the brittleness of concrete. While concrete with plastic box waste, the cracking load is increased as the percentage of waste increased in tension zone, in which for 5% ***(B4-2-ho-5%-S)*** and 10% ***(B8-2-hy-5% 10%-S)*** the cracking loads are 35kN and 40kN, respectively, namely with the increasing percent of 0% and 14.3%. Thus, plastic boxes increase the cracking capacity and the brittleness of concrete.

Table (4-8): First cracking load of Tested Beams

Beam designation	Pcr(kN)	Pu(kN)	Pcr/Pu %	Pcr/Pcr(Reference beam) %	Changing in first cracking load
B1-0-ho-0%-S	35	82.5	0.42	100	----
B2-0-ho-0%	20	30	0.66	57	-43
B3-1-ho-1.25%-S	35	87.5	0.4	100	----
B4-2-ho-5%-S	35	84	0.417	100	----
B5-3ai-ho-1.5%-S	40	75	0.53	114.3	+ 14.3
B6-3ar-ho-1.5%-S	40	72.5	0.55	114.3	+ 14.3
B7-1-hy-1.25% 10%-S	30	70.5	0.43	85.7	-14.3
B8-2-hy-5% 10%-S	40	74	0.54	114.3	+14.3
B9-3-hy-1.5%bi 3%ar-S	35	70.5	0.49	100	----
B10-0-ho-0%-P1	10	12.5	0.8	28.6	-71.4
B11-0-ho-0%-P2	10	15	0.66	28.6	-71.4
B12-0-ho-0%-P3	10	15	0.66	28.6	-71.4
B13-0-ho-0%-P4	10	20	0.5	28.6	-71.4
B14-0-ho-0%-P5	12.5	20	0.625	35.7	-64.3
B15-0-ho-0%-P6	35	85	0.41	100	----
B16-0-ho-0%-P7	12.5	25	0.5	35.7	-64.3
B17-0-ho-0%-P8	10	30	0.333	28.6	-71.4
B18-0-ho-0%-P9	15	30	0.5	42.8	-57.2
B19-0-ho-0%-P10	10	15	0.66	28.6	-71.4

Also, as percentage of PET fiber in tension zone increased the cracking capacity is decreased as shown in Table (4-8), for 1.5% PET (***B5-3ai-ho-1.5%-S and B6-3ar-ho-1.5%-S)*** and 3% PET ***(B9-3-hy-1.5%bi 3%ar-S),*** the cracking load is 40kN and 35kN respectively namely with reduction percent of 14.3%, 14.3%, and 0%.

Thus, percentages of plastic boxes as sand replacement of 5% is optimum for both strength and ductility requirements. Similarly, 1.5% of PET fiber and 1.25% PVC are optimum for both strength and ductility requirements.

4.4.3.2 Cracks Pattern

Fig. (4-18) shows the crack patterns for all beams at failure. 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. In beams(***B10-0-ho-0%-P1, B11-0-ho-0%-P2, B12-0-ho-0%-P3, B13-0-ho-0%-P4, B14-0-ho-0%-P5, B16-0-ho-0%-P7, B17-0-ho-0%-P8, B18-0-ho-0%-P9, B19-0-ho-0%-P10)*** that contained on PET bars as tension reinforcement; they appeared as one crack in the left side of the mid-span, then widen with increasing the load and continued until it is reached to the compression zone. While the beams (***B3-1-ho-1.25%-S, B4-2-ho-5%-S, B5-3ai-ho-1.5%-S***, ***B6-3ar-ho-1.5%-S***, ***B7-1-hy-1.25% 10%-S***, ***B8-2-hy-5% 10%-S***, ***B9-3-hy-1.5%bi 3%ar-S***) that contained on plastic waste with different types and 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.

a) B1-0-ho-0%-S

b) B2-0-ho-0%

c) B3-1-ho-1.25%-S

d) B4-2-ho-5%-S

Fig. (4-18): Crack pattern for beams tested.

e) B5-3ai-ho-1.5%-S

f) B6-3ar-ho-1.5%-S

g) B7-1-hy-1.25% 10%-S

h) B8-2-hy-5% 10%-S

Fig. (4-18): Continued.

i) B9-3-hy-1.5%bi 3%ar-S

j) B10-0-ho-0%-P1

k) B11-0-ho-0%-P2

l)B12-0-ho-0%-P3

Fig. (4-18): Continued.

m) B13-0-ho-0%-P4

n) B14-0-ho-0%-P5

o) B15-0-ho-0%-P6

p) B16-0-ho-0%-P7

Fig. (4-18): Continued.

q) B17-0-ho-0%-P8

r) B18-0-ho-0%-P9

s) B19-0-ho-0%-P10

Fig. (4-18): Crack pattern for beams tested.

4.4.3.3 Spacing between Cracks

The spacing between cracks varies between (116.7 – 700) mm as shown in Table (4-9). All beams (***B10-0-ho-0%-P1, B11-0-ho-0%-P2, B12-0-ho-0%-P3, B13-0-ho-0%-P4, B14-0-ho-0%-P5, B16-0-ho-0%-P7, B18-0-ho-0%-P9, B19-0-ho-0%-P10)*** that contained on PET bars as tension reinforcement, the spacing between cracks was 700mm which was the lower number of cracks compared with the reference beam (***B1-0-ho-***

0%-S) which had 116.7mm. The beams (***B3-1-ho-1.25%-S***, ***B6-3ar-ho-1.5%-S***) the spacing between cracks was 155.6mm. The beams (***B4-2-ho-5%-S, B9-3-hy-1.5%bi 3%ar-S***) the spacing between cracks was 140mm The beams ***(B5-3ai-ho-1.5%-S***, ***B8-2-hy-5% 10%-S***) the spacing between cracks was 116.7mm which was the higher number of cracks and the lower spacing between cracks while for the beams (***B2-0-ho-0%, B17-0-ho-0%-P8***) the spacing between cracks was 466.7mm. For the beam (***B7-1-hy-1.25% 10%-S)*** the spacing between cracks was 200mm. Thus, the addition of plastic waste with different shapes and percentages decreases the number of cracks and reduces the spacing between cracks.

Table (4-9): Spacing between Cracks of concrete Beams

Beam designation	***Number of cracks***	***The spacing between cracks (mm)***
B1-0-ho-0%-S	11	116.7
B2-0-ho-0%	2	466.7
B3-1-ho-1.25%-S	8	155.6
B4-2-ho-5%-S	9	140
B5-3ai-ho-1.5%-S	11	116.7
B6-3ar-ho-1.5%-S	8	155.6
B7-1-hy-1.25% 10%-S	6	200
B8-2-hy-5% 10%-S	11	116.7
B9-3-hy-1.5%bi 3%ar-S	9	140
B10-0-ho-0%-P1	1	700
B11-0-ho-0%-P2	1	700
B12-0-ho-0%-P3	1	700
B13-0-ho-0%-P4	1	700
B14-0-ho-0%-P5	1	700
B15-0-ho-0%-P6	10	127.3
B16-0-ho-0%-P7	1	700
B17-0-ho-0%-P8	2	466.7
B18-0-ho-0%-P9	1	700
B19-0-ho-0%-P10	1	700

Chapter Five
Conclusions and Recommendations

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1: GENERAL

In this chapter, the main conclusions of the experimental work that study the behavior of concrete included plastic waste particles with different shapes types, and percentages are presented. Also, the recommendations for future work are presented in this chapter.

5.2: CONCLUSIONS

Based on the results of the tests of concrete mixtures with different types and percentages of plastic wastes, and the results of nineteen concrete beams specimens with different plastic waste percentages within the mixture or with PET bar as tension reinforcement the following conclusions can be drawn:

5.2.1 Workability

1. The results of all concrete mixtures demonstrated that the slump decreases with the increasing of plastic waste particles for all types of plastic waste
2. The mixtures that contain on 1.25% PVC, 2.5% plastic boxes and 1.5% PET are the optimum percentages for knowing the workability. In all mixtures, the best mixture that has the higher workability is the mixture that contains on 2.5% of plastic boxes.

5.2.2 Compressive Strength

1. The results indicated that the compressive strength increased at the optimum percentage of PVC, plastic boxes, and PET particles as sand

replacement or as fiber compared to the reference mixture for most mixes and at all ages of test

2. The compressive strength increases with the increase of PVC particles content compared to the reference mixture for all mixes of w/c = 0.41 and 0.53 and both 7 and 28 days.
3. For Plastic boxes waste particles, the dose of 5% is the optimum percentage as a sand replacement. Thus, 10% replacement yield compressive strength close to that of reference mixture.
4. The samples that contain machine PET fiber show a slight increase in compressive strength for both dosages 1.5% and 3%. While the samples that contain hand PET fiber show an increase in compressive strength in the mixes that contain on 1.5 %, while 3% of hand PET fiber led to drop in compressive strength.

5.2.1 Splitting Tensile Strength

1. The results showed that the samples that contain PVC particles yield an increase in split tensile strength for a w/c ratio of 0.41and 0.53, while plastic boxes particles show a decrease in split tensile strength for all percentages.
2. The percentage of 1.25% PVC is considered the optimum percentage.
3. The samples which contain plastic boxes particles show decreases in split tensile strength for all percentages.

5.2.2 Flexural Strength

1. The results indicated that the flexural strength increased at the optimum percentage of PVC particles content compared to the reference mixture for all mixes of w/c = 0.41 and at all ages of the test. Thus 1.25% sand

replacement with PVC waste particles is the optimum dose for both w/c ratios.

2. The percentage of 2.5% sand replacement by plastic boxes waste particles is the optimum dose for w/c = 0.41.
3. The samples that contain machine PET fiber show a slight decrease in flexural strength in all the mixes, while the samples that contain hand PET fiber show a slight increase in flexural strength in the mixes that contain on 1.5 % PET fiber and drop for 3% PET fiber.

5.2.3 Ultimate load of tested beams

1. Addition of PET bars as tension reinforcement affect negatively on the ultimate load while using the plastic waste within the mixture affect positively.
2. The beams (***B3-1-to-1.25%-S &B4-2-ho-5%-S***) which have a homogenous section of concrete with 1.25% PVC plastic waste and 5% Plastic boxes waste as the sand replacement, respectively, showed higher ultimate failure load than reference beam by about 6.06% and 1.81%, respectively. Hence the maximum percentages of sand replacement with plastic wastes yield higher ultimate loads.
3. For hybrid section beams, the beam (***B9-3-hy-1.5%bi 3% ar-S***) which have 1.5% and 3% of PET fiber in compression and tension zones respectively, showed a reduction in the ultimate load of 14.5%. Thus, the best hybrid section is with Plastic boxes wastes in which only about 10.3% reduction in ultimate load.

So, the use of hybrid section beams yields ultimate loads of about 85%-89% of the reference beam, namely acceptable results taking into account the number of plastic wastes that recycled into concrete beams.

4. In the present study it's tried to use PET as tension reinforcement in different shapes and configurations, but all presented plastic bars are failed except one case in which the deformed steel bar is used with additional layer of PET bottle cut into two parts, namely beam (***B15-0-ho-0%-P6***) in which the ultimate load reached to 85 kN, i.e., 3.03 % larger than reference beam.

5.2.4 Deflection of Tested Beams

1. The beams that contain plastic wastes with concrete mixture showed maximum deflection larger than the reference beam, which led to improving the ductility by about (3.14-6.98) %.
2. The beams that contained plastic bars show an increase in deflection that led to an increase the ductility by about (2.99-85.25) %.
3. Using PET layers in addition to steel reinforcement in tension zone, considerably increase the maximum deflection. Thus for ***(B15-0-ho-0%-P6)***, the maximum deflection is 27.05 mm which higher than that of the reference beam by about 113.83%. Thus, the PET layer improves the beam ductility without any reduction in its load.
4. Thus, the inclusion of any type of plastic wastes in any shape much improves the beam ductility.
5. Thus, percentages of plastic boxes as sand replacement of 5% are optimum for both strength and ductility requirements. Similarly, 1.5% of PET fiber and 1.25% PVC are optimum for both strength and ductility requirements.

5.3: RECOMMENDATIONS

1- Working the same study with different percentages of PVC substituted from coarse or fine aggregate or using PVC as powder substituted by weight of cement.
2- Working the same study with different sizes and percentages of Plastic box substituted from the coarse or fine aggregate.
3- Working the same study with different lengths and percentages of PET substituted from the coarse or fine aggregate.
4- Try other ways for manufacturing and improve the bonding of PET bars to promote the tension reinforcement to get on higher values.
5- Drawing a stress-strain curve.
6- Calculate I_{eff} and I_{cr}.
7- Calculate the impact.
8- Calculate the poison’s ratio.
9- Calculate energy absorption.

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Appendix

Flexural reinforcement

All beams were designed according to ACI318-95 Code. The steps of analysis of the reference beam as follows:

From the design of the beam in Fig. (3-15)

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

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

Let concrete cover = 20 mm.

So, d =164mm

As = 2 * $\frac{\pi}{4}$ * d^2 = 0.0092

❖ $\rho = \frac{226.08}{150*164}$ = 0.092

$\because \rho_{max} = 0.75\, \rho_b = 0.75 * [\, 0.85\, \beta_1 * \frac{f`c}{fy} * \frac{600}{600+fy}\,]$

$\beta_1 = 0.85 - 0.005\ \frac{f`c-28}{7} > 0.65$ for f`c > 28 MPa

$\because$ concrete strength f`c equal to 30.35MPa and yield strength of reinforcement equals 493MPa

❖ $\beta_1 = 0.8483$

❖ ρ_{max} = 0.0182

∵ $\rho < \rho_{max}$

❖ Ignore the compression reinforcement and analysis as simply reinforced beam

∵ ρ = 0.0092

And $\rho_b = 0.85\ \beta_1 * \frac{f`c}{fy} * \frac{600}{600+fy}$ = 0.0244

So, $\rho < \rho_b$

❖ fs = fy

From Whitney Block

C = T

❖ 0.85 * f`c *b *a = As * fy

❖ a = 28.8 mm

∵ Mn = C (d- $\frac{a}{2}$) = 0.85 * f`c * b * a * (d- $\frac{a}{2}$) = 16.7 kN.m

ML = Mn – Md

Md = $\frac{Wu\ L^2}{8}$

Wu = 1.2 W_{beam} = 1.2 * density * volume

= 1.2 * 2374.113 * 0.15 * 0.2 * 1.4 = 1.17kN

Md = $\frac{1.17 * \ 1.4^2}{8}$ = 0.287 kN.m

ML = 16.7 – 0.287 = 16.413 kN.m

$ML = \frac{p}{2} * 405 =$

❖ $P_{flexural} = 81.05$ kN

Shear reinforcement

All beams were designed according to ACI318-95 Code. The steps to calculate the shear load as follows:

1. $Vu = Ø\ Vn = Ø\ (Vc + Vs)$
2. $Ø\ Vc = Ø * (\frac{1}{6}) * \sqrt{f`c} * bw * d * 10^{-3}$

   $Ø\ Vc = 0.75 * (\frac{1}{6}) * \sqrt{30.35} * 150 * 164 * 10^{-3} = 16.9$ kN
3. $Ø\ Vs = \frac{Ø\ Av\ fy\ d}{s}$

   Let s = 60 mm

   $Av = 2 * \frac{\pi}{4} * d^2 = 157\ mm^2$

   ❖ $ØVs = 165.8$ kN
4. Vu = 16.9 + 165.8 = 182.7 kN

   ❖ $P_{shear} = 182.7$ kN > $P_{flexural} = 81.05$kN

الملخص

يمكن الحد من مشكلة تراكم الملخلفات البلاستيكية من خلال مفهوم إعادة التدوير وإحدى الطرق المحتملة لإعادة تدوير هذه النفايات هو استخدامها في البناء الخرساني. يهدف هذا البحث إلى دراسة إمكانية إعادة استخدام النفايات البلاستيكية مثل البولي فينيل كلوريد والصناديق البلاستيكية لإنتاج الركام الناعم كبديل جزئي للرمل داخل خليط الخرسانة بالإضافة إلى إعادة استخدام مخلفات القناني البلاستيكية (البولي اثيلين تيرفيثلايت) كألياف داخل الخلطة الخرسانية. بعد ذلك ، تم التحري عن سلوك العتبات الخرسانية ذات الاسناد البسيط التي تحتوي نسبًا مختلفة من هذه النفايات داخل الخليط الخرساني أو المسلحة بقضبان البولي اثيلين تيرفيثلايت بأنماط مختلفة وتم فحصها من خلال تأثير هذه النفايات على المقاومة والقابلية الخدمية لهذه العتبات الخرسانية. تم اختبار وفحص 19 عتبة خراسنية بأبعاد (150 * 200 * 1400) ملم. حيث تم إجراء فحوصات تجريبية لتقييم الخواص الميكانيكية للخلطات التي تحتوي على هذه النفايات ومقارنتها بالخلطة المرجعية. حيث استخدمت حبيبات البولي فينيل كلوريد في الخلطة بنسب أستبدالية (0٪ ، 1.25٪ ، 2.5٪ ، 3.75٪ ، 5٪) من وزن الرمل ، في حين تم استخدام الصناديق البلاستيكية بنسب استبدالية (0٪ ، 2.5٪ ، 5٪) **و** 10 ٪) من وزن الرمل ، وألياف البولي اثيلين تيرفيثلايت المضافة بنسب مئوية (0 ٪ ، 1.5 ٪ ، و 3 ٪) من حجم الخلطة الخرسانية. وشملت الخواص الميكانيكية التي تم تقييمها مقاومة الانضغاط ، ومقاومة الشد ومقاومة الانحناء. أظهرت النتائج أن الخليط الذي يحتوي على 1.25 ٪ من حبيبات البولي فينيل كلوريد ، و 5 ٪ من الصناديق البلاستيكية ، و 1.5 ٪ من ألياف البولي اثيلين تيرفيثلايت هي أفضل النسب المئوية لاستخدام هذه النفايات داخل الخليط الخرساني ، حيث أعطت مقاومة أعلى من مقاومة الخلطة المرجعية.

اشتملت المتغيرات للعتبات الخرسانية المسلحة على الحمل الاقصى والانحناء واالمطيلية وانماط التشققات. حيث أظهر اختبار العتبات الخرسانية انخفاضًا في الحمل النهائي لجميع الحزم التي تحتوي على قضبان البولي اثيلين تيرفيثلايت كتسليح للشد. حيث كان الانخفاض في الحمل النهائي (63.63 ٪ -84.84 ٪) ولكن كل هذه العتبات تزيد من المطيلية. في حين أن العتبات التي تحتوي على 1.25 ٪ من البولي فينيل كلوريد ونفايات الصناديق البلاستيكية بنسبة 5 ٪ كبديل جزئي للرمل تظهر حمل فشل نهائي اعلى من العتبة المرجعية بحوالي 6.06 ٪ و 1.81 ٪ ، على التوالي وزيادة في المطيلية حوالي 8.27 ٪ و 124.14 ٪ ، على التوالي. في حين أن العتبات التي تحتوي على الياف البولي اثيلين تيرفيثلايت بنسبة 1.5 ٪ من حجم الخليط ، كان هناك انخفاض طفيف في الحمل 9.09 ٪ و

12.12 ٪ ، على التوالي وزيادة في المطيلية بنحو 22.4 ٪ و 28.27 ٪ على التوالي. تظهر العتبات التي تحتوي على مقطع هجين يتكون من نفايات البولي فينيل كلوريد بنسبة 1.25٪ ونفايات صناديق بلاستيكية بنسبة 5٪ كبديل للرمل في جزء الانضغاط واستبدال الرمل بنسبة 10٪ لكل من الصناديق البلاستيكية و البولي فينيل كلوريد في جزء الشد انخفاضًا صغيرًا نسبيًا في الحمل النهائي بنسبة 14.5 ٪ و 10.3 ٪ ، على التوالي ولكن هذه العتبات تزيد من المطيلية بنحو 95.17 ٪ و 140.7 ٪. بينما بالنسبة للعتبة التي تحتوي على 1.5 ٪ و 3 ٪ من ألياف البولي اثيلين تيرفيثلايت في جزئي الانضغاط والشد ، على التوالي ، تظهر انخفاضًا في الحمل النهائي بنسبة 14.5 ٪ وزيادة في المطيلية بحوالي 45.17 ٪. وبالتالي ، كان أفضل مقطع هجين هوالعتبة التي تحتوي على نفايات الصناديق البلاستيكية حيث انخفضت فقط حوالي 10.3 ٪ في الحمل النهائي ، وهذه العتبة اعطت مطيلية أعلى حوالي 140.17 ٪.

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة ميسان / كلية الهندسة

قسم الهندسة المدنية

خواص وسلوك الانثناء للعتبات الخرسانية المسلحة باستخدام النفايات البلاستيكية المعاد تدويرها

اطروحة
مقدمة إلى قسم الهندسة المدنية في جامعة ميسان كجزء من متطلبات نيل شهادة الماجستير في علوم الهندسة المدنية/انشاءات

من قبل

همسة ماهر عدنان
(بكالوريوس هندسة مدنية 2016)

باشراف

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جمادي الآخرة 1440 **شباط 2019**