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FLEXURAL BEHAVIOR OF LIGHT WEIGHT CONCRETE BEAMS INCORPORATING PLASTIC WASTES

By

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the Master of Science degree in Civil Engineering
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بسم الله الرحمن الرحيم

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سورة طـه الآية 114

صدق الله العلي العظيم

DEDICATION

I would like to express my deepest gratitude to those who have stood by me and supported me throughout the years:

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To my parents, for their unwavering love, support, guidance, and belief in me, even during the toughest times.

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ABSTRACT

This study investigates the potential of incorporating recycled plastic materials—polyethylene terephthalate (PET) and polyvinyl chloride (PVC)—as partial replacements for both fine and coarse aggregates in lightweight concrete. PET, sourced from discarded plastic bottles, and PVC, derived from fragmented construction pipes, were used to replace sand and gravel, respectively. The primary objective was to develop a concrete mix with a density below 1900 kg/m^3 and a compressive strength exceeding 21 MPa while evaluating the impacts on the concrete's physical and mechanical properties and analyzing the flexural behavior of reinforced lightweight concrete beams.

A series of concrete mixes with varying ratios of PET and PVC were prepared. Specifically, coarse aggregate (gravel) was partially replaced with PVC, and fine aggregate (sand) was replaced with PET. The experimental program included mixes with the following ratios: B1 (35% PET & 35% PVC), B2 (30% PET & 40% PVC), B3 (25% PET & 50% PVC), B4 (15% PET & 60% PVC), and B5 (10% PET & 70% PVC). A control mix containing no PET or PVC was also tested. All mixes maintained a consistent ratio of 1:1.1:2 for the aggregates.

Workability, assessed through slump tests, showed a notable reduction of up to 56% in mixes with 35% PET and 35% PVC, primarily due to the lower density and poor bonding of the recycled plastics. While higher PVC content slightly enhanced workability, it was still significantly lower than that of the control mix.

Compressive strength tests indicated a general decline with PET and PVC additions, with the B1 mix (35% PET and 35% PVC) showing a 26.3% reduction after 28 days. Tensile and flexural strengths also decreased, with reductions up to 42.1% in tensile strength and 38.2% in flexural strength compared to the control mix.

Density measurements decreased with higher plastic content, with the B5 mix (10% PET and 70% PVC) achieving a 22% reduction compared to the control. This indicates the effectiveness of PVC in creating lightweight concrete. The absorption ratio also increased, with the B1 mix showing a 62.1% rise to 1.91%, while the highest PVC content (70%) combined with 10% PET resulted in a ratio of 1.57%, demonstrating a nonlinear relationship between absorption and plastic content.

Ultrasonic Pulse Velocity (UPV) measurements indicated a decrease in concrete quality with increasing plastic content. The control mix had the highest UPV, reflecting superior density and uniformity. Increased plastic content led to lower UPV values, signifying reduced density and internal uniformity. The B1 mix maintained a good quality rating, while mixes with higher PVC content (e.g., B5) showed poorer quality ratings due to significant internal defects.

Structural testing of lightweight concrete beams under static loads revealed ultimate load-carrying capacities ranging from 141.5 kN to 164 kN and deflections between 30.59 mm and 61.34 mm. Beams with higher PVC content exhibited improved ductility and energy absorption, with the B5 mix showing a 12.99% increase in ductility index and a 180% increase in energy absorption compared to the control beam. However, these benefits were achieved at the expense of reduced compressive strength and stiffness

The load-deflection behavior showed that beams made with recycled plastic waste generally exhibited reduced stiffness and increased deflection compared to the control. For instance, the B5 mix demonstrated a 200% increase in deflection. Overall,

SUPERVISOR CERTIFICATION

I certify that the preparation of this thesis entitled " **FLEXURAL BEHAVIOR OF LIGHT WEIGHT CONCRETE BEAMS INCORPORATING PLASTIC WASTES** " was presented by " **Mustafa Mohammed Abdulhasan** ", and prepared under my supervision at The University of Misan, Department of Civil Engineering, College of Engineering, as a partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Structural Engineering).

Signature:
Prof. Dr. Abbas Oda Dawood
Date:

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

Signature:
Assist Prof. Dr. Murtada Abass Abd Ali
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EXAMINING COMMITTTEE’S REPORT

We certify that we, the examining committee, have read the thesis titled **(FLEXURAL BEHAVIOR OF LIGHT WEIGHT CONCRETE BEAMS INCORPORATING PLASTIC WASTES)** which is being submitted by (**Mustafa Mohammed Abdulhasan**) and examined the student in its content and in what is concerned with it, and that in our opinion, it meets the standard of a thesis for the degree of Master of Science in Civil Engineering (Structures).

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLES

ε_c	Compression Strain
D.I	Ductility Index
fc`	Cylinder concrete compressive strength in MPa
f_{cu}	Cube Compressive Strength in MPa
fr	Modulus of rupture in MPa
ft	Tensile strength in MPa
fy	Yield strength in MPa
ɣ	Density in Kg/m^3
I.S	Initial Stiffness in kN/mm
Pcr	First Crack Load in kN
Pu	Ultimate Load in kN
Δu	Deflection in mm

LIST OF ABBREVIATIONS

Ab	Absorption
ACI	American Concrete Institute
ASTM	American Society for Testing and Materials
BS	British standard
HDPE	High Density Polyethylene
LDPE	Low-density polyethylene
PET	Polyethylene Terephthalate
PP	Polypropylene
PPVC	Plasticized Polyvinyl Chloride
PS	Polystyrene
PVC	Polyvinyl chloride
RAC	Recycled Aggregate Concrete
SP	Superplasticizer
UPV	Ultrasonic Pulse Velocity
UPVC	Unplasticized Polyvinyl Chloride
w/c	Water to cement

CHAPTER ONE: INTRODUCTION

1.1 General

Among building materials, concrete is the most widely used and accepted. After water, it is the most consumed substance on Earth. It is used twice as much worldwide than steel, aluminum, and wood put together. By 2025, the global ready-mix concrete industry is predicted to generate over $600 billion in sales [1]. The primary binding component of concrete is cement, which is made from naturally occurring minerals including shale, clay, and lime. A significant amount of carbon dioxide is generated during the cement-making process, which pollutes the environment. Concerned, researchers have been looking at ways to lower it. On the one hand, the production of cement involves the loss of natural resources, significant energy needs, and greenhouse gas emissions. However, growing issues related to trash and how it is handled also occupy academics' time. Researchers have been exploring with various wastes in an effort to reduce the amount of cement used in concrete. Research studies promoting the partial substitution of other materials, particularly wastes, for cement in the concrete industry are critical. In general, practitioners and researchers have been addressing the problems associated with managing waste in an environmentally responsible way. As evidenced by recent research, one method of treating waste is to incorporate it into concrete, which allows it to be properly used as a building material without damaging the environment. As a result, the researchers have been hard at work testing various wastes and how they might be used to make concrete. Some examples of these wastes include foundry trash, waste from granite and glass powder, agricultural waste, carbon fiber waste, carpet waste, and plastic wastes. There is a new sentence that researchers are using, "green-concrete," which suggests that their attempts to decrease the amount of cement used in concrete are serious. Concrete and waste-based research often focus on engineering qualities as well as chemical analysis. As with the use of concrete, it is critical to examine the dose of a specific waste and its influence on engineering qualities so that appropriate procedures may be implemented when utilizing it as a construction material.

1.2 Lightweight concrete

Lightweight concrete has a history spanning over two millennia, with its origins traced back to ancient Rome. Roman engineers utilized lightweight aggregates such as pumice and volcanic ash in the construction of enduring structures like the Pantheon dome and aqueducts, showcasing their innovative use of materials and their durability. The modern evolution of lightweight concrete began in the early 20th century, driven by the demand for materials that offer enhanced thermal insulation and reduced structural loads. Over the years, technological advancements have introduced various lightweight aggregates, including expanded clay, shale, and, more recently, recycled materials like plastic waste. Continuous research and development efforts are further enhancing the performance and sustainability of lightweight concrete, solidifying its role as an essential material in contemporary construction [2,3].

When it comes to density, lightweight concrete is less dense than regular concrete. Utilizing naturally occurring lightweight aggregates, such as (Pumice, Diatomite, Scoria, sawdust) or plastic lightweight aggregates such as (foamed slag, fly ash, and expandable shales) [4], lightweight aggregates such as shale, slate, or expanded clay, or by using air entrainment agents. The primary benefits of lightweight concrete include decreased structural load, upgraded thermal and acoustic isolation, and ease of handling and installation. It is commonly used in building construction, particularly for flooring, roofing, and wall panels where weight reduction is advantageous.

There are several types of lightweight concrete, including: [5].

- The compressive of Structural lightweight concrete should be more than 17 MPa at 28 days and the density should be not more than 1850 kg/m³.
- The compressive strength of isolating lightweight concrete between 0.7 up to 7 MPa and the density less than 800 kg/m³.

1.2.1 Lightweight Aggregate Classification [6, 7]

1. Lightweight Aggregate Concrete: Uses lightweight aggregates to decrease the density of the concrete. Figure1.1 shows the sorts of the lightweight aggregate.
2. No-fined concrete: No-fined concrete is made by normal components of concrete without fine aggregate (sand). With this mixture, a layer of cement paste thicknesses up to 1.3 mm thick is applied to each coarse aggregate particle. The kind and grading of the aggregate determine the density of fine concrete.
3. Aerated lightweight concrete: Aerated concrete, a one of kind of lightweight concrete also famous as cellular concrete, is categorized into two types based on production methods:
4. Foamed Concrete (Non-Autoclaved Aerated Concrete, NAAC): Made by insert preformed stable foam or adding a foaming agent to a mix of cement mortar.
5. Autoclaved Aerated Concrete (AAC): A mixture of high silica sand, cement or lime, and water is sprayed with aluminum powder and other additives.

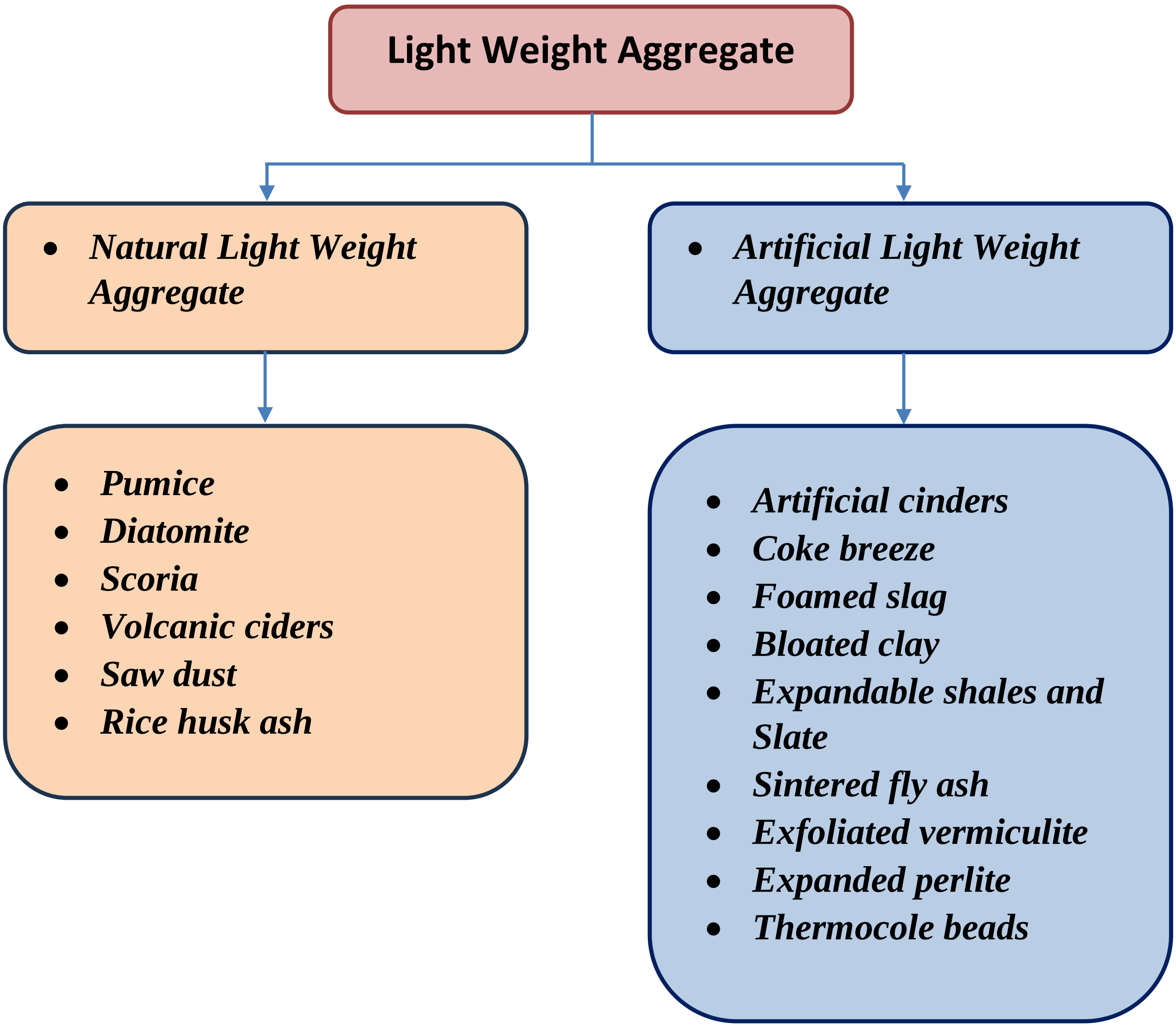


Figure 1.1 Lightweight aggregate Classification

1.3 Incorporation of Plastic Waste in Concrete to Produce Light Weight Concrete

The primary goal of employing lightweight aggregate in concrete is to minimize the material's self-weight, hence reducing the foundation's dimensions and saving money. Structural lightweight concrete (SLWC) is defined as concrete with a compressive strength greater than 17.2 MPa and an air-dried density at 28 days ranging from 1120 to 1920 kg/m3. There is. One approach to meeting rising aggregate demand is to seek out a whole or partial substitute for traditional natural aggregates. One of the most prevalent materials used in place of natural aggregates is recycled plastic, which not only mitigates the negative effects of natural aggregates but also contributes to the solution of the urgent problem of plastic waste. There are two primary classifications of plastic waste: recyclable and non-recyclable. The unfortunate reality is that landfills receive over 80% of the waste, with the remaining percentage being split nearly evenly between burning and recycling [8]. There are many different types of plastic, but products based on polyethylene make up the majority of waste—29% of all waste—according to Directorate General Environment (2011). This covers all types of polyethylene, including HDPE, LLDPE, and LDPE. Approximately 20% of plastic waste worldwide is made of polyethylene terephthalate (PET), 18% is made of polypropylene, and the rest 33% is formed of diverse polymer types (DG Environment, 2011). [9].

1.4 Research Objectives

The objective of this thesis is to investigate the feasibility of replacing varying percentages of fine and coarse aggregates with PET (Polyethylene Terephthalate) and PVC (Polyvinyl Chloride) in the production of lightweight concrete. In this study, the focus will be on two commonly used types of plastic: Polyethylene Terephthalate (PET) and Polyvinyl Chloride (PVC). Recent study investigations show that researchers have experimented with diverse wastes, including different kinds of plastics.

1.5 Aim of Study

The aim of the study is to incorporate recycled plastic waste into concrete to produce a lightweight material, thus reducing its overall weight. The study aims to evaluate the resulting mechanical and physical properties of the modified concrete, including compressive strength, tensile strength, density, and durability, compared to conventional concrete

1.6 Thesis Layout

The work presented in this thesis are illustrated in the Figure 1.2 which shows a flowchart of the whole work starting with studying and gathering the required information and study the light weight concrete in previous researches and then investigate the best concrete mixes in the laboratory and test complete the necessary lab test for both wet and dry concrete and on the other hand implement these concrete mix in the concrete beams to study the flexural behavior of the lightweight concrete under the effect of PET, PVC particle replacement and represent the results of deflection, crack pattern, strains, stiffness, ductility and other results in order to derivate a solid conclusion related to the effect of PET, and PVC on the concrete beams

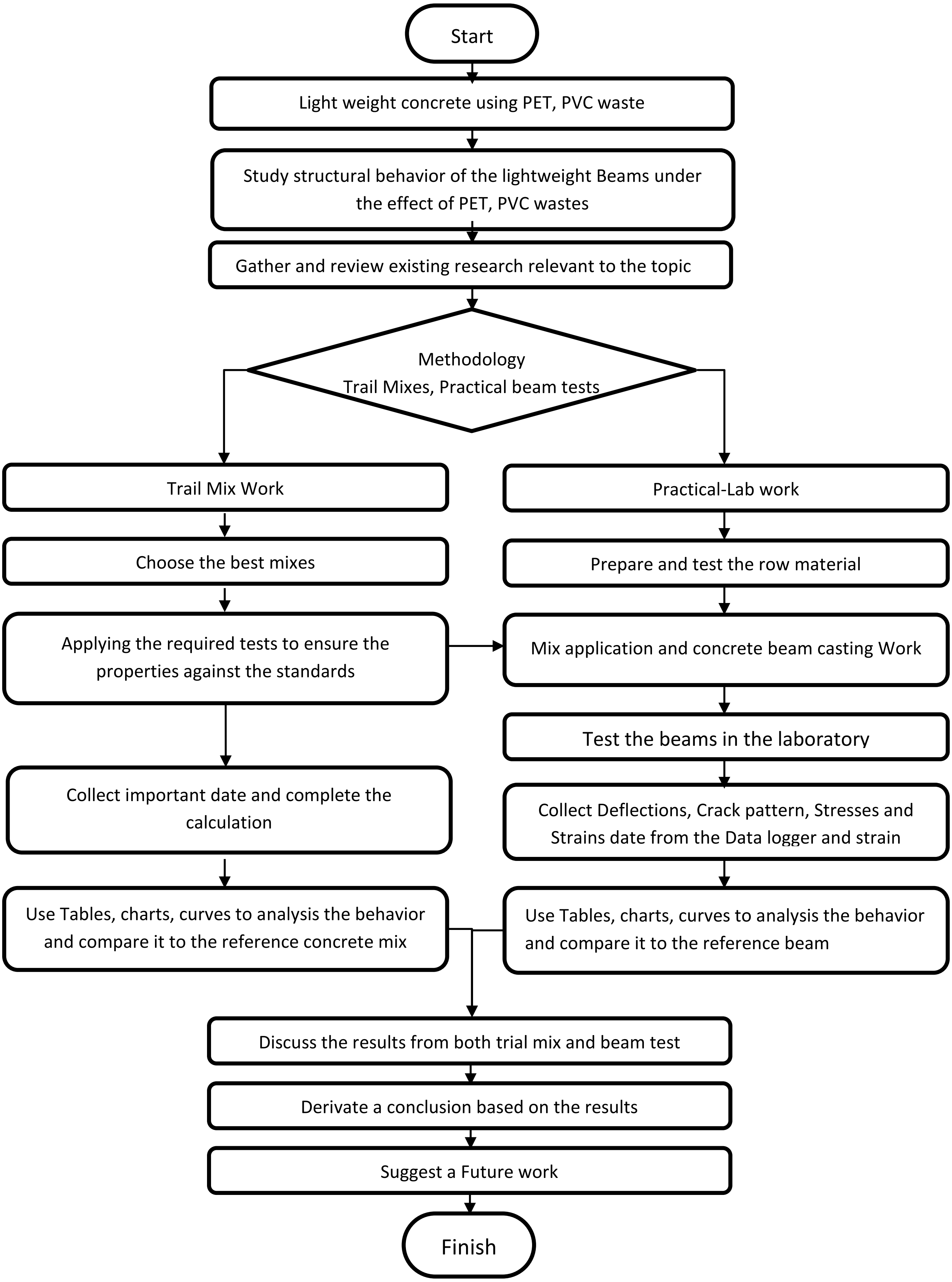


Figure 1.2 Thesis Flow Chart

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The aggregate occupies about 65–80% of the concrete volume, and it significantly affects the concrete characteristics such as workability, density, strength, durability, and stability. Several studies have examined the use of plastic recyclable material as whether fine or coarse aggregate in concrete mixes. The past studies were limited the quantity of plastic particles in concrete to 20% to avoid a significant decrease in its mechanical properties. As a result, the large proportion of plastic waste particles in the concrete mix has not been completely investigated in concrete building materials. The most common type of trash is polyethylene terephthalate material used in recycled concrete studies. The first part of this chapter describes the most important and advancements in this field of usage the polyethylene terephthalate (PET) trash as a sand and gravel aggregate replacement in various percentages. The second part deals with studies that use polyvinyl chloride (PVC) waste as a partial replacement for aggregate in concrete. but there is limited research regarding the effect of using PVC waste in concrete mixtures. The third part includes studies regarding the utilization of various types of plastic garbage as a substitute for fine and coarse aggregate to produce lightweight concrete.

2.2 Plastic Waste

The global production of plastics has surged from 2 million tons annually in the 1950s to 368 million tons in 2019, with a cumulative total of 8.3 billion tons produced by 2017. Plastics, used primarily for packaging food and beverages, are highly effective due to their lightweight and durable nature, but they are typically single-use and non-biodegradable. The rapid increase in plastic use has led to significant waste management issues, with 6.3 billion tons of plastic waste generated by 2015. Only 9% of this waste has been recycled, while the rest ends up in landfills, is incinerated, or contaminates the environment. Incineration, while reducing volume, releases hazardous substances and CO2. The production of concrete, which uses Portland cement, also impacts the environment significantly, accounting for 5-8% of global CO2 emissions due to its energy-intensive manufacturing process. Integrating plastic waste into concrete presents a potential solution, allowing for its long-term containment and reduced environmental impact. This approach aligns with the "Waste Hierarchy," emphasizing reduction, reuse, and recycling of waste materials [10].

2.2.1 Adding Plastic Waste to Concrete

Incorporating plastic waste into concrete can enhance sustainability and reduce the volume of waste sent to landfills. This method not only provides a disposal solution but also improves certain properties of concrete.

2.2.2 Types of Plastic Waste Used in Concrete

- Plastic Fibers: Shredded plastics like PET bottles can be added to concrete to improve its tensile strength and crack resistance.
- Plastic Aggregates: Recycled plastics can replace some natural aggregates in concrete, reducing density and improving thermal and acoustic insulation.
- Plastic Fillers: Finely ground plastics can substitute for part of the cement or sand in concrete mixes, lowering the carbon footprint.

2.2.3 Benefits of Using Plastic Waste in Concrete

- Environmental:
    - Reduces landfill waste.
    - Conserves natural resources by decreasing the need for raw materials.
    - Lowers the carbon footprint of concrete production.

- Mechanical:
    - Enhances tensile strength and ductility.
    - Improves crack resistance and durability.
    - Potentially reduces concrete weight for lightweight applications.
- Thermal and Acoustic:
    - Improves insulation properties, making concrete more energy-efficient and noise-reducing.

2.2.4 Challenges and Considerations

- Compatibility: Ensuring plastic waste integrates well with concrete.
- Durability: Testing the long-term performance of plastic-infused concrete.
- Processing: Proper handling and processing of plastic waste to ensure uniform distribution.

2.2.5 PET Waste

Polyethylene terephthalate (PET) is a durable, lightweight plastic primarily used in beverage and food packaging. PET’s non-biodegradability poses environmental challenges, and improper disposal can lead to pollution. While incineration of PET generates harmful emissions, recycling PET into construction materials offers a viable solution. Methods include [11,13].

- Depolymerization: Converting PET into polyester resin to create polymer concrete, which has high strength but is costly and temperature-sensitive.
- Fibers: Adding PET fibers to concrete to enhance ductility and reduce cracking, though this method only recycles a limited amount of PET.
- Aggregates: Replacing some natural aggregates with PET to produce lightweight concrete, although it can reduce some mechanical properties.
- Binders: Using melted PET flakes as binders in a new type of mortar, though this method requires further research.

2.2.5.1 Used PET Waste in Building Materials

Used PET bottles can be transformed into construction materials through several methods. One approach is depolymerizing PET into polyester resin to create polymer concrete, which has high strength but is costly and temperature-sensitive. Another method involves using PET fibers to enhance concrete's ductility, although this can lead to poor fiber-cement bonding and limited plastic recycling. A third method replaces some concrete aggregate with PET waste, which is cost-effective but reduces concrete's strength. A newer technique blends recycled PET with soil to produce a material called plastic-soil, showing promise but needing further research [14-16].

2.2.6 PVC Waste

Polyvinyl chloride (PVC) is a widely used thermoplastic in construction and other industries. Its disposal presents challenges [17, 18].

- Landfills: PVC waste fills landfills, which are becoming less available and pose environmental hazards.
- Burning: PVC’s chlorine content makes it hazardous to incinerate, releasing toxic gases.
- Recycling PVC, though energy-intensive and VOC-emitting, helps mitigate environmental contamination when used in concrete with other plastics.

2.3 RECYCLE OF PET WASTE IN CONCRETE

In this part, the impact of adding PET waste particles as a fine or coarse aggregate instead of sand or gravel in the concrete mixture on the material's behavior was examined and investigated.

In 2005, Y. Choi et al. [19] replaced fine aggregate in concrete with volumetric ratios (0%, 25%, 50%, and 75%) of polyethylene terephthalate (PET) and used various w/c ratios (0.45, 0.49, and 0.5) by using waste of PET bottles with a size range of 5–15 mm Figure 2.1. The results as the ratio of replacement grew the mix's workability, increased and the mixture's density and compressive strength decreased (When the replacement ratio is 75% in comparison to the reference mix, the maximum decreased in compressive strength is around 33%).

Figure 2.1 PET Wastes particles [19].

In 2009, C. Albano et al. [20] used recycled Polyethylene Terephthalate (PET) with varying Water/cement ratios of 0.50 and 0.60 for fine aggregate, with particle sizes ranging from 0.26 cm to 1.14 cm. By volume, the replacement ratios were 10% and 20%. It has been found that an increment in PET content caused a drop in the parameters measured by modulus of elasticity, ultrasonic pulse velocity, compressive, tensile, and flexural strengths. As PET is less workable than concrete, it increases the porosity of the mixture. When these characteristics change, the proportion of water absorption in concrete-PET mixes increases. It is often asserted that recycled PET bottles can be used to make concrete aggregates, reducing the weight of the concrete and protecting the environment. The compressive strength testing Figure 2.2 depicts various failure mechanisms.

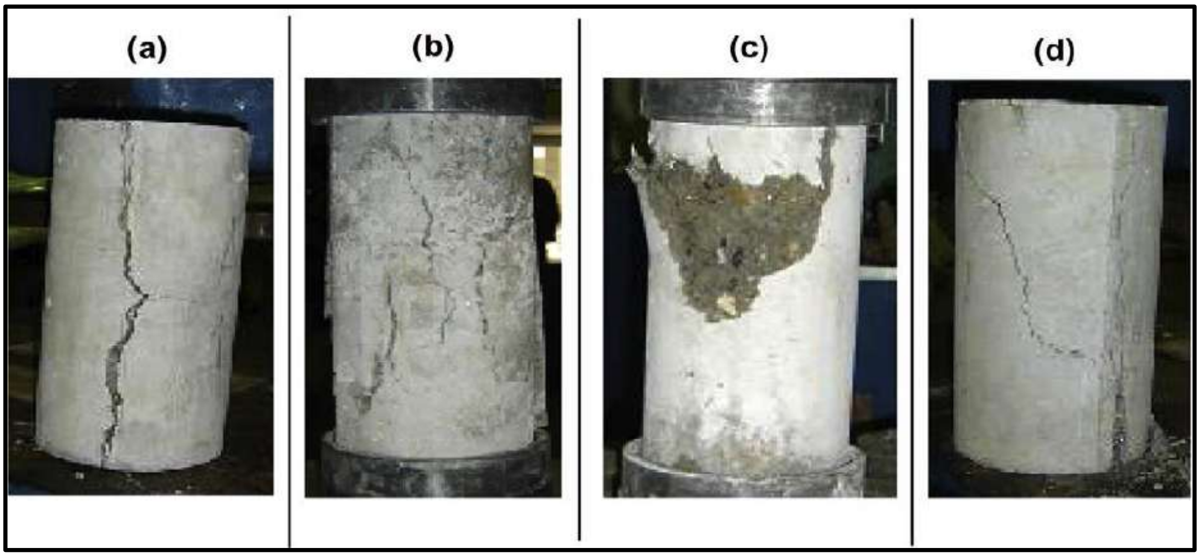


Figure 2.2 Cylinder Failure Modes Under Compressive Loading [20].

In 2010, Akcaozoglu et al. [21], used discarded PET bottle shreds as sand in lightweight concrete. Two mortar sample sets were displayed; the first included just aggregates made from PET wastes, while the second included both aggregates made from PET wastes and sand. The water/cement ratio (w/c) is 0.45, and PET/cement ratio (0.50) is utilized in the mixtures. Two mortar combinations were prepared using shredded PET granules with a size range of 0–4 mm. Test results included measurements of the specimens' dry and fresh unit weights, flexural, tensile, and compressive strengths, as well as the water absorption and shrinkage rates. Researchers found that mixtures including both sand aggregates and PET aggregates had higher unit weight, flexural-tensile strength, and Compressive Strength values than mixes containing PET particles separately. Furthermore, lower shrinkage values and water absorption ratios were observed in mortars without sand. It can be helpful to design a seismic building since crushed waste PET particles are added to concrete to lower the building's danger of earthquakes.

In 2010, M. Frigione [22] substituted fine aggregate with PET bottle waste ranging in size from 0.1 to 5 mm at a weight ratio of 5%. The mixture and water content are around 300-400 kg/m^3 and 0.45-0.55, respectively. The results revealed that there was a modest decline in compression strength and tensile strength of around 0.4% and 1.9%, respectively, under the reference mix, with little improvement in ductility.

In 2013, E. Rahmani et al. [23] the PET bottle was employed as a partial substitution for fine aggregate in the concrete mixture at volume replacement rates of 5%, 10%, and 15%, with a maximum aggregate size of 7 mm, as illustrated in Figure 2.3 for two mixes. Both fresh and hardened concrete were tested. The decline decreased as the percentage of plastic waste increased. Furthermore, w/c = 0.42 results in increased strength, and it was discovered that the best percentage for sand replacement was 5%, but 10% sand substitution made the same compressive strength as reference specimens.

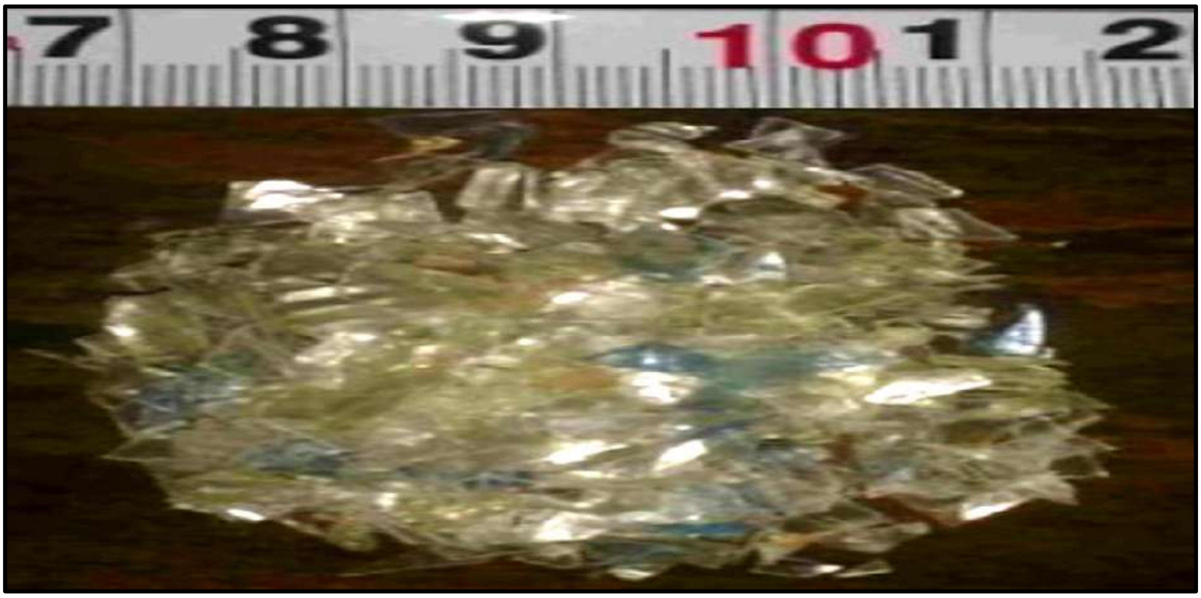


Figure 2.3 PET plastic Waste [23].

In 2014 Prabhu et al. [24], PET bottle was utilized to partially substitute fine aggregate in the shape of fiber in the concrete mixture. The replacement rates were 0.5%, 1.0%, and 1.5% by volume. This study employed three fiber dimensions: 50*3 mm, 100*3 mm, and 150*3 mm, with a mixing ratio of 1: 1.48: 2.54 and a water-to-cement ratio of 0.45. Compressive and Flexural strength tests were conducted at the ages of 3, 7, and 28 days. They discovered that fibers with dimensions of 100*3 mm had greater strength, and 1.0% sand replacement by volume fraction was the optimal percentage for both compressive and tensile strength.

In 2015 Khanna et al. [25], PET waste plastic fibers were used as a partial alternative for fine particles in the concrete mixture, as shown in Figure 2.4 PET waste was employed as a partial substitute for sand at percentages of 10%, 20%, 30%, and 40% (by volume). Fly ash was utilized to partially replace cement at 5%, 10%, and 15% by weight. The water to cement ratio was 0.45. The Super plasticizer ratio in each combination was 0.01. They concluded that when the amount of PET waste fibers and fly ash content increases, the compressive strength decreased. They also observed that the largest increase in compressive strength occurred when fly ash content was 10% with a partial replacement of PET waste plastic fibers of up to 30% by volume. Figure 2.5 displays failure mode of cubes.

Figure 2.4 PET fibers Waste [25].

Figure 2.5 failure mode of cubes [25].

In 2016, A.M. Azhdarpour et al. [26] studied replacing sand in concrete with two different diameters using plastic waste from polyethylene terephthalate bottles. As seen in Figure 2.6, the first dimension was 2-4.9 mm (pc), while the second size was better at 0.05–2 mm (Pf). The weight of sand is substituted in partial ratios of 0%, 5%, 10%, 15%, 20%, 25%, and 30%. They used w/c 0.5 and mixed quantities (1 cement: 2.5 sand: 2.5 gravel). They noticed that the wet and dry density values diminished as the plastic ratio increased. At 5% and 10% replacement, compressive strength improved by 39% and 7.6%, respectively. When the replacement ratio exceeded 10%, the flexural strength began to decrease. Furthermore, when the replacement ratio was raised from 5% to 15%, the tensile strength increased by 26-34%. They also noticed that when the elastic modulus decreased, the deformability of the concrete increased.

Figure 2.6 PET plastic waste in various shapes [26].

In 2020, I. Almeshal et al. [27] Investigated the impact of adding PET particles on the mechanical and physical characteristics of concrete. As seen in Figure 2.7, they substituted PET for sand, the maximum size is 0.075-4 mm and a thickness of 1-1.5 mm. 10%, 20%, 30%, 40%, and 50% and (1 cement: 1.6 sand: 3.37 gravel) were the partial replacement ratios and mixing proportions, respectively, with 0.54 w/c ratio. Slump, dry density (which decreased by 31.6 percent at 5% PET), and ultrasonic pulse velocity (which decreased by 4.5 percent to 1.9 kilometers per second at 50% PET) were all reduced, according to the results. At a 50% replacement ratio, compressive strength is reduced by 90.6%, tensile strength by 85.5%, and flexural strength by 84.2%, respectively.

Figure 2.7 Crushed PET Plastic [27].

In 2021, A. Dawood et al. [28] the fine aggregate replaced by PET from bottle waste having a maximum size of 4.75 mm as shown in Figure 2.8 and sand ratios of replacement were 5%, 7.5%, 10%, 12.5%, 15%, and 20%. The mix design had 1 cement, 1.5 fine aggregates, and 3 coarse aggregates, in addition utilized 0.41 and 0.4% w/c and superplasticizer respectively. When the replacement ratio increased from 5% to 12.5%, the compressive, splitting tensile, and flexural strengths increased by 26.8%–43.64%, 18.6%–26.9%, and 18.1%–30.2%, respectively. Also, workability, density, ultrasonic pulse velocity, and elastic modulus were all reduced. When the quantity of plastic in the concrete mixture increases, while the water absorption and ductility of the mixture increase.

Figure 2.8 PET Waste particles [28].

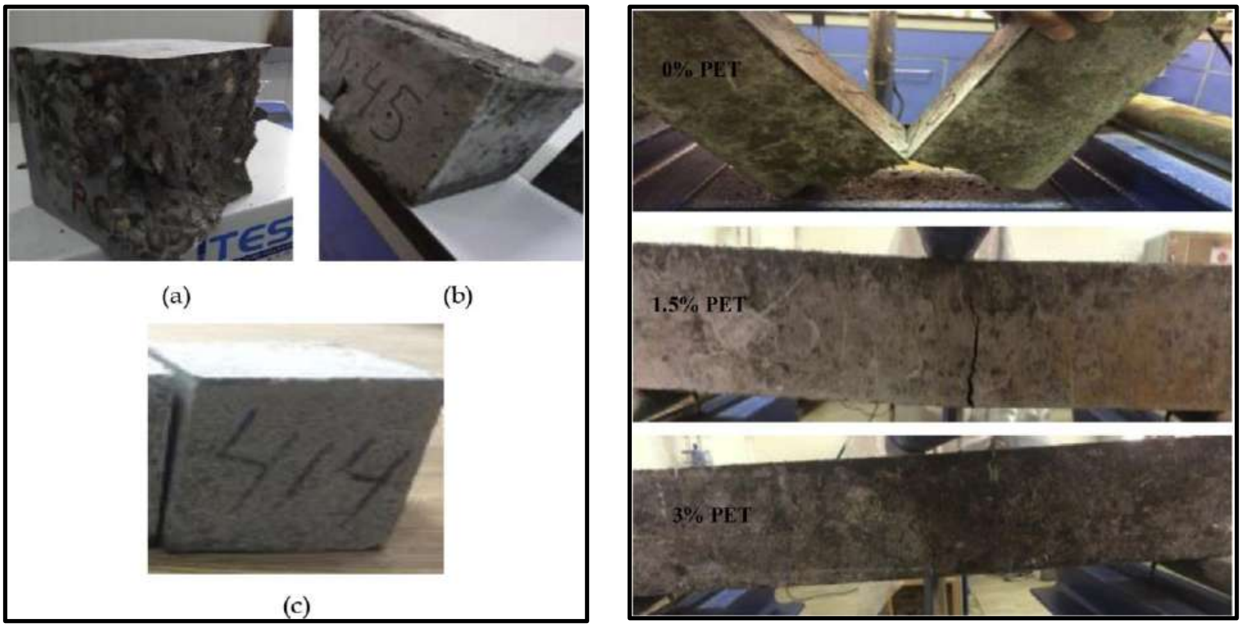
In 2022 R. Falih et al. [29] investigated PET waste's effect on reinforced concrete beams' structural performance. The same materials, replacement ratio, and mixture ratios as those mentioned in [28]. The study's findings demonstrated that the reference beam's ultimate failure load was quite close to all of the beam ratios that were employed. The maximum deflection, ductility, compression strain, energy absorption, and load at first crack were also observed to increase at a maximum substitution ratio of 20% when the percentage of additional PET increased by 97%, 91.37%, 1140%, 2749%, and 121.19%, respectively.

In 2020, Hamsa M. Adnan and Abbas O. Dawood. [30] added waste from polyethylene terephthalate (PETWF) in two fiber form with maximum size particles of 4.75 mm (cutting by machine) and 25.4mm (cutting by hand) as displayed in Figure 2.9, in concrete mixture with volumetric ratios of 0%, 1.5%, 3% (for each shape of waste) with water to cement ratio of 0.41. The results indicated that the increase of PET fiber in reduced the workability, flexural strength and the ultimate load while had a positive effect on the compressive strength and ductility. The failure mode of cubes, prisms and concrete beams has been showed in in the Figure 2.10, and Figure 2.11 .

PET cutting by machine

PET cutting by hand

Figure 2.9 PET Waste types [30].



1.Concrete cube failure modes with percentages of 0., 1.5%, and 3% of PET, respectively

2.Concrete prism failure mode with various PET fiber percentages.

Figure 2.10 failure modes under compressive and flexural loads [30].

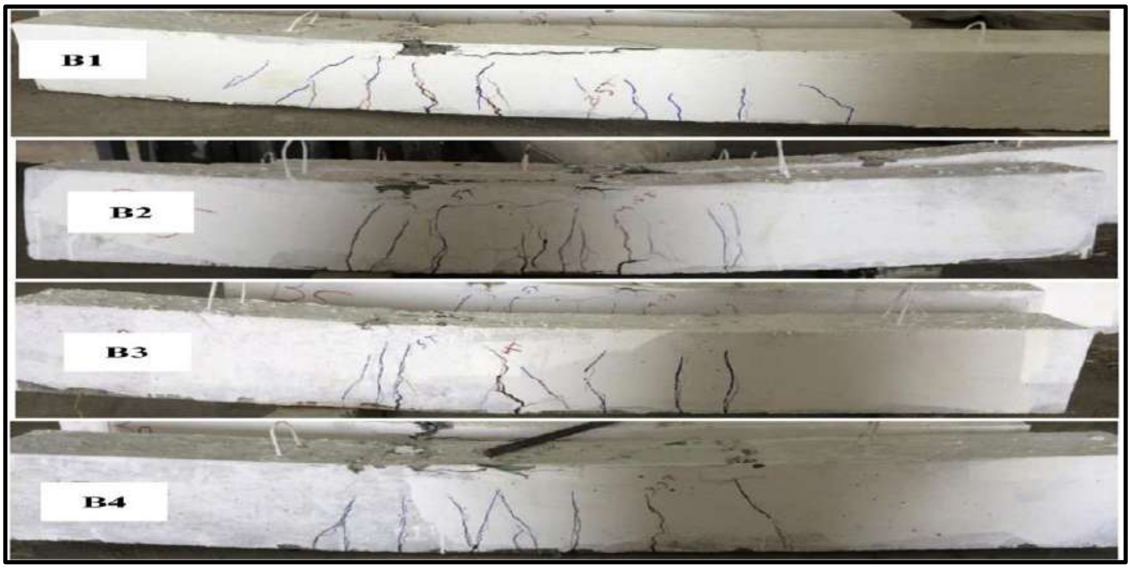


Figure 2.11 failure modes of reinforced concrete beams [30].

In 2020, Raad S.Falih et al. [31] studied the impact of using PET waste form bottles as a reinforcement bars in beams of concrete. As shown in Figure 2.12, they used long strip of 6000–11000 mm length, 6mm of width and o.5 of thickness. PET bars are placed in the same place of as rebar to replace main steel bars with Five (150 x 200 x 1400 mm) concrete beams. The results indicated the specimens gave ultimate load that 1/4 of ultimate load of steel reinforced concrete beams and 3 times of plain concrete ultimate load. Also noticed decreased in the deflection by 50% and enhanced in the values of stiffness and ductility. The Crack pattern of all concrte beams samples shown in Figure 2.13 below.

Figure 2.12 the reinforcement for all concrete beams and PET waste bars [31].

Figure 2.13 cracks modes in concrete beams [31

2.4 Recycle of PVC waste in concrete

Few studies have proposed PVC waste as a partial substitute to the aggregate. It will be discussed some of the studies with their results in this field, which are as follows:

In 2009, S. Kou et al. [32] used Scraped PVC pipe particles to partially replace river sand as fine aggregates in concrete. PVC particles were used to substitute fine aggregate in the following volume ratios: (0%, 5%, 15%, 30%, and 45%). Figure 2.14 shows the particle sizes of PVC plastics that passed through a 5mm sieve. The results indicated an effective impact: first, by lowering the dry density and dry shrinkage of concrete; and second, by increasing ductility (by decreasing modulus of elasticity) and resistance to chloride ion penetration. When the replacement ratio was increased, the workability, compressive (the maximum reduction is about 47.3% when the replacement ratio is 45%), and tensile splitting strengths of the concrete mixture decreased.

a b

Figure 2.14 PVC Waste: a. Before Crushing b. After Crushing [32].

In 2015, Y. Senhadji et al. [33] As shown in Figure 2.15, they utilized PVC plastic waste as an aggregate (sand and gravel) in concrete with two classes of granules, 0/3 and 3/8, with volumetric dosages of replacement of 30%, 50%, and 70%. The mix proportions were 1 cement: 1.175 sand (0-1 mm): 2.625 medium aggregate (3-8 mm): 0.675 coarse aggregate (8-15 mm) and a water to cement ratio of 0.48. The investigation of data found improvements in workability and resistance to chloride ion penetration, which may give efficient defense to steel reinforcing. The results also showed that increasing the PVC dosage resulted in a decrease in density, ultrasonic wave velocity, and compressive strength. Figure 2.16 illustrates the failure mode of compressive strength test specimens.

a b

Figure 2.15 a and b the difference between PVC Wastes and natural aggregate [33].

PVC:0% PVC:30% PVC:50% PVC:70%

Figure 2.16 Specimens Failure Mode [33].

In 2016, H. Bolat et al. [34] substituted aggregate with two forms of PVC waste, as represented in Figure 2.17, powder and granules, with diameters of 0-0.25 mm and 2-4 mm, respectively. The replacement percentages by volume were 10%, 20%, and 30%. Two mixtures were prepared: a standard mix of concrete with proportions of 1 cement: 2.27 sand: 2.46 gravel and w/c 0.53, and a heavy weight mix of concrete with proportions of 1 cement: 1.5 sand: 1.68 gravel and w/c 0.39 as well. They discovered that while lower slump and compressive strength values were detrimental, the concrete's enhanced properties included greater resistance to abrasion, less water absorption, and decreased wet and dry densities.


a
b

Figure 2.17 Particles of PVC a-Powder, b-Granules [34].

In 2016, N. Haghighatnejad et al. [35] the PVC was used as a substitute of sand as the fine aggregate under various curing conditions. They prepared four concrete mixtures with PVC contents of 20%, 30%, 40%, and 50% in addition to the reference mixture with mix ratios of 1 cement: 2 sand: 2.6 gravel. They used scraped PVC pipes, with the maximum size of particles approximately 5 mm, as shown in Figure 2.18. The selected w/c ratio was 0.4. The results indicated that adding PVC affected the samples' mechanical characteristics, as measured by compression, splitting tensile strengths, and elastic modulus, and decreased workability by 48% under the control ratio. Additionally, the water absorption of value was decreased, indicating that the concrete was of high quality.

Figure 2.18 Particles of PVC Waste [35].

In 2017, H. Hussein et al. [36] utilized PVC recycled from doors and windows to partially replace the sand in the concrete mixture. As seen in Figure 2.19, the PVC particle size was 4.75 mm after passing through the sieve at weight quantities of 2.5%, 5%, 7.5%, 10%, 12.5%, and 15%. For every 100 kg of cement, the mix's ratios were 1 cement, 1.63 sand, 2.4 gravel, 0.4 w/c, and 1 liter of superplasticizer (HRWRA). The study's findings indicated that when the PVC ratio increased, the wet and dry densities as well as workability decreased. It was also observed that the increased PVC ratio resulted in an approximately 68.9% loss in compressive strength in addition to decrease in flexural and splitting tensile and strengths. The good aspect of this investigation was the improvement of the acoustic and thermal properties when the replacement ratio rise.

Figure 2.19 PVC Fine Particulates [36].

In 2017, H. Patel, et al. [37] Substitute sand with PVC powder (90-600 microns) and glass (150-600 microns) in the concrete mixture at ratios of 0%, 5%, 10%, 20%, 25%, and 30%, respectively. The mix ratios were (1: cement, 1.3: sand, 2.8: gravel), with W/C ratios of 0.44, 0.5, and 0.55. The outcomes indicated that the replacement mixture behaved like regular concrete up to 15%. Increased replacement ratios had a negative impact on mechanical characteristics (compressive and flexural strengths), but significantly improved workability, density, and water absorption, in additional to durability requirements.

In 2018, C. Aciu et al. [38] PVC waste was used to substitute sand in mortar. The PVC waste, which had a maximum size of 8 mm, was replaced with sand at a weight ratio of (0%, 25%, 50%, and 100%). The mix ratios were 1 cement:4.5 sand, using a water-to-cement ratio of 0.5. The results demonstrated that increasing the amount of PVC replacement reduced the density, compressive, and flexural strengths of mortar, but the 25% ratio produced the best results and was closest to the reference mix. Figure 2.20 depicts the failure of mortar prisms.

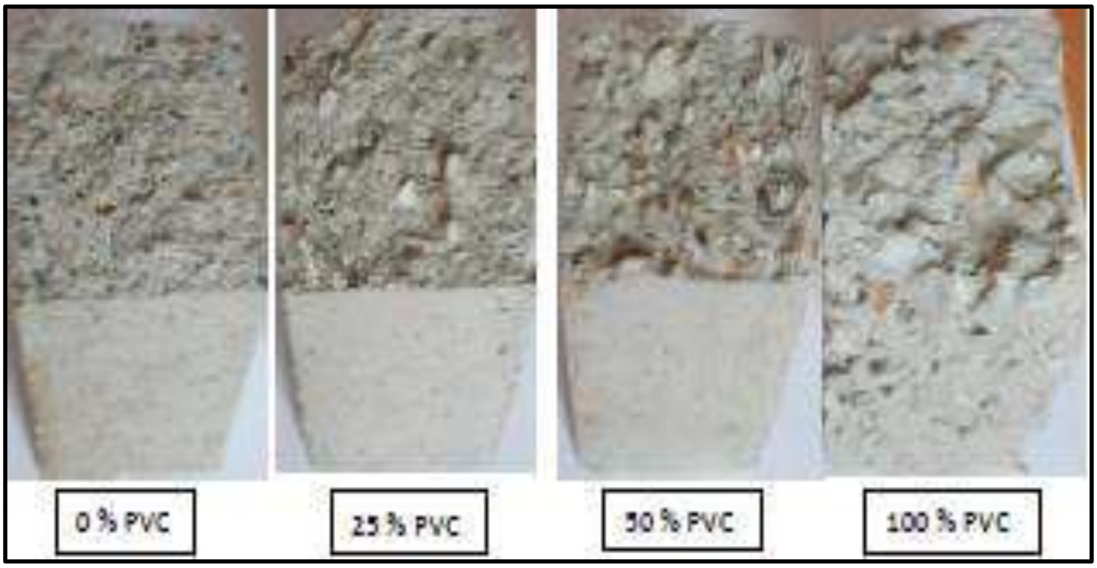


Figure 2.20 The mortar prism breaking part [38].

In 2019, Y. Senhadjiused et al. [38] used recycled polyvinyl chloride (PVC) to replace the fine aggregate to produce light weight mortar. As showed in Figure 2.21, the recycled PVC with a particle size 0-4 mm and replacement ratios of

10%, 30%, 50% and 70%. The mix percentage were 1: 3 (Cement: Sand), and W/C ratio of 0.6. The results showed that the use of PVC in mortar reduced the density where the mortar is behaved as lightweight mortar at 70% PVC substitution with reduction up to 30%. At the same time, the compressive and flexural strengths decreased at 70% by 19%, and 49% respectively. On the other hand, the replacement of sand by PVC waste improved the resistance to the strong acids and enhanced the ductility of mortar. Figure 2.22 Showed the mode failure of prisms contained PVC waste as a partial replacement of sand under flexural test.

Figure 2.21 Recycled PVC [39].

Figure 2.22 Comparison between reference and 50% PVC under flexural test [39].

In 2019, A. Mohammed et al. [40] studied the ability to replace the aggregate in concrete with two different sizes (fine and coarse) using plastic waste from PVC sheets. As seen in Figure 2.23, the particles of replaced PVC are obtained by primary and secondary crushing, and their size is finer than gravel and coarser than sand. The partial ratios were 5%, 15%, 30%, 45%, 65%, and 85%. The w/c was 0.52 and mixed quantities (1 cement, 1.25 sand, and 2.5 gravel). As the results showed, the workability, density, ultrasonic pulse velocity, and water absorption stay almost unchanged when fine aggregate is substituted with PVC aggregate at a maximum ratio of up to 45% or coarse aggregate with a maximum PVC aggregate ratio of up to 30%. Also, the reduction in mechanical properties such as compressive, splitting, and flexural strengths is less when the replacement is sand (about 8%) than gravel. Figure 2.24 and Figure 2.25 shows the failure mode of cylindrical samples under compressive and tensile tests.

PVC from primary crushing

PVC from secondary crushing

Figure 2.23 PVC waste obtained from sheets [40].

Figure 2.24 cylinder failure mode under tensile load [40].

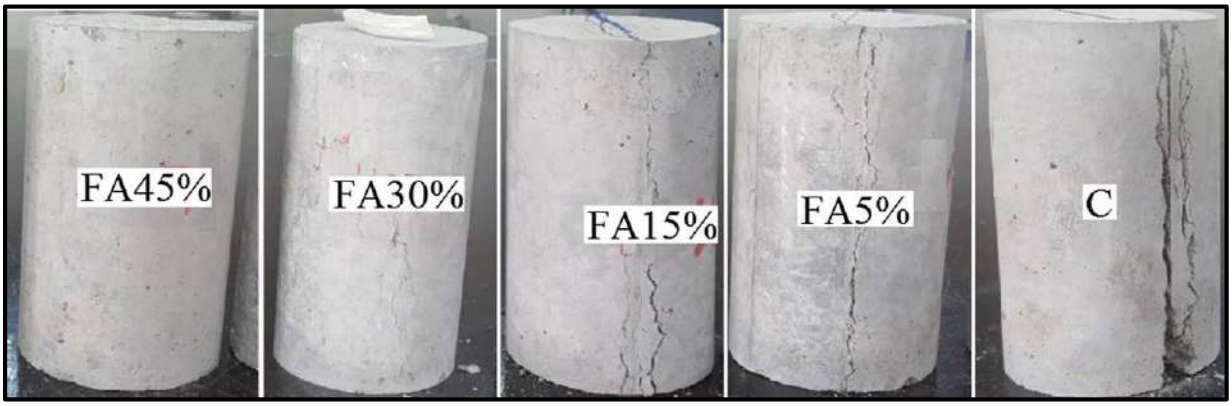


Figure 2.25 cylinder failure mode under tensile load [40].

In 2020, M. Belmokaddem et al. [41] recycled polyvinyl (PVC) as a partial natural aggregate replacement with two sizes 0/3 for sand and 3/8 for medium aggregate as shown in Figure 2.26. The ratios of PVC were (25%, 50%, and 75%), the mix proportions were 1.72 sand (0-3 mm): 2.57 medium aggregate (3-8 mm): 0.77 coarse aggregate and water to cement ratio of 0.48 with various ratios of superplasticizer to justify the workability of concrete that replaced with plastic. Results of testing indicated this form of plastic waste could effectively impact thermal insulation in concrete and can be considered as a component of a building solution to boost a building's thermal efficiency. For other properties of concrete, the bulk density and compressive strength, decreased when the replacement ratios increased.

Figure 2.26 PVC wastes [41].

In 2020, Abbas O. Dawood and Hamsa M. Adnan [42] studied the effect of replacing polyvinyl plastic waste (PVC) to the concrete mixture as a sand. As shown in Figure 2.27, PVC granules with max size of 9.5 has been used in this research, with partial replacement ratios of 1.25%, 2.5%, 3.75%, and 5%. Two values of w/c equal to 0.41 and 0.53 has been used, in addition to superplasticizer to control workability of the mix. The results showed that increasing the plastic ratio reduced workability, tensile and flexural strength while have a positive effect on the compressive strength compared with the reference specimen. For the structural characteristic of the beam the results showed a little rise in the ultimate failure load, good impact on the deflection and ductility. Furthermore, shown an improvement in the first crack's strength when compared to the reference concrete beam.

Figure 2.27 sample of PVC waste used [42].

In 2020, Athar Luaibi Mhawi and Abbas O. Dawood [43] attempted to investigate the impact of incorporate two types of PVC such as Polyvinyl chloride from crushed pipes and Polyvinyl Chloride sawdust with max size of 4.75mm to substitute fine aggregates as displayed in Figure 2.28 The sand is being substituted with different percentages such as 1.25%, 2.5%, and 5%, mix proportions of 1cement: 1.3 sand : 2gravel and W/C of 0.39 for both types of PVC waste .for the slump test the results showed the increasing of both PVC types percentages in the concrete mix led to reduce the workability. while for mechanical properties (compressive, splitting and flexural strengths) has been observed positive behavior when replaced with PVC crushed pipes and negative when used sawdust.

crushed pipes PVC **sawdust PVC**

Figure 2.28 types PVC waste [43].

In 2023, Maryam. S. Jabar et al. [44] employed the recycled UPVC (Unplasticized Polyvinyl Chloride) from crushed pipes to replace fine aggregate in concrete mixture. As showed in Figure 2.29, the PVC particles with a max size of 4.75 mm, was substituted with percentages of 5%, 10%, 15%, 20%, and 30% by weight of sand. The mixture proportions were 1cement :1.5sand :2.45gravel, and w/c of 0.38 and superplasticizer of 0.5% from cement weight. The results showed that the use of 10% of PVC in the concrete increased the compressive, flexural and splitting strengths, after this ratio the strength start to drop until reach to the percentage of 30%. Moreover, the rise of PVC content in mix reduced the density, workability and ultrasonic velocity and increased the water absorption. The failures mode for mechanical properties shown in Figure 2.30 below.

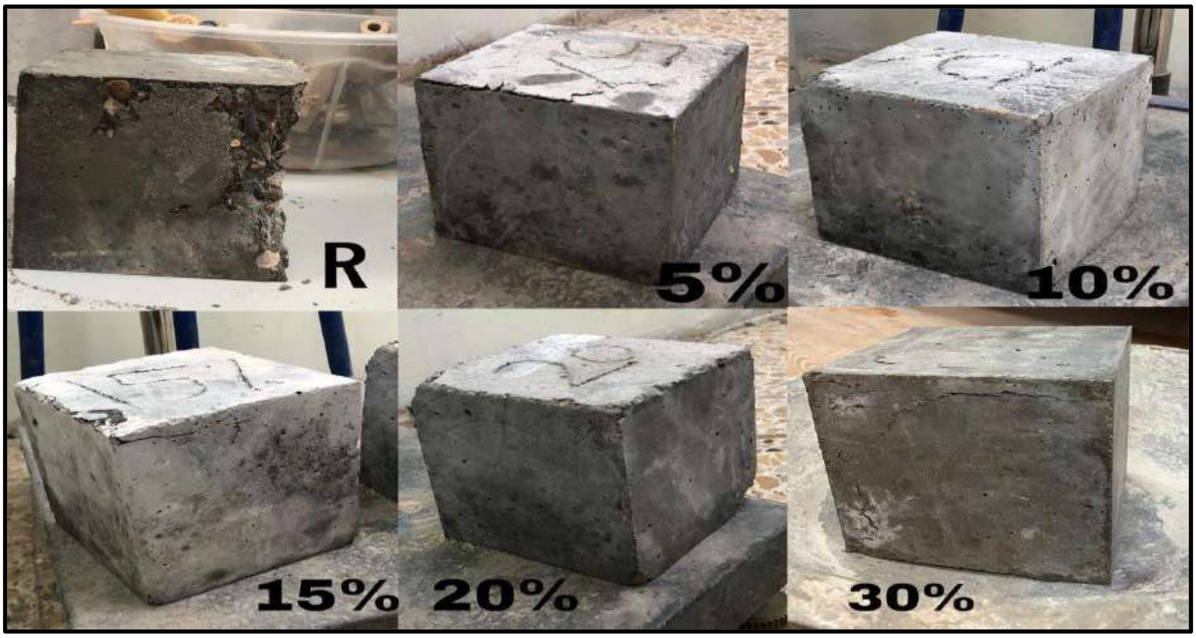
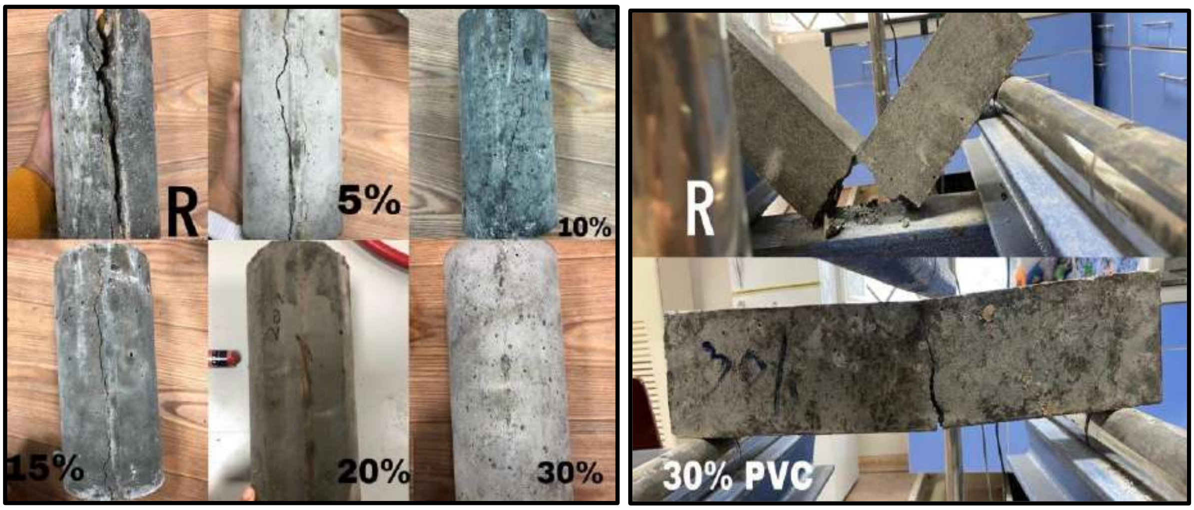


Figure 2.29 Failure mode under compressive strength



Failure mode under spitting strength Failure mode under flexural strength

Figure 2.30 The failures mode of mechanical properties [44].

2.5 Employing different types of plastic waste to produce lightweight Concrete

There is limited research in this area. This section presents the incorporation of various types of plastics to produce lightweight concrete and will be reviewed as follows:

In 2008, Z. Ismail and E. Al-Hashmi [45] investigated the plastic waste from plastic containers (it is made of 20% polystyrene and 80% polyethylene) with various lengths and widths of 0.15–12mm and 0.15–4mm, respectively, as shown Figure 2.31 Sand is replaced in partial ratios, which are 0%, 10%, 15%, and, 20% by weight in the mixture of concrete. They used mixed proportions (1cement: 1.88 sand: 2.68 gravel) with w/c 0.53. These mixtures were cured for 3, 7, 14, and 28 days for fresh and hardened concrete. noted that increasing in plastic ratio led to decrease the values of slump, dry density, compressive strength, and flexural strength in all ages.)

Figure 2.31 Plastic waste [45].

In 2011, J. Galvãoet al. [46] investigated the impact of incorporating Low-density polyethylene (LDPE), crushed polyethylene terephthalate (PET), and rubber from unwanted tires with maximum sizes of 2.4, 12.5 and 2.4 mm respectively as fine aggregate replacement. The ratios of partial replacement were 0.5%, 1.0%, 2.5%, 5.0%, and 7.5% by weight. The mixing proportions were (1 cement: 1.93 sand: 3.07 gravel) with a 0.45 water to cement ratio. The result showed a reduction in the value of slump and compressive strength with an increase of polymers added to the concrete. The addition of polymeric waste to the concrete improved its resistance to underwater erosion and abrasion tests.

In 2020, M. Belmokaddem et al. [47] as seen in Figure 2.32, they replaced the fine and medium aggregate in the concrete mixture with three different types of plastic waste (PVC, HDPE, and PP) that had diameters of of 0-3mm and 3-8mm, respectively. The ratios of plastic waste were (0%, 25%, 50%, and 75%) by volume. With w/c equal to 0.48 and a superplasticizer of (0.6-1%), the mix proportions were 1 cement: 1.72 sand (0-3 mm): 2.57 medium aggregate (3-8 mm): 0.77 coarse aggregate. Positive results were observed as the proportion of plastic in the mixture increased. This resulted in decreased density, enhanced thermal insulation, and higher ductility by a reduction in the modulus of elasticity. Furthermore, a reduction in the compression strength was caused by the higher replacement ratio.

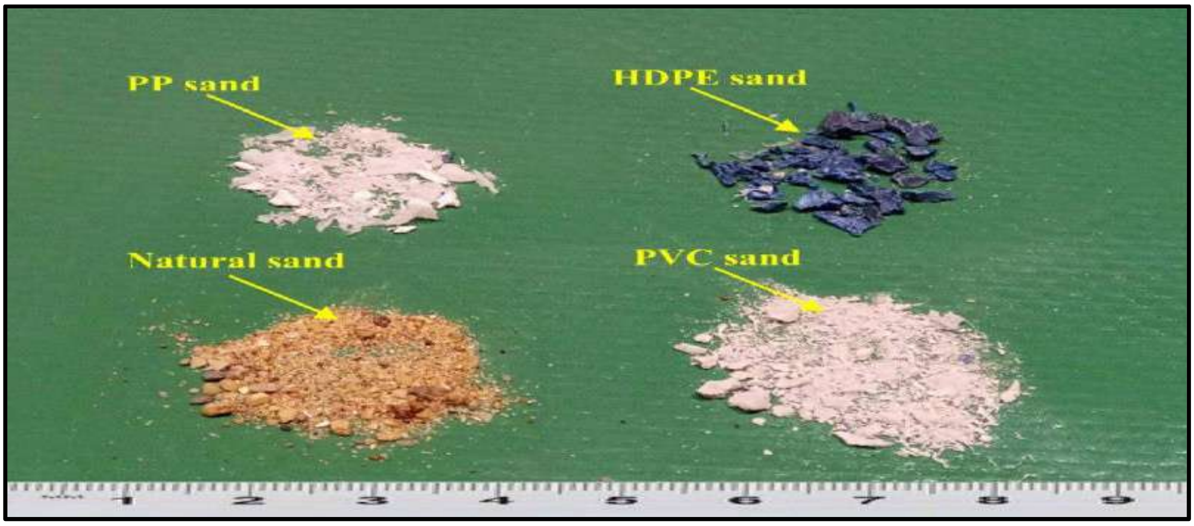
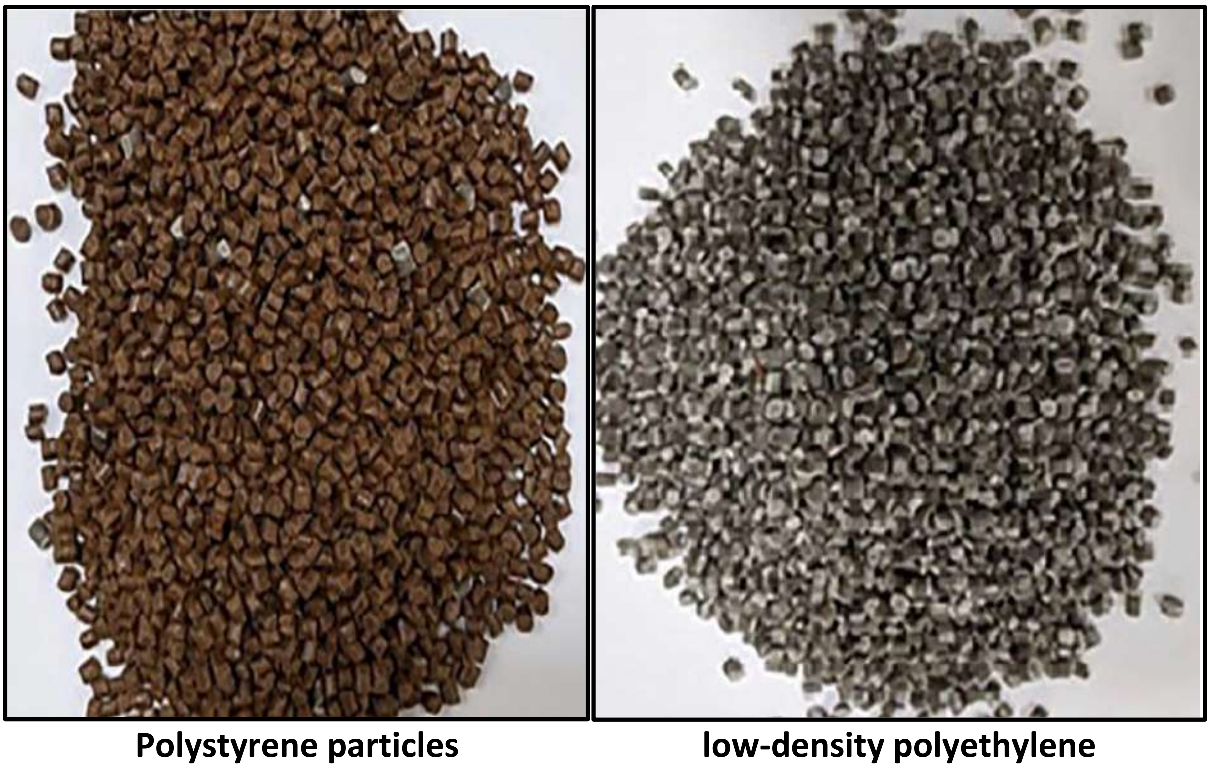


Figure 2.32 Natural Sand and Various Plastic Waste Types [47].

In 2021, O. Olofinnade et al. [48] studied the impact of incorporating polystyrene (HIPS) and low-density polyethylene (LDPE) plastic particles to produce light-weight concrete of high strength. They used the type of plastic above as a partially sand replacement with size of particles 2 mm, as illustrated in Figure 2.33. the ratios of partial replacement were 0%, 10%, 30%, and 50% by weight, and the mixing ratios of 1 cement: 1.5 fine aggregate: 3 coarse aggregates with a w/c of 0.5. The result showed a reduction in the variables of slump, dry density, and compressive strength below the values of reference concrete when plastic content increased. In summary, it found the concrete with plastic up to 10% replacement gave good performance compared with reference concrete.



Polystyrene particles **low-density polyethylene**

Figure 2.33 Plastic Waste Particles [48].

2.6 Concluding Remark

The studies reviewed highlight the evolving role of recycled plastics, particularly polyvinyl chloride (PVC) and other types, in concrete and mortar applications. The use of plastic waste as a partial replacement for conventional aggregates demonstrates both opportunities and challenges.

Enhanced Thermal and Acoustic Properties: A consistent finding across multiple studies is the improvement in thermal insulation and acoustic properties when plastics are incorporated into concrete. For instance, PVC replacements have shown potential in enhancing thermal efficiency, which can be beneficial in building construction.

Impact on Mechanical Properties: While the inclusion of plastic waste can lead to decrease workability and reduced density, it generally results in decreased compressive, tensile, and flexural strengths. The extent of this reduction varies with the type of plastic, its particle size, and the replacement ratio. For example, up to 10% PVC replacement has been shown to improve certain strength properties, while higher percentages tend to decrease these strengths.

Workability and Density: Incorporating plastic waste often leads to decreased workability due to the reduced density and altered flow characteristics of the mix. However, this improvement is accompanied by a decrease in the overall density of the concrete, which can affect structural integrity and performance.

Durability and Environmental Impact: Studies have demonstrated that plastic waste concrete has improved resistance to certain types of environmental degradation, such as abrasion and underwater erosion. This suggests that plastic waste can contribute to more durable concrete structures. Additionally, using recycled plastics helps mitigate environmental issues associated with plastic waste disposal, offering a sustainable alternative.

Variability and Further Research: The effects of plastic waste on concrete properties are influenced by numerous factors, including plastic type, particle size, replacement ratio, and curing conditions. The variability in results indicates that further research is needed to optimize these factors and fully understand the implications for different concrete applications.

Overall, integrating recycled plastic waste into concrete presents a viable strategy for enhancing sustainability in construction. However, careful consideration of the trade-offs between improved environmental performance and potential reductions in mechanical properties is essential for effective implementation. Continued research and development will be crucial to refining these materials and establishing best practices for their use in construction.

CHAPTER THREE: EXPERIMENTAL WORK

3.1 General

In this study, various forms of plastic waste are utilized. Specifically, PET (polyethylene terephthalate) is used as a partial replacement for sand (fine aggregate), while PVC (polyvinyl chloride) is used as a partial replacement for gravel (Coarse aggregates) in the concrete mixture to produce lightweight concrete.

This chapter encompasses the assessment of material properties utilized in lightweight concrete mixtures, such as the composition and proportions of materials, their physical and chemical attributes, concrete mix design, specimen specifications including their ages and curing methods, and testing procedures. Moreover, this chapter examines the utilization of PET and PVC waste in lightweight concrete as fine and coarse aggregate replacements and provides a comparative analysis of concrete mixtures with varying percentages of PET and PVC particles. Furthermore, it presents comprehensive information on concrete beams incorporating various PET and PVC waste replacements. All experimentation and testing were carried out within the laboratories of construction and material at the Engineering College at Misan University and Technical Institute of Amarah..

3.2 Experimental Program

This chapter is structured into two sections. The first portion gives an overview of the various types of PET and PVC wastes, considering their diverse applications in concrete mixtures with varying proportions fine and coarse aggregate. The second part focuses on the influence of PET and PVC waste, on the performance in lightweight concrete beams.

3.3 Material properties

These locally available materials were utilized in the present work, including ordinary Portland cement, fine and coarse aggregates, potable water, PET bottle waste, PVC waste particles (unwanted pipes), and additives such as superplasticizers, which are employed to improve the workability of the concrete mixture.

3.3.1 Cement

The type of cement is CIM I-42.5, was employed in this research. Cement's physical and chemical characteristics are detailed in Table 3.1 and Table 3.2, respectively. These analyses were conducted per Iraqi Standard No.5/2019 [49] at the Material and Construction laboratory at Amarah Technical Institute.

Table 3.1 Physical Properties of Cement

Test Name	Result	Specification limit
Initial setting time	75 min	≥ 45 minutes
Final setting time	4:45 hrs	≤ 10 hrs
Compressive strength at 3 days MPa	16.2 MPa	≥ 10 MPa
Compressive strength at 28 days MPa	34.1 MPa	≥ 32.5 MPa

Table 3.2 Chemical Compositions of Cement

Chemical Compound		Test Result	Iraqi specification limits No. 5/2019 [45]
Percentage %	SIO_2	23.2	-------
	AL_2O_3	8.01	-------
	FE_2O_3	3.54	-------
	Cao	61.5	-------
	Mgo	3.9	Not more than 5%
	C_3A	1.2	-------
	SO_3	2.1	Not more than 2.8%

Loss on Ignition (L.O.I)%	2.9	Not more than 4%
Insoluble material (I.R)%	0.75	Not more than 1.5%
Imia saturation (L.S.R)%	0.98	0.66-1.02
Main Compounds (Bogue's Equation)		
C_4AF	9.88	-------
C_2S	8.38	-------
C_3A	8.15	-------
C_3S	50.94	-------

3.3.2 Fine Aggregate

The fine aggregate grading, complying with the standards stated in Iraqi Specifications No. 45/2019 [50], Zone II, is provided in Table 3.3 and Figure 3.1.

Table 3.3 The Grading of Sand

Standard sieve size	Cumulative Passing %	Cumulative Retained %	Cumulative passing % Iraqi specifications limits No.45/2019[46], Zone II
10mm	100	0	100
4.75mm	97	3	90-100
2.36mm	86	14	75-100
1.18mm	70	30	55-90
0.6mm	47	53	35-59
0.3mm	16	84	8-30
0.15mm	7	93	0-10

The **Fineness Modulus (F.M.)** of the sand sample is **2.77**.

This value suggests that the sand falls within the typical range for fine aggregates used in concrete, which generally ranges between 2.3 and 3.1

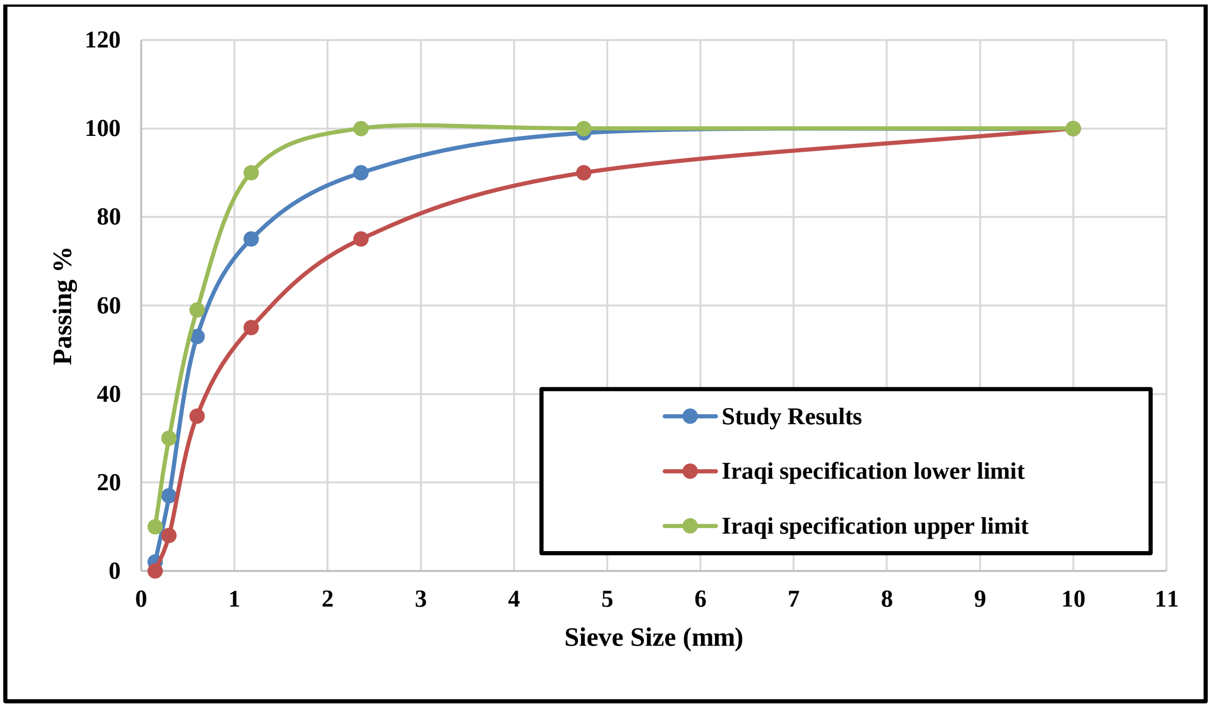


Figure 3.1 Grading graph of fine Aggregate.

3.3.3 Coarse Aggregate

Naturally occurring coarse aggregates were sourced from the eastern Amarah region, specifically from Chilat, near the Iraqi-Iran border. These coarse aggregates have a max size of 20 mm. The grading of these coarse aggregates conforms to Iraqi Specification No. 45/2019[50], the details show in Table 3.4.

Table 3.4 The Grading of Gravel

Standard sieve size	Cumulative passing %	Iraqi specification No. 45/ 2019
37.5mm	100	100
20mm	96.8	95-100
10mm	37	30-60
5mm	2	0-10

3.3.4 Mixing Water

In this work, potable water was utilized for casting and curing all specimens.

3.3.5 Admixture

Incorporating polyvinyl chloride (PVC) and Polyethylene Terephthalate (PET) in this study necessitated the use of a superplasticizer admixture to improve the workability of the concrete mixture. Specifically, employed Sika ViscoCrete-180 GS, a liquid superplasticizer that complies with the superplasticizer requirements outlined in ASTM C494-Types G and F [51]. Can refer to Table 3.5 for the international mechanical specifications of Sika ViscoCrete-180 GS.

Table 3.5 The technical specifications of Sika ViscoCrete-180 GS

Chemical base polymer	**Modified polycarxylates based polymer**
Appearance/colors liquid	Light brownish
Composition	Aqueous solution of modified polycarboxylates
Dosages	(0.5 % - 2 %) by weight of total cementitious materials.
Specific gravity	1.070 ± (0.02) g/cm3
Storage condition/ Shelf Life	In dry conditions at temperature between +5°C and +35°C. Protect from direct sunlight/12 months from date of production

3.3.6 Steel Reinforcing

In this research, the steel reinforcement rebar was employed as both transverse and longitudinal reinforcement in the concrete specimens. The rebar used had three different sizes: Ø10 mm, and Ø12 mm, indicating their respective diameters. A tensile test was carried out to evaluate the quality and applicability of the steel reinforcement, following the guidelines outlined in the ASTM A615 specification [52]. ASTM A615 is a globally acknowledged standard that offers requirements for the mechanical characteristics and excellence of deformed steel bars employed in reinforcing concrete. Table 3.6 displays the findings from the tensile test conducted on the steel reinforcement. These results were obtained by subjecting the steel reinforcement samples to tension until fracture and measuring various mechanical characteristics, the results from the tensile examination were then compared to the limitations and criteria outlined in the ASTM A615 specification [52]. By ensuring that the results conform to the limitations specified in the ASTM A615 specification, the study confirms that the steel reinforcement used in the concrete specimens meets the required mechanical properties and quality standards. This verification is essential to ensure the reliability and performance of the reinforced concrete structures under investigation.

Table 3.6 Characteristics of Reinforcing Bars

Type of bar	**Nominal Diameter (mm)**	**Area of bar (mm^2)**	**Yield strength f_y (MPa)**	**Tensile strength f_u (MPa)**	**Elongation (%)**
Steel Stirrups	10	78.5	514	645	18
Longitudinal steel bar	12	113.04	568	658	12

3.3.7 Plastic Waste

3.3.7.1 PET Waste

The plastic used in this study is Polyethylene Terephthalate (PET) bottle waste. PET bottles of varying sizes and colors were finely chopped into small particles, with all particles passing through sieve No. 4, meaning that the maximum particle size was less than 4.75 mm, as illustrated in Figure 3.2.

These PET bottle waste materials were procured from Al-Naseri Group's factories and Choppers, specifically from the Sama Pack branch located in the AL-Tajiat region, Baghdad city. This branch specializes exclusively in recycling PET waste. To evaluate the particle size distribution of PET particles, a sieve analysis was conducted, and the results were compared to the particle size distribution of sand in accordance with Iraqi Standard No. 45/2019 [50]. Variations were observed primarily in the finer sieves, as outlined in Table 3.7 and depicted in Figure 3.3. Additionally, the specific gravity of PET particles was found to be 1380 kg/m³ [28].

Figure 3.2 PET molecules produced by chopping water bottles and soft drinks

Table 3.7 PET waste particles grading

Sieve size (mm)	PET percent passing %
10	100
4.75	97.64
2.36	95.5
1.18	18.72
0.60	2.55
0.30	0.5
0.15	0.19

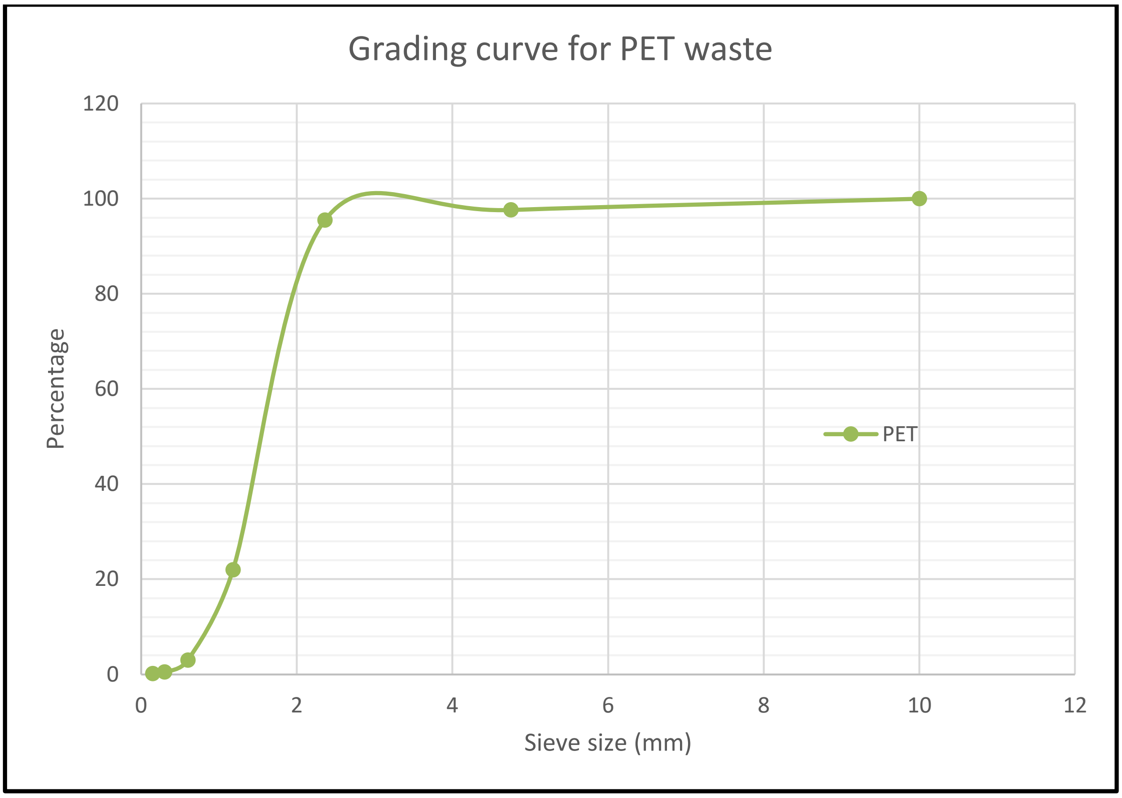


Figure 3.3 Grading curve for PET waste

3.3.7.2 PVC Waste

Utilizing discarded PVC (Polyvinyl Chloride) pipes as a partial replacing for gravel in concrete is a viable option, as depicted in Figure 3.4, but it necessitates thorough consideration due to PVC's distinctive properties and its potential influence on concrete performance. In this experiment, incorporated unwanted PVC pipes are utilizing as a partial substitute for gravel in concrete mixes. Additionally, the specific gravity of PVC was found to be 1400 kg/m³ [32].

Figure 3.4 Unwanted PVC Pipes

To begin, collected unwanted PVC pipes, ensuring they were free from contaminants and devoid of any fittings, adhesive residues, or foreign materials. Employed specialized machinery at the Misan Factory of Plastic to crush these discarded PVC pipes into small pieces. These PVC fragments are relatively diminutive, with a maximum size not exceeding 20 mm, as outlined in Table 3.8 and depicted in Figure 3.5. and they formed a fundamental component of our experiment, as visually depicted below in Figure 3.6.

Table 3.8 PVC waste particles grading

Sieve size	Cumulative passing%	Limits according to IQS 45/2019
20	100	100
14	95	85-100
10	22	0-25
4.75	8	0-10

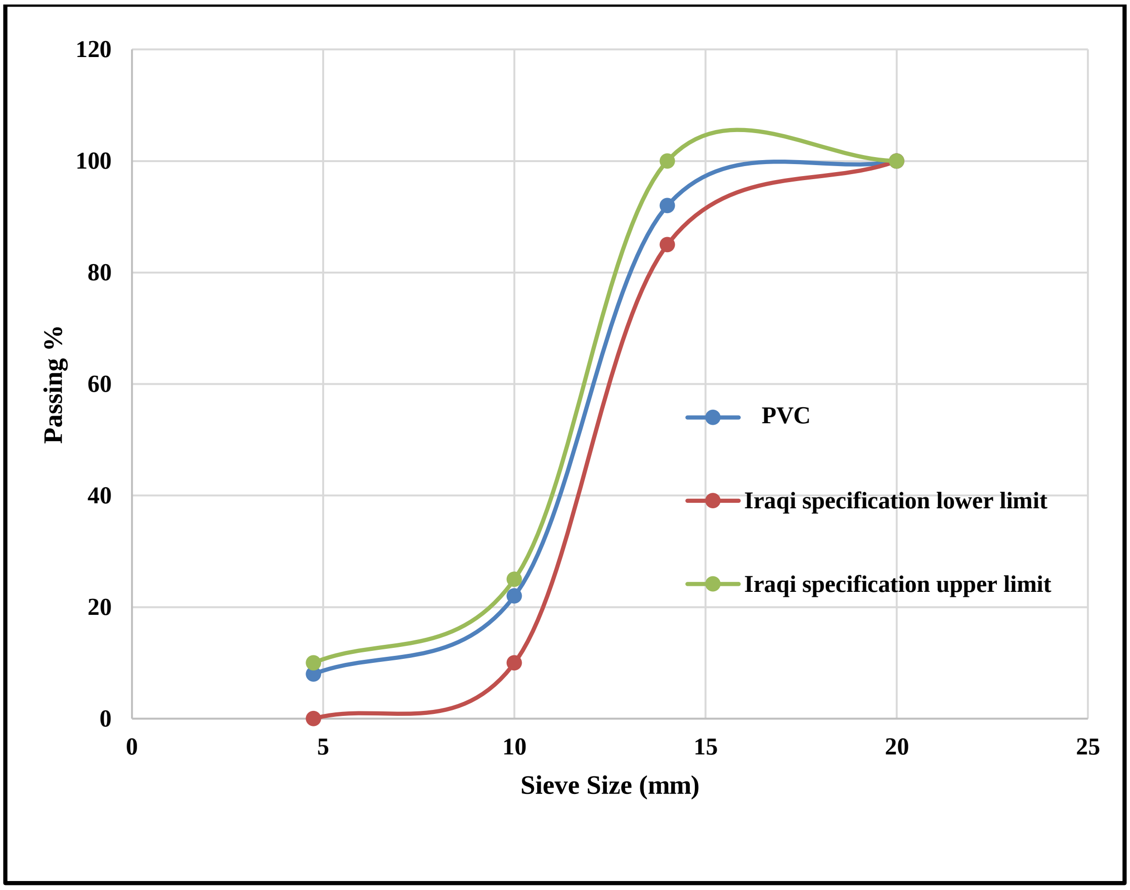


Figure 3.5 Grading curve for PVC waste

Figure 3.6 The PVC Pipes Waste in Misan Plastic Factory.

3.4 Pre-Mix Design Process for Lightweight Concrete

In this phase of research, a series of trial mixes were formulated and tested with the intent to create lightweight concrete by partially replacing natural aggregates with PET and PVC materials, in order to identify the optimal combination of PET and PVC replacements for producing lightweight concrete. The goal was to achieve a concrete mixture with a density below 1900 kg/m³ and a compressive strength greater than 21 MPa. Different mix designs were tested, each incorporating different proportions of PET as a fine aggregate replacement and PVC as a coarse aggregate replacement. The mix designs were evaluated to find the optimal balance for lightweight concrete. Here is a summary of the nearest results to the lightweight concrete criteria in Table 3.9. These mixtures were evaluated for the first two mixes (Specimens 1 and 2) were designed with lower PET and PVC content (10% and 20%). These mixes achieved compressive strengths of 27 MPa and 26 MPa, respectively, but had densities of 2200 kg/m³ and 2100 kg/m³, which exceed the threshold for lightweight concrete. By increasing the PET and PVC replacement ratios, the density of the concrete was progressively reduced. For example, Specimen 3, with 30% PET and 30% PVC, achieved a compressive strength of 23 MPa and a density of 1976 kg/m³, approaching the lightweight category. both compressive strength and density to identify the optimal configuration for lightweight concrete. Specimen 4, which incorporated 25% PET and 35% PVC, improved the balance between strength and density. It achieved a compressive strength of 24 MPa and a density of 1935 kg/m³, still slightly above the lightweight concrete threshold. Specimen 5, which used 20% PET and 40% PVC, resulted in a compressive strength of 22.9 MPa with a density of 1960 kg/m³. Although slightly higher in density, the mixture remained competitive in terms of compressive strength. Increasing the replacement levels of PET and PVC continued to reduce the density but resulted in a drop in compressive strength. Specimen 6 (40% PET and 40% PVC) achieved a density of 1720 kg/m³, well within the lightweight range, but the compressive strength dropped to 20 MPa, falling below the target. Specimen 9, with 50% PET and 25% PVC, had the lowest compressive strength of 14 MPa with a density of 1740 kg/m³, indicating that excessive replacement negatively impacts structural integrity. The most promising mixtures were Specimen 3 (30% PET and 30% PVC), which achieved 23 MPa compressive strength with a density of 1976 kg/m³, and Specimen 4 (25% PET and 35% PVC) with 24 MPa compressive strength and 1935 kg/m³ density. Both mixtures are close to the desired properties for lightweight concrete, offering a viable balance between strength and weight. Further modifications, such as Specimen 10 (5% PET and 80% PVC), managed to achieve a compressive strength of 19 MPa and a density of 1720 kg/m³, although the compressive strength did not meet the minimum requirement of 21 MPa. The pre-mix phase demonstrated that controlling the percentage of PET and PVC replacement significantly impacts both compressive strength and density. While higher replacement percentages effectively reduce density, they also tend to lower compressive strength. Through this trial process.

Table 3.9 Pre Mix Design

Specimen	Mix Design	Fine PET	Coarse PVC	W/C	Super	Compressive Strength	Density
1	1:1.25:2.25	10%	10%	0.35	0.70%	27	2200
2	1:1.25:2.25	20%	20%	0.35	0.70%	26	2100
3	1:1.20:2.20	30%	30%	0.35	1%	23	1976
3	1:1.15:2.15	25%	35%	0.4	1%	24	1935
5	1:1.1:2	20%	40%	0.4	1%	22.9	1960
6	1:1.1:2	40%	40%	0.4	1%	20	1720
7	1:1.1:2	40%	30%	0.4	1.5%	18.3	1865
8	1:1.1:2	40%	50%	0.45	1.5%	17.7	1815
9	1:1.1:2	50%	25%	0.4	1%	14	1740
10	1:1.1:2	5%	80%	0.4	1%	19	1720

The extensive testing of various trial mixes allowed for a systematic evaluation of how different percentages of PET and PVC replacements influenced the properties of structural lightweight concrete. Analyzing the results from these trials helped identify mixes that effectively balance lower density with adequate compressive strength, leading to recommendations for optimal mix compositions.

3.5 Program of Experimental Work

The experimental program comprises two primary components.

- In the first part, focus on incorporating PVC and PET wastes at varying percentages to replace gravel and sand in the concrete mixture, aiming to products lightweight concrete. This part of the study investigates the impact of these substitutions on the mechanical and physical characteristic of lightweight concrete.
- The second part of the program examines how the inclusion of these PVC and PET percentages affects the flexural performance of reinforced concrete beams.

3.5.1 Selection of PET and PVC Waste Percentages as a Fine and Coarse Aggregate Replacement

In this study, a comprehensive series of trial experiments were meticulously conducted to gain a precise understanding of how lightweight concrete, when enriched with PET and PVC plastic waste, behaves and what unique characteristics it exhibits. The primary objective of these experiments was to determine the appropriate quantities and proportions of PET and PVC materials and to investigate how they effectively substitute traditional aggregates. In pursuit of this goal, proactive experiments were systematically executed to pinpoint a specific range of weight percentages that is most suitable for PET and PVC inclusion.

These trial mixes were prepared by mixing different percentages of PET and PVC waste with the concrete mix. These mixtures underwent several tests to assess a range of concrete properties, including mechanical strength, workability, and more, for each combination.

Throughout this process, a delicate balance was sought between the imperative for weight reduction, which is achieved by increasing the percentage of PET and PVC waste, and the essential requirement for maintaining structural integrity. It is crucial to strike the right balance as lightweight concrete may exhibit reduced strength compared to traditional concrete.

Moreover, a comprehensive cost-effectiveness analysis was conducted, considering the expenses associated with processing and incorporating PET and PVC materials versus the potential savings and environmental benefits they offer. The ultimate aim of these experimental mixtures was to precisely determine the optimal proportions at which PET and PVC waste can efficiently replace traditional fine and coarse aggregates, ultimately leading to the production of lightweight concrete with the desired performance characteristics.

The table displays the resulting lightweight characteristics achieved with different proportions of PET and PVC, as outlined in Table 3.10.

Table 3.10 PET and PVC Percentages as a fine and Coarse Replacement

Beam	**% PET**	**% PVC**	**W/C Ratio**	**superplasticizer**
R	0	0	0.4	1 %
B1	35	35	0.4	1 %
B2	30	40	0.4	1 %
B3	25	50	0.4	1 %
B4	15	60	0.4	1 %
B5	10	70	0.4	1 %

3.5.1.1 Mixing procedure for Natural Aggregate and Recycled plastic waste

In the study, the mixed design of the concrete was a significant aspect that influenced the overall properties and performance of the beams. The process of creating a concrete mixture involves considering the characteristics of the materials used and determining the appropriate mix proportions. In this particular study, six trial concrete mixes were prepared to achieve there are two types of concrete. The first type of concrete utilized natural coarse aggregate, while the second type incorporated recycled plastic waste (PET and PVC) as a partial substitute for natural coarse aggregate. By replacing a portion of the regular coarse aggregate with recycled plastic waste, the examine aimed to analyses the effects of incorporating regained materials on the characteristics and behavior of the concrete mixture. The replacements range were in the limits of 70%-80% distributed between the PET and PVC as seen in Table 3.11.

In terms of the mixing technique, mixing preparation is crucial to acquire the requisite workability and homogeneity in the concrete mix. In the research conducted, a high-speed mixer was used to mix the concrete component. Before initiating the mixture process, it was crucial to ensure that the mixer was Clean, moist, and free of extra water. This step is necessary to create an optimal environment for the mixing process. Based on previous work, a fixed mixing procedure was adopted and followed consistently all over the research. This procedure was specifically designed to achieve two objectives: maximize the efficiency of the superplasticizer and ensure the complete dispersion of its particles within the mortar or concrete mixture. Concrete mixing is implemented in several stages, which include first adding the cement and then sand. Water and Superplasticizer were added to the mix. Then, the coarse aggregate was added. To avoid the conglomerate in the mix and offer higher workability and a good consistency for the concrete mix, the materials are added gradually in small amounts. It should be noted that the mixing time is 10 min.

For concrete mixes with the replacement of aggregate, mixing took longer than expected. A quick mixing process of the components must be taken into account to secure a more uniform distribution of the concrete components, especially the recycled plastic waste, while the results are shown in Table 3.11. At the end of 24 h after casting, the concrete was removed from the molds and was put in the curing basin underwater until the age of 28 days. For the experimental investigation, five different concrete mixes are prepared, and the reference mixture serves as a baseline and does not include plastic waste (normal concrete (NC)). The proportions of the components are in a ratio of (1:1.1:2). The second one is a concrete mixture containing PET-PVC in ratio of 70% (35%/35% for each type of shredded piece). The third, fourth, fifth, and sixth concrete mixture included utilizing type is 30%/40%, 25%/50%, 15%/60, and 10%/70%.in Table 3.11.

3.5.1.2 Specimens of Experimental Work

The experimental work involved the use of various types and sizes of specimens for testing the physical and mechanical characteristics of concrete: Cubes: A total of twelve cubes, the dimensions of each cube are 150 * 150 *150 mm, were prepared. These cubes were utilized to conduct tests related to density, compressive strength, ultrasonic pulse velocity, and absorption. Cylinders: Six cylindrical specimens, with dimensions of 300*150 mm, were specifically cast for the splitting tensile strength test.

Prisms: Six prismatic specimens, the dimensions of each prismatic are 500 * 100 * 100 mm, were employed to evaluate the Flexural Strength of the concrete. For each percentage of PET and PVC waste replacement, these specimens were meticulously prepared, to carry out a comprehensive range of tests to assess the concrete's mechanical and physical properties.

Table 3.11 Proportions of Concrete Mixture for All PET and PVC Substitutions.

Material /(kg/m^3)	**R**	**B1**	**B2**	**B3**	**B4**	**B5**
Cement.	540	540	540	540	540	540
Coarse aggregate	1080	702	648	540	432	324
Fine aggregate	594	386.1	415.8	445.5	475.2	534.6
Super PS.	5.4	5.4	5.4	5.4	5.4	5.4
PET	0	207.9	178.2	148.5	118.8	59.4
PVC	0	378	432	540	648	756
w/c.	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
Density	2288.89	1896.3	1881.48	1837.04	1807.41	1777.78

3.5.1.3 Concrete Tests

3.5.1.3.1 Test of Fresh Concrete

3.5.1.3.1.1 Slump Test

The slump test stands as one of the most critical assessments of a concrete mixture's properties. It serves as a reliable indicator of the mixture's consistency and offers a straightforward means of ensuring concrete quality. A concrete mixture is considered workable when it displays a suitable consistency, doesn't segregate when handled, maintains homogeneity upon casting, and requires minimal effort during compaction.

This test adheres to the specifications outlined in ASTM C143 [54]. A slump equipment test is employed. During the test, the concrete mixture is carefully placed into the cone in three level, with each level occupying approximately one-third of the mold's volume. Consequently, each layer is compacted by applying 25 rod strokes with a tamper rod. As illustrated in Figure 3.7.

Figure 3.7 slump Test.

The slump value is straightaway determined by measuring the deviation between the initial mold height and the height of the vertical axis of the specimen, as depicted in Figure 3.7.

3.5.1.3.2 Mechanical Tests of Hardened Concrete

3.5.1.3.2.1 Density Test

The dry density of hardened concrete cubes was determined using concrete specimens with dimensions of 150x150x150 mm, by the procedures outlined in British Standards BS 1881-Part 114:1983 [55]. To ensure the accuracy of this assessment, the concrete cubes were cured for three different age intervals—7 days, 14 days, and 28 days under standard conditions. Following this curing period, the specimens were carefully dried and then weighed with precision. The density was calculated by dividing the measured mass by the cube's volume, yielding the dry density of the hardened concrete.

This concrete mix incorporates waste materials, specifically Polyethylene Terephthalate (PET) and Polyvinyl Chloride (PVC), as partial replacements for traditional fine and coarse aggregates, such as sand and gravel. These substitutions are aimed at producing more sustainable and lightweight concrete while maintaining structural integrity. The specific mix design and proportions used for these replacements, along with the effects on the concrete's density, are illustrated in Figure 3.8. Which provides a visual representation of the material distribution and the corresponding outcomes. As depicted in Figure 3.8.

Figure 3.8 The Density Test.

3.4.1.3.2.2 Compressive Strength Test

Following the completion of the density test, the compressive strength of the concrete specimens was evaluated using the same cubes, each with dimensions of 150x150x150 mm. This procedure was carried out in strict accordance with the guidelines set forth in British Standards BS 1881-Part 116:1983 [56], ensuring the consistency and reliability of the results.

The compressive strength test was performed using a high-capacity compressive testing machine, capable of applying a maximum load of 2000 kN, as shown in Figure 3.9.

Figure 3.9 The Compressive Test.

3.4.1.3.2.3 Splitting Tensile Strength

The splitting tensile strength is assessed by utilizing cylindrical concrete specimens measuring 150 x 300 mm. This test follows the guidelines specified in ASTM-C496 [57]. The test is conducted with a compressive strength machine having a capacity of 2000 kN , and it takes place in the Civil Engineering research facility at the University of Misan, as depicted in Figure 3.10. To calculate the splitting tensile strength by below formula:

$$ft = \frac{2P}{\pi DL}$$

Where:

ft: splitting tensile strength in MPa.

P: the maximum applied load in N.

L: the length of the cylinder in mm.

D: the diameter of the cylinder in mm

Figure 3.10 The Splitting Tensile Test.

3.4.1.3.2.4 Flexural Strength Test

The Flexural Strength is measured using prism-shaped concrete specimens measuring 100*100*500 mm. The testing is conducted according to the ASTM. -C78 [58] standard. To carry out this test, a flexural Machine with a capacity of 5000 kN is employed. This testing takes place the Civil Engineering research facility at the University of Maysan, as depicted in Figure 3.11. The flexural strength is calculated with the following equation:

$$fr = \frac{3PL}{2bd^2}$$

Where:

fr: the modulus of rupture in MPa.

P: the maximum applied load in N.

L: the length of the span in mm.

b: the average width of the specimen in mm.

d: the average depth of specimen in mm.

Figure 3.11 The Flexural Strength Test.

3.4.1.3.3 Hardened Physical Tests

3.4.1.3.3.1 Absorption Test

The absorption test, conducted in accordance with ASTM C642, "Standard Test Method for Density, Absorption, and Voids in Hardened Concrete," was employed to evaluate the water absorption characteristics of the concrete specimens. Cube specimens, with dimensions of 150 mm x 150 mm x 150 mm, were prepared following ASTM C642 specifications [59]. The steps of the procedure are detailed as follows: The concrete specimens were oven-dried at a temperature range of 100 to 110°C until a constant mass was achieved. After removal from the oven, the specimens were allowed to cool in dry air (preferably in a desiccator) to room temperature, between 20 and 25°C. Once the specimens had cooled, the dry mass of each specimen was recorded as Mass A. Following the determination of the dry mass, the specimens were submerged in water at room temperature for 48 hours to allow full absorption. After this immersion period, the specimens were removed from the water, and surface moisture was wiped off. The surface-dry mass was then recorded as Mass B. This procedure was crucial in determining the water absorption properties of the concrete, which are directly linked to its porosity and durability.

Absorption (%) = $\frac{(B-A)}{A}$ **x** 100 %

The test is designed to assess the physical properties of hardened concrete, particularly its absorption capacity, which is a key indicator of the material's porosity and permeability.

Figure 3.12 Drying the Specimens in the Oven.

3.4.1.3.3.2 Ultrasonic pulse velocity test (UPV)

The ultrasonic pulse velocity (UPV) in concrete cubes is determined in accordance with the ASTM C597 [60] standard. Cube specimens, each with dimensions of 150 *150*150 mm, are used for this test. An ultrasonic pulse velocity apparatus, as depicted in Figure 3.13, is employed. The UPV test is carried out using the PUNDIT PC 1012 equipment, which provides measurements with an accuracy of 0.1 microseconds. This test is conducted using the direct method, involving measurements taken from two different directions. UPV is a valuable non-destructive test for assessing the quality and integrity of concrete structures.

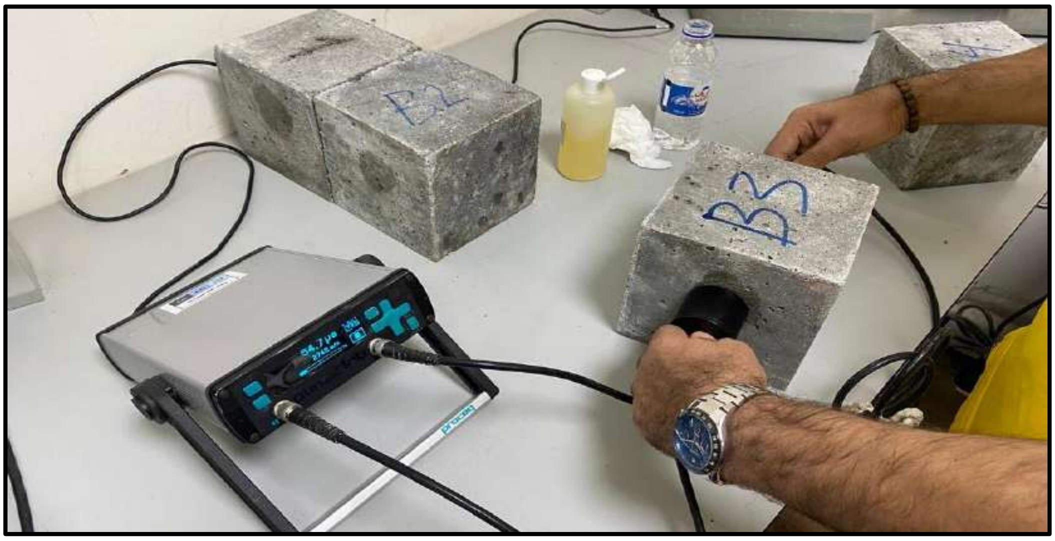


Figure 3.13 The Ultrasonic Pulse Velocity Test.

3.5.2 Reinforced Beam Specimens

The primary objective here is to investigate how the incorporation of PET and PVC waste as partial substitutes impacts the performance and behavior of structural lightweight concrete beam specimens. This research is geared toward assessing the specific effects of these material substitutions on the structural characteristics of lightweight concrete beams.

3.5.2.1 Beams details

This study encompassed a comprehensive investigation involving the casting and testing of concrete beams. A total of six concrete beams were experimentally designed and fabricated, incorporating various parameters, as revealed in Table 3.12 and as shown in Figure 3.14. The rectangular beams had dimensions of (150 * 300 * 2300) mm and the reinforcement of the beams was done in accordance with the specifications laid out by ACI 318-19 [62], which guarantees controlled Failure occurs in the compression and tension zones. In the tension zone, there were three of 12 mm bars for flexural reinforcement and in the compression zone, there were two 12 mm bars. There were stirrups measuring Ǿ10 @ 60 mm apart in the shear span and 120 mm apart in the central area for shear reinforcement.

Table 3.12 Details of beams.

ID	PVC Ratio	PET Ratio	Dimensions (mm)	Main Reinforcement	Transverse Reinforcement
R	0%	0%	150 x300x 2300	3 ϕ 12	ϕ10 @60
B1	35%	35%	150 x300x 2300	3 ϕ 12	ϕ10 @60
B2	40%	30%	150 x300x 2300	3 ϕ 12	ϕ10 @60
B3	50%	25%	150 x300x 2300	3 ϕ 12	ϕ10 @60
B4	60%	15%	150 x300x 2300	3 ϕ 12	ϕ10 @60
B5	70%	10%	150 x300x 2300	3 ϕ 12	ϕ10 @60

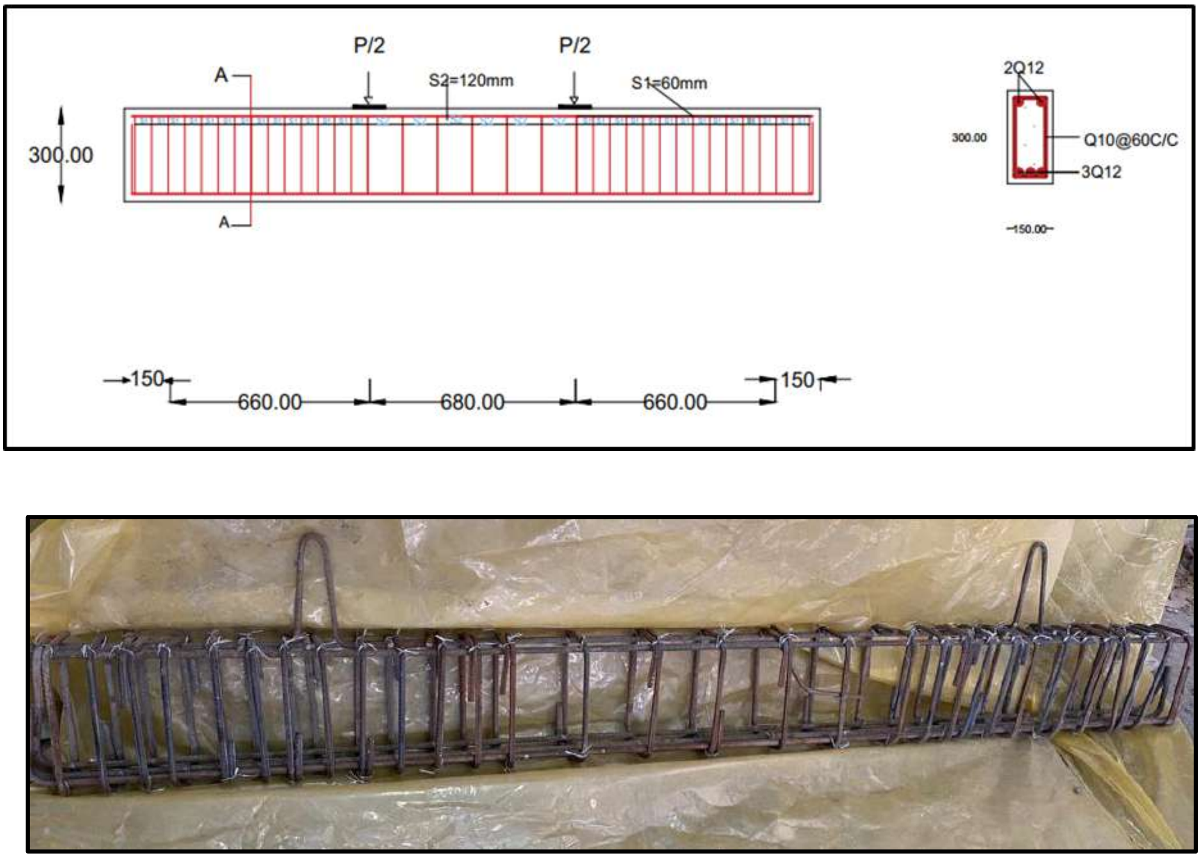


Figure 3.14 The Details of Reinforcement and Method of Loading for Concrete. Beams

3.5.2.1.1 Mold Preparation

In the research work, a total of nine molds were utilized. These molds were designed to match the dimensions of the fabricated beams, which measured 150 mm * 300 mm * 2300 mm. The molds were an essential component in the process of casting the concrete beams. To prepare the molds, they were first cleaned and then coated with oil using a scraper and a steel brush. This oil coating is applied to facilitate the demolding process, ensuring that the concrete beams can be easily removed from the molds without any damage or sticking. The forms for the beam specimens were made from 20 mm plywood sheets.

These plywood sheets were meticulously cut and assembled to achieve precise vertical sides and create 90-degree corners. The plywood was used to form the bottom part of the mold, as illustrated in Figure. 3.15. This configuration allowed for the proper shaping and containment of the concrete during the casting process.

Figure 3.15 The Details of Formwork and Reinforcement for Concrete Beams.

3.5.2.1.2 Casting and Curing Procedure of Beams

In the study, a 100 kg mixer was used to mix the concrete. Before inserting the reinforcement, cage, or casting control specimens, the forms and control molds were oiled. This oiling process helps to ensure that the concrete does not stick to the forms, allowing for easy demolding. To maintain the appropriate concrete cover, steel bars were placed inside the forms and securely positioned. These steel bars act as spacers and ensure that the reinforcement is properly embedded within the concrete at the specified depth.

All constituents of the concrete mixture, such as fine and coarse aggregates, in addition to the plastic that will be used in this study, cement, and water, were accurately weighed and carefully placed in a clean metal container before mixing. This process ensures the correct proportioning of the materials and helps maintain consistency in the mixture. Figure 3.16 illustrates the casting process, which involved using plywood forms for the molds and steel forms.

The plywood forms were used to shape the main body of the concrete specimens, while steel forms may have been employed for specific areas or features requiring additional support or reinforcement. After the concrete was mixed and cast into the forms, the forms remained in place for 24 hours to allow the concrete to solidify.

Subsequently, the forms were removed, the specimen were cured for 28 days. It helps maintain proper moisture levels and promotes strength and durability development. Additionally, samples of the poured concrete were taken and cast into concrete cubes and cylinders. These samples were used to estimate the concrete properties, such as compressive strength, which is a fundamental characteristic for assessing the quality and performance of the concrete.

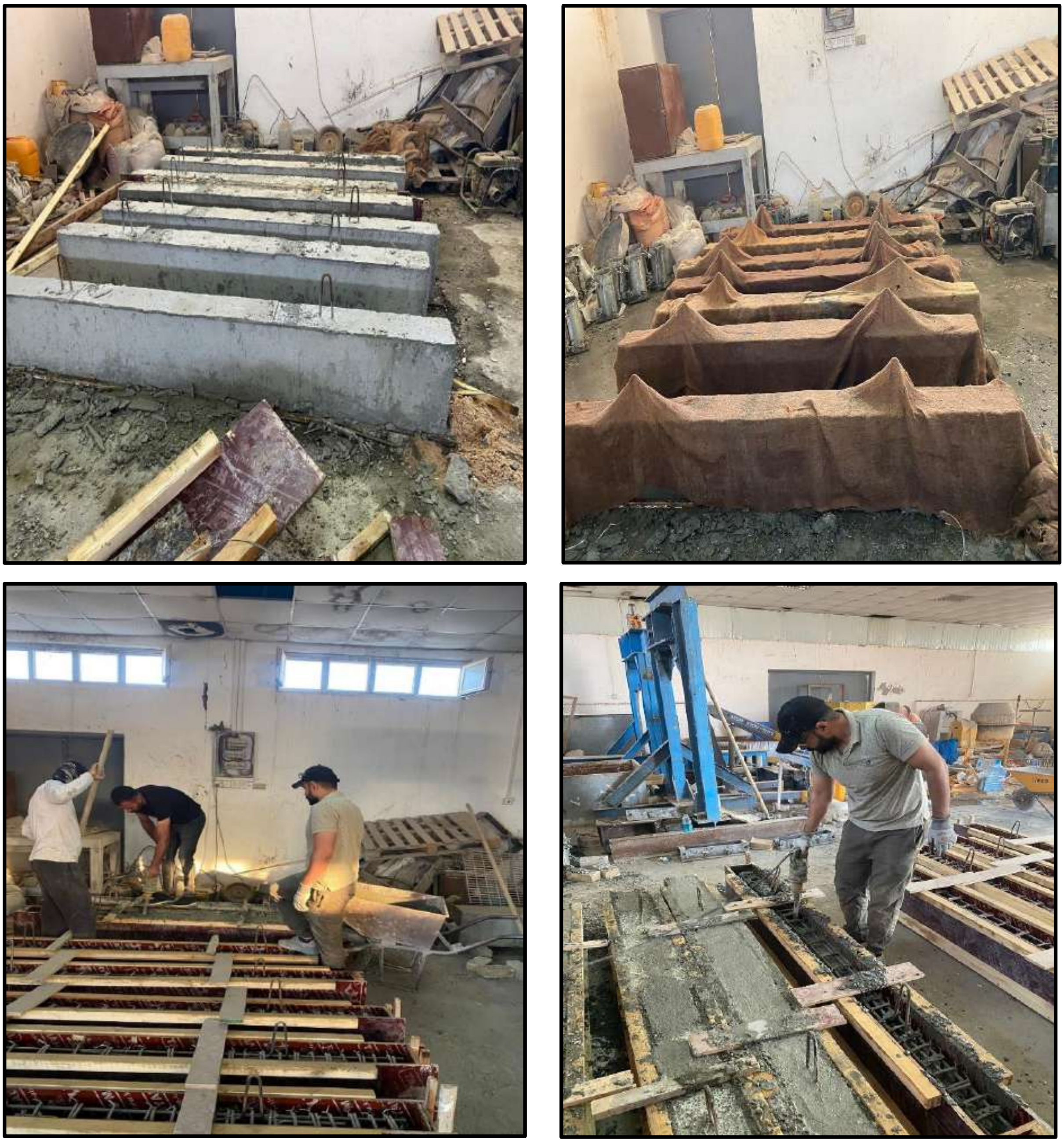


Figure 3.16 The Casting Curing of Beams.

3.5.2.2 Testing of Concrete Beams

3.5.2.2.1 Strain Gages

For varying percentages of replacement, three strain gages of 60 mm length were used, one is placed in the tension zone, the other one are attached in the compression zone and the last one in the share. All the strain gages were located in the center of each beam before testing., as shown in Figure 3.17. to obtain a reading of strain at each load increment, the strain gauges were connected to a data logger (a data acquisition device that contained 16 channels supplied with DATACOMM software for PC data acquisition.

The strain gauge type PL-60-11 was used to precisely monitor the stress and strain responses of concrete beams with different mix designs that included PTE and PVC aggregate replacements. They provide accurate and dependable data for analysis purposes. According to the Tokyo Measurement Laboratory, the PL-60-11 strain gauge is selected for its suitability with concrete surfaces and its capacity to offer precise results in both dynamic and static settings. The strong and durable design, along with its high sensitivity, enables it to accurately detect even small variations in strain. This makes it ideal for conducting in-depth analysis of material properties Strain gauges will be selectively affixed to the surface of the concrete beams in the experimental setup, namely at crucial regions that are prone to stress concentration. These sites typically consist of the tension, compression, and shear zones. Furthermore, they guarantee optimal data capture for thorough analysis.

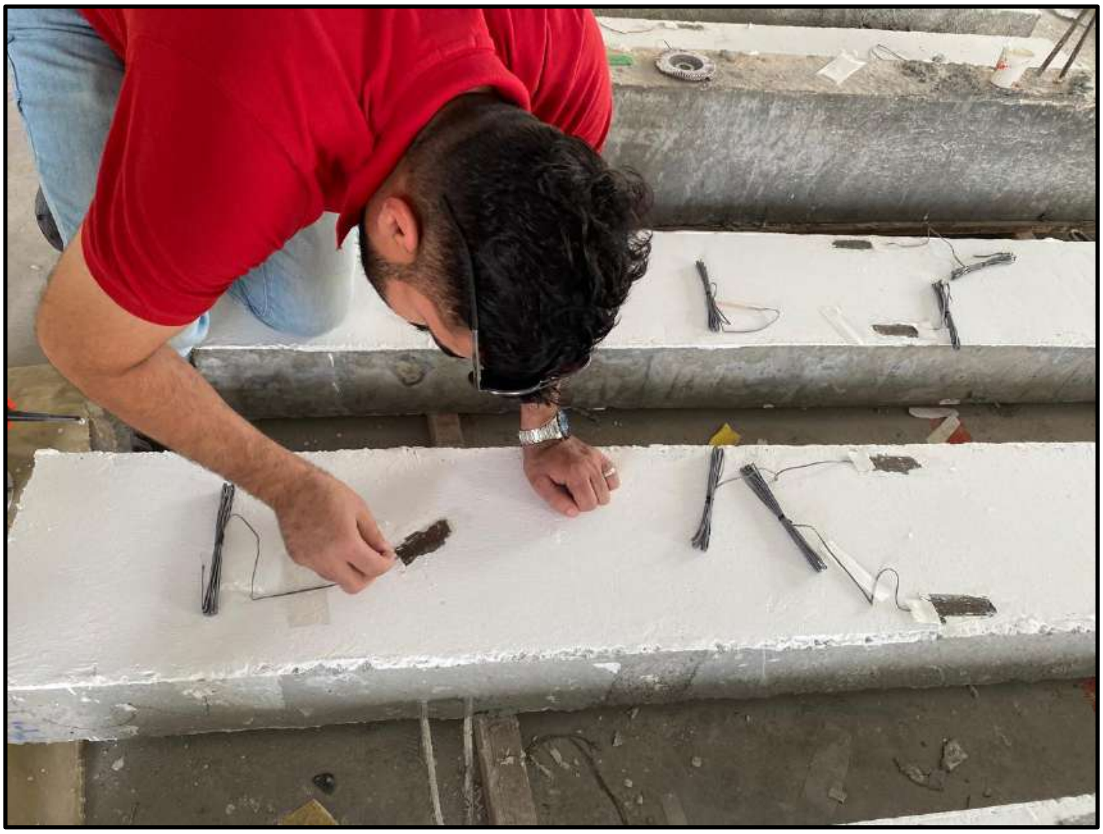


Figure 3.17 Strain Gages and Their Attaching.

3.5.2.2.2 Testing Machine

In the experimental testing of the fabricated beams, a testing machine with a capacity of 60 tons was utilized. This testing machine is capable of applying controlled loads to the specimens and measuring their response. A dial gauge with a sensitivity of 0.010 mm (10 microns) was employed to evaluate the deflection behavior of the beams. The dial gauge was utilized to measure the deflection or displacement during the loading process. This measurement provides insights into the flexibility and deformation characteristics of the beams, as seen in Fig. 3.18. During the loading procedure, both the loading data and displacement were measured at each load increment or step.

Figure 3.18 Testing of the experimental specimens.

These measurements were recorded to establish the load-displacement relationship and to monitor the response of the beams as the load increased. This data collection helps understand the structural behavior of the beams under different loading conditions. Strain gauges with a precision of one micron were used to measure the strains experienced by the concrete specimens. These strain gauges are sensitive enough to detect very small changes in strain. All beams tests were performed at the loading step of 3 kN to provide the optimum testing conditions and prevent the initial failure or crushing of the concrete due to the large step of loading. At the end of each loading step, deflection and strain were recorded. Regarding the crack width, the cracks were remarked with the use of a pen, as revealed in Figure 3.19. All concrete specimens were tested by the flexural Testing Machine. Concerning the test procedure, the test of the specimens was carried out at the age of 28 days after casting. All specimens were cleaned and painted with white paint before testing in order to clarify the propagation of cracks. The concentrated load was applied through a steel load moving plate used to achieve uniform contact. The test stage involved placing the specimen on the testing machine and adjusting it so that the centerline, supports, and line loads were fixed in their correct locations. All the instruments that were needed to complete the testing were then connected. Cracking and load were recorded.

Figure 3.19 Results recording of the experimental specimens

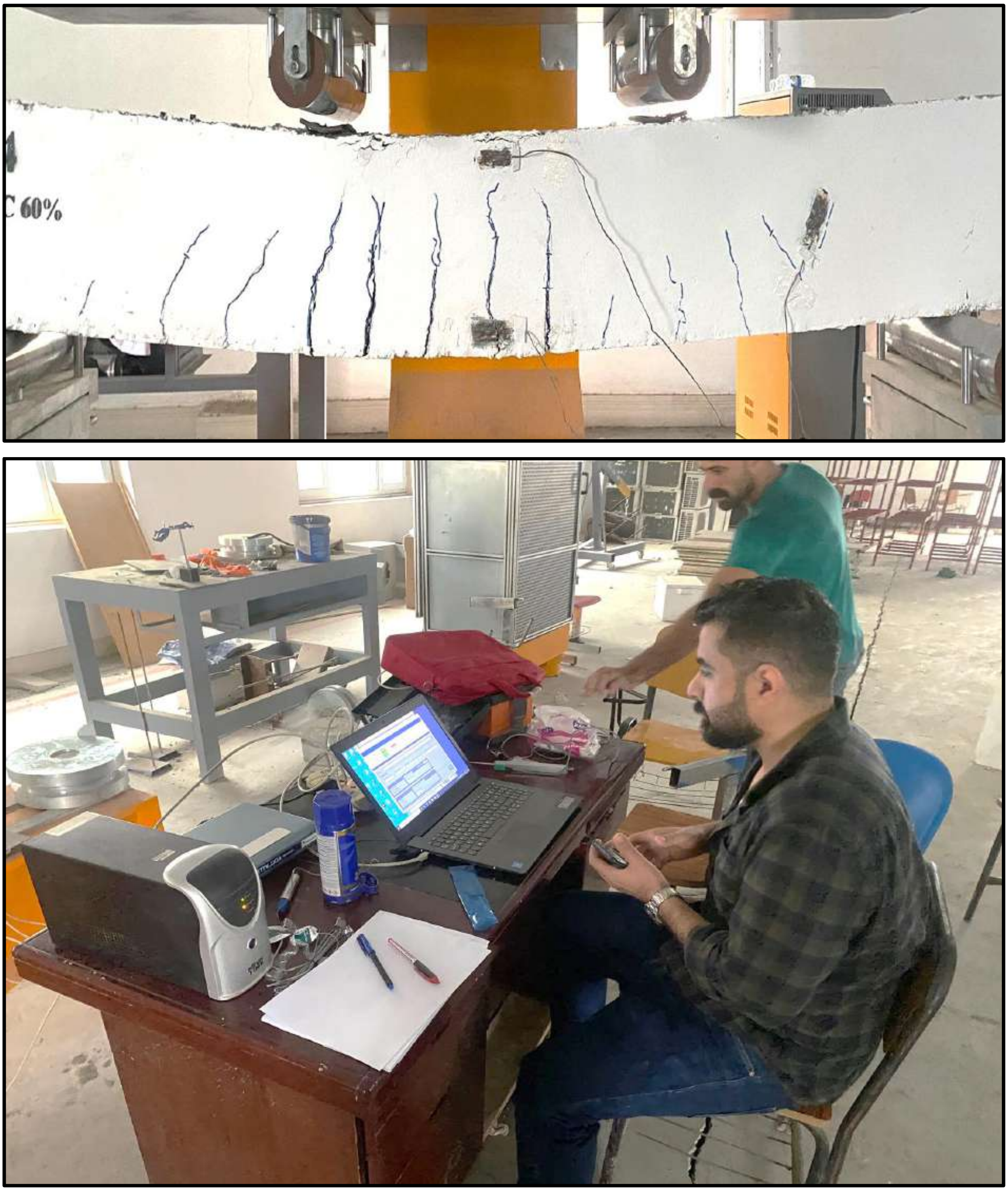


Figure 3.19 cont.

CHAPTER FOUR: RESULTS & DISCUSSION

4.1 General

The results and discussion for both fresh and hardened concrete are given in this chapter. The slump test findings are emphasized for freshly concrete. Results of several tests, such as compressive strength, splitting tensile strength, and flexural strength, are shown for hardened concrete. Tests for density, absorption, and ultrasonic pulse velocity are also discussed. Six mix ideas are covered: one reference mixture, five mixes with PET and PVC replacing some of the natural sand and coarse aggregate, respectively. The full-scale beam's structural behavior data for each replacement ratio are also shown. These results include relationships for each parameter and cover the following topics: strain, energy absorption, ductility, ultimate load, ultimate deflection, and the load at which the first crack appears.

4.2 Part One: Test Results of Mechanical and Physical Properties

4.2.1 Workability (Slump Test)

The results of the slump test show how varying amounts of PVC (polyvinyl chloride) and PET (polyethylene terephthalate) effect a concrete mix's slump. The consistency and workability of freshly mixed concrete are evaluated using the slump test. At the outcomes in in Table 4.1 and Figure 4.1. This is the control mix without any PVC or PET added. A concrete mix with standard aggregates exhibits a high workability value of 160 mm. However, when 35% PET and 35% PVC are added, the slump significantly decreases to 70 mm, indicating a notable reduction in workability. This results in a 56% variation in slump between the mix with normal aggregates and the one incorporating 35% PET and 35% PVC. This 56% decrease highlights that PET and PVC significantly impact the mixture, making it less flexible and more challenging to handle. This mixture also yields a significant reduction in droop to 78 mm for the second mix (30, 40%). Although marginally better than the 35%/35% combination, the third mixture with replacement proportion (25%, 50%) shows a 49% drop in workability. The 49% decline suggests that raising the PVC content while significantly reducing the PET component still leads to lower workability. It appears from this that the consistency of the concrete is still greatly impacted by a larger PVC content, albeit marginally less so than in the 30%/40% combination. The B4 mix, which has a 15% sand replacement and a 60% coarse replacement percentage, has an 85 mm slump, meaning that its workability has decreased by 46.88%. In comparison to the higher PET percentages, there is a trend toward somewhat improved workability when PET is further reduced and PVC is increased. The variation of the slump of a 45% reduction in workability for the final mix design of light weight concrete in this study, with partial replacement of sand at 10% PET and gravel replacement up to 70%, suggests that the negative impact on workability slightly lessens as the PET content decreases and the PVC content increases, but the mix is still significantly less workable than the control.

Table 4.1 Slump Test result

Beam ID	Slump (mm)	Variation in slump %
R	160	0%
B1	70	-56.25
B2	78	-51.25
B3	81	-49.38
B4	85	-46.88
B5	88	-45

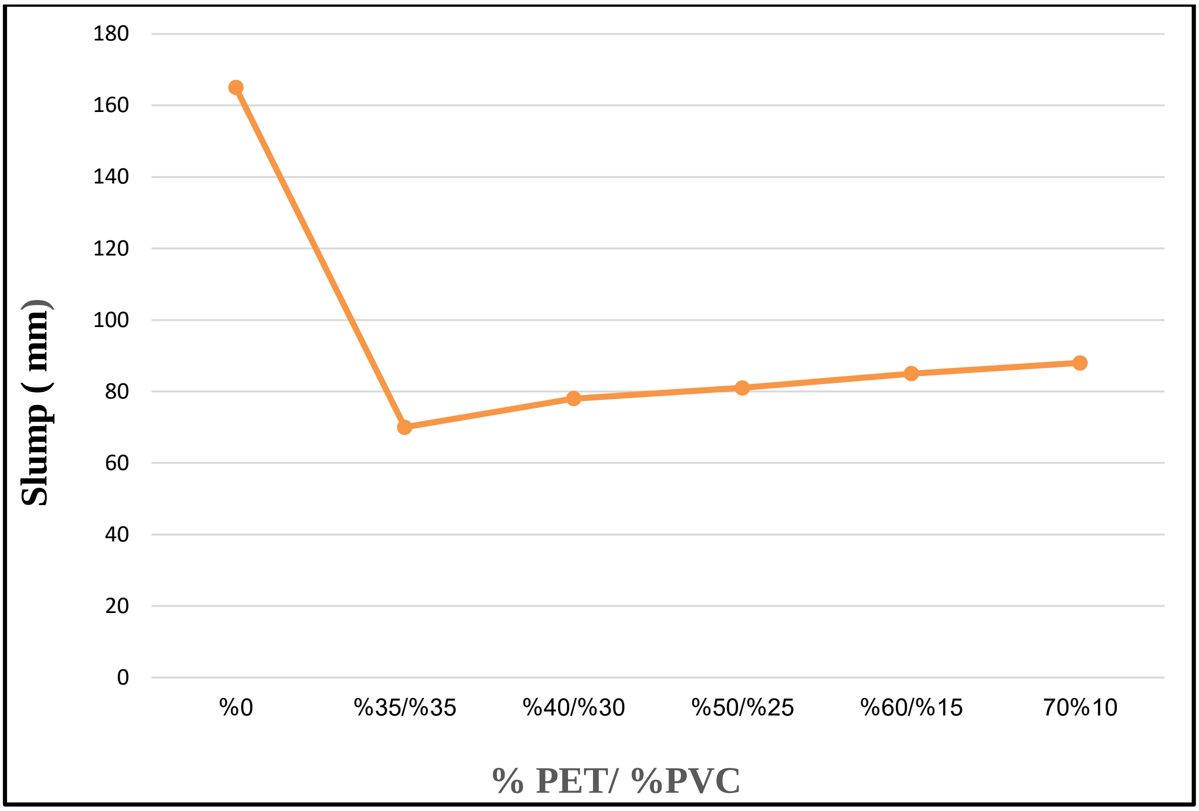


Figure 4.1 Slump Test result

4.2.2 Results of Mechanical Properties

4.2.2.1 Compressive Strength

To evaluate the failure stress of the concrete specimens under uniaxial compression, the compressive strength test was performed. The testing procedure adhered to the guidelines outlined in BS 1881-part 116-83 [56], compression machine was utilized for conducting the test. In accordance with the specifications provided in BS 1881-part 116-83 [56], nine 150 mm cube specimens were prepared for each batch of concrete mix. These specimens were used for the compressive strength testing. The cube specimens used in compressive strength testing are widely employed and provide a representative measure of concrete strength. The compressive strength test was conducted at three different ages: 7 days, 14 days and 28 days. These specific time periods were selected to monitor the progress of compressive strength development over time. The results showed in Table 4.2 that transforming the concrete beam from normal to lightweight due to the presence of PET and PVC led to decrease in the compressive strength depending on the percentage of plastic waste. For the seven days' test, the concrete compressive strength decreased when the concrete contained plastic waste reduced when PET to PVC of 35%/35% was added which revealed that a decrement in the compressive strength to 15.31 MPa which equal to 26.34% as shown in Figure 4.2. and Figure 4.3 For the ratio of plastic waste (30%/40%, 25%/50%, 15%/60, and 10%/70%.) led to variable decrease in the compressive strength which were 17.87%, 13.78%, 9.64%, and 14.95% respectively. Concerning the twenty-eight-day testing, the standard concrete mixture exhibited a compressive strength of 28.93 MPa, but the lightweight concrete displayed a drop in compressive strength. The ratio of PET to PVC, at 35%/35%, resulted in a decrease in the ultimate compressive strength to 21.31 MPa, which is equivalent to a reduction of 26.3% as depicted in Figure 1. The different ratios of plastic waste (40%/30%, 25%/50%, 60%/15%, and 70%/10%) resulted in varying reductions in compressive strength, namely 24.27%, 21.47%, 19.77%, and 23.5% respectively.

Table 4.2 Compressive Strength result

Beam ID	**Density Kg/m^3**	**Fcu (MPa) (7 days)**	**Fcu (MPa) (14 days)**	**Fcu (MPa) (28 days)**	**Changing in compressive strength (%)(28 Days**
R	2288.89	20.54	24.88	28.93	-------
B1	1896.3	15.13	17.69	21.31	-26.34%
B2	1881.48	16.87	20.81	21.91	-24.27%
B3	1837.04	17.71	19.77	22.72	-21.47%
B4	1807.41	18.56	21.59	23.21	-19.77%
B5	1777.78	17.47	18.35	22.11	-23.57%

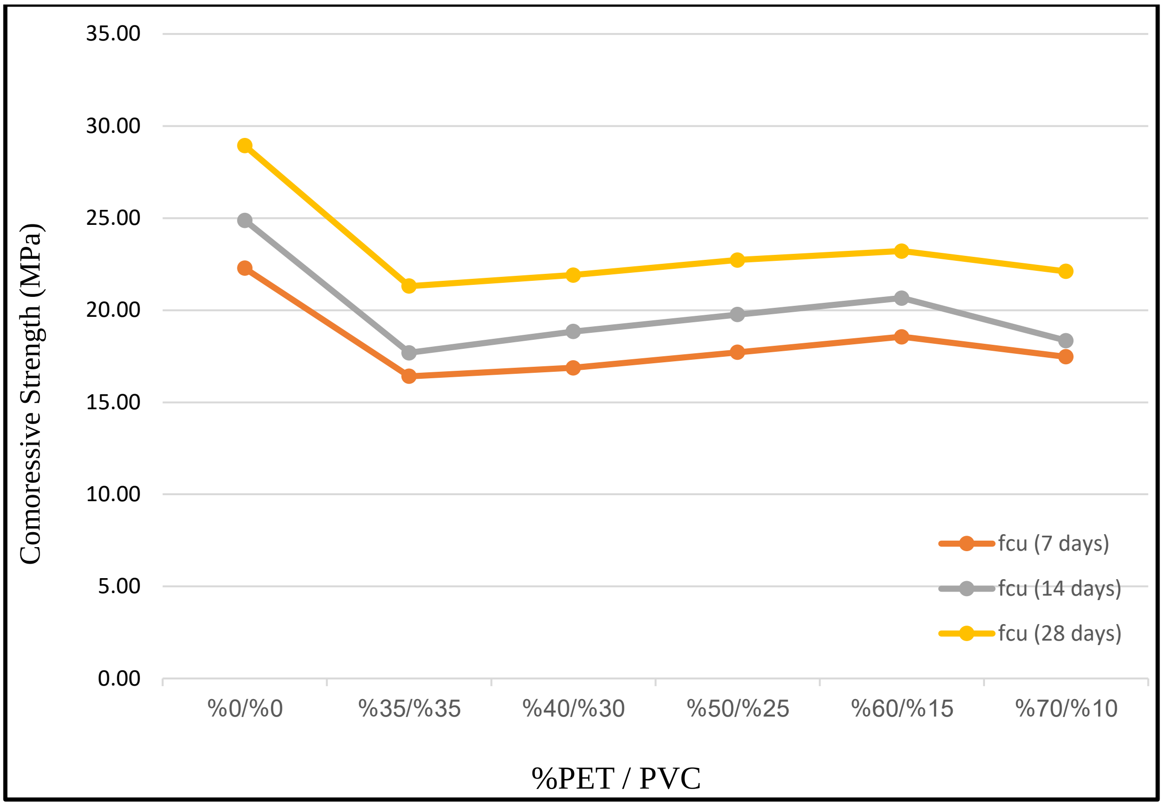


Figure 4.2 Compressive Strength Result for 7,14 and 28 day

Figure 4.3 Compressive Strength Test

4.2.2.2 Splitting Tensile Strength

By adhering to the requirements specified in ASTM-C496 [57], standardized testing techniques are followed, which in turn enables the obtainment of trustworthy and comparable results. The inclusion of three distinct curing durations, namely 7 days, 14 days, and 28 days, holds great significance as it enables the assessment of the progressive enhancement of the concrete's strength over a certain timeframe. The tensile strength test was performed at three distinct time points: 7 days, 14 days, and 28 days. The chosen time intervals were designated to observe the advancement of tensile strength over time. The findings indicated that the conversion of the concrete beam from standard to lightweight, as a result of the inclusion of PET and PVC, caused a reduction in the tensile strength, which varied depending on the proportion of plastic waste. As shown in the result in Table 4.3, during the seven-day test, the tensile strength of the concrete fell when plastic waste in the form of PET to PVC at a ratio of 35%/35% was added. This resulted in a reduction in tensile strength from 2.73 MPa to 1.61 MPa, which is equivalent to a 41% decline, as depicted in Figure 4.4.The plastic waste ratios of 30%/40%, 25%/50%, 15%/60%, and 10%/70% resulted in varying reductions in tensile strength, namely 35.9%, 15.8%, 5.1%, and 27.5% respectively. Regarding the twenty-eight-day testing, the conventional concrete mixture showed a tensile strength of 3.85 MPa, but the lightweight concrete revealed a decrease in tensile strength. The PET to PVC ratio of 35%/35% led to a fall in the ultimate tensile strength to 2.23 MPa, which corresponds to a reduction of 42.1% as shown in Figure 4.4 The plastic waste ratios of 30%/40%, 25%/50%, 15%/60%, and 10%/70% led to distinct losses in tensile strength, namely 37.7%, 23.4%, 15.8%, and 31.2% respectively.

Table 4.3 Splitting Tensile result

Beam ID	**Density Kg/m^3**	**ft (MPa) (7 days)**	**ft (MPa) (14 days)**	**ft (MPa) (28 days)**	**Changing in (%) (28 Days)**
R	2288.89	2.73	3.31	3.85	
B1	1896.3	1.61	1.85	2.23	-42.1%
B2	1881.48	1.75	2.28	2.40	-37.7%
B3	1837.04	2.30	2.57	2.95	-23.4%
B4	1807.41	2.59	3.01	3.24	-15.8%
B5	1777.78	1.98	2.20	2.65	-31.2%

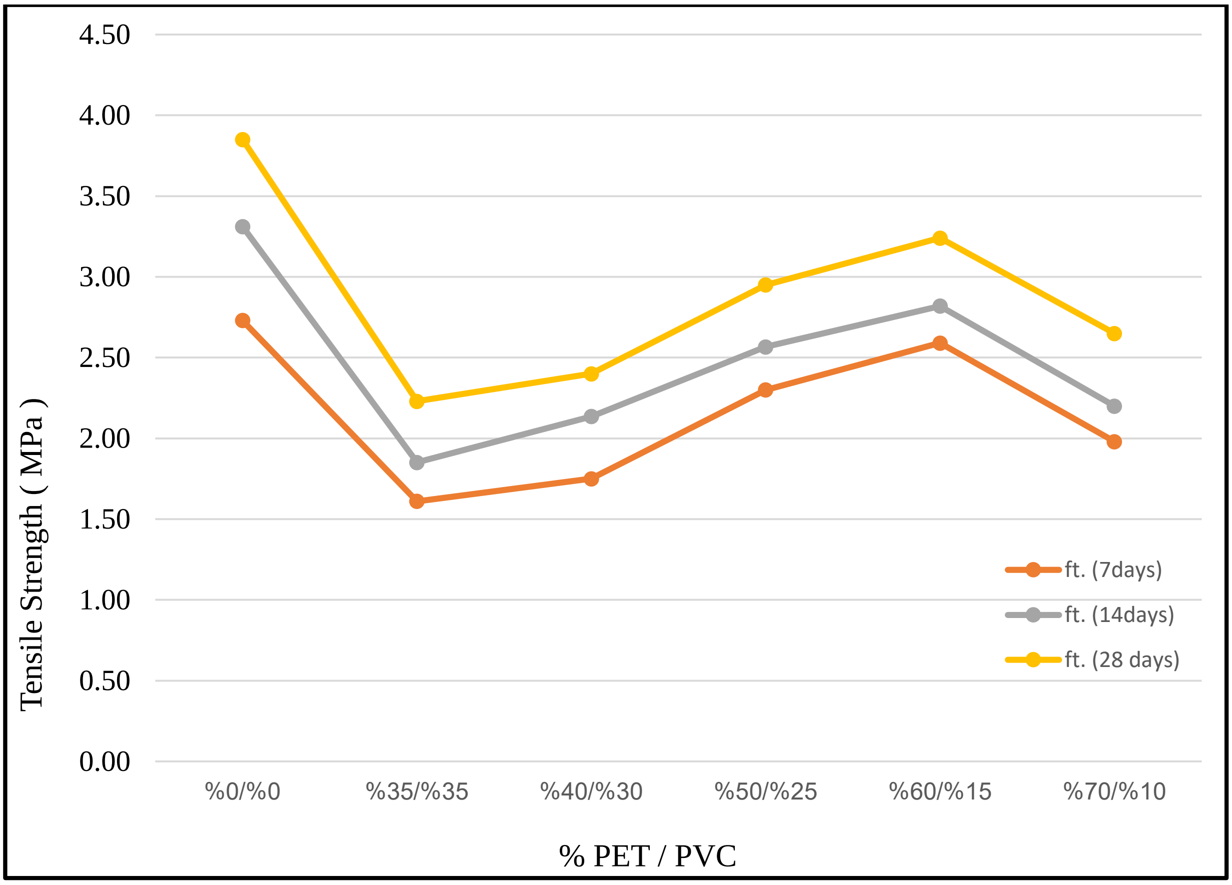


Figure 4.4 Tensile strength results

4.2.2.3 Flexural Strength

There were three distinct ages that were used for the flexural strength test: seven days, fourteen and twenty-eight days. For the purpose of tracking the development of flexural strength over time, these particular time periods were chosen for monitoring development. According to the findings, the flexural strength of the concrete beam decreased as a result of the presence of PET and PVC, which caused the beam to become lighter than usual. The degree of reduction in flexural strength was proportional to the amount of plastic waste present. In the course of the seven-day test, the flexural strength of the concrete fell when the concrete contained plastic waste. This occurred when a ratio of 35% PET to 35% PVC was added to the concrete. The results of this test in Table 4.4. demonstrated that the flexural strength decreased to 1.71 MPa, which is equivalent to 40%, as depicted in Figure 4.5. A varying drop in the flexural strength was observed for the ratio of plastic waste, which was found to be 23.2%, 3.5%, 0.7%, and 17.9% accordingly.

The ratios of plastic waste were as follows: 30%/40%, 25%/50%, 15%/60%, and 10%/70%. With regard to the twenty-eight-day testing, the regular concrete mixture demonstrated a flexural strength of 3.9 MPa, but the lightweight concrete demonstrated a decrease in flexural strength. Using a ratio of 35% PET to 35% PVC, the ultimate flexural strength was reduced to 2.41 MPa, which is comparable to a reduction of 38.2%, as shown in Table 4.4. This was the consequence of the ratio.

The reductions in flexural strength that were brought about by the many different proportions of plastic waste were as follows: 20.8%, 4.6%, 0.5%, and 15.1% respectively. The ratios of plastic waste were as follows: 30%/40%, 25%/50%, 15%/60%, and 10%/70%.

Table 4.4 Flexural Strength result

Beam ID	**Density Kg/m^3**	**fr (MPa) (7 days)**	**fr (MPa) (14 days)**	**fr (MPa) (28 days)**	**Changing in (%)(28 Days**
R	2288.89	2.85	3.35	3.90	
B1	1896.3	1.71	2.00	2.41	-38.2%
B2	1881.48	2.19	2.94	3.09	-20.8%
B3	1837.04	2.75	3.24	3.72	-4.6%
B4	1807.41	2.83	3.61	3.88	-0.5%
B5	1777.78	2.34	2.75	3.31	-15.1%

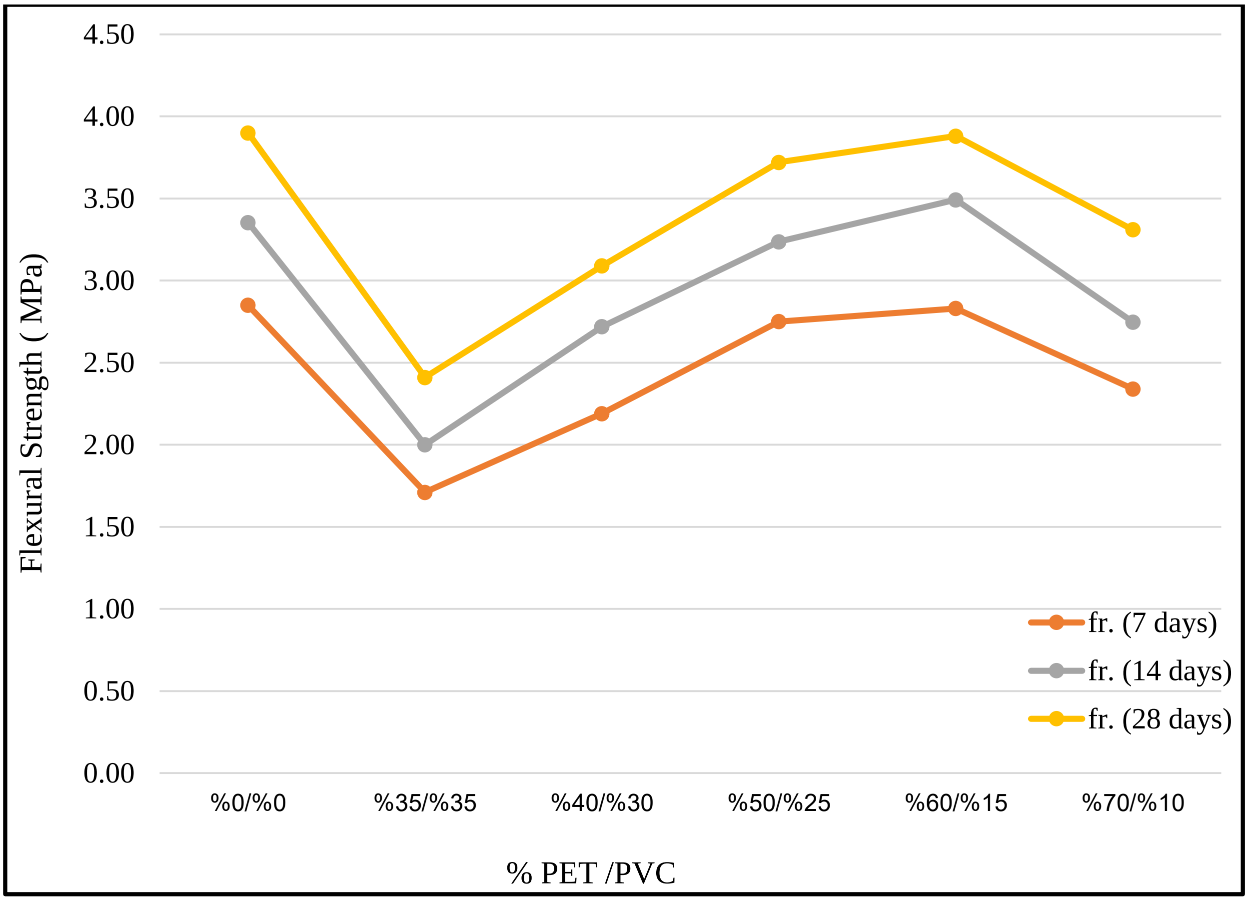


Figure 4.5 Flexural strength results

4.2.3 Results of Physical Properties

4.2.3.1 Density

The density measurements of several PET/PVC combinations at three different age intervals—7 days, 14 days, and 28 days—are shown in the Table 4.5. The results indicated a distinct trend in density change with PET and PVC percentage, the control mix, which contains 0% PET and 0% PVC, has the highest density and is representative of ordinary concrete. This provides a reference point for comparison. In comparison to the control sample, there is a noticeable decrease in density in the second mix (35%, 35%). A decline of more than 17% suggests a significant shift to lightweight concrete.

The third mixture is composed of 40% PVC and 30% PET. The density is nearly reduced by 18% with this combination. This helps achieve the objective of making concrete lighter 25% PET/50% PVC is the fourth replacement proportion. Density decreases with increasing PVC concentration, reaching a nearly 20% reduction. This indicates significant advancements in the field of lightweight concrete 15% PET is included in the fifth batch. The density drops by more than 21% at 60% PVC, indicating that a higher PVC content greatly lowers the weight of the concrete. With the highest PVC content, the final mixture (10%, 70%) has the lowest density, a drop of more than 22%.

This suggests that using larger PVC ratios to produce lightweight concrete works quite well. Lightweight Achievement: The data in Table 4.5 and Figure 4.6 shows that concrete's density is greatly reduced when PET and PVC content are increased. This all comes together to make lightweight concrete.

The combination of 10% PET and 70% PVC produced the lowest density out of all the tested combinations, making it the most viable option for lightweight concrete.

Table 4.5 Results of Density for PET and PVC Percentages Replaced.

Beam ID	Density (ɣ) kg/m^3			Change rate for age 28 days %
	Age 7 days	Age 14 days	Age 28 days	
R	2285.1	2316.777	2288.89	0
B1	1885.592	1875.021	1896.3	-17.152%
B2	1888.535	1894.414	1881.48	-17.799%
B3	1829.864	1837.048	1837.04	-19.741%
B4	1793.314	1813.653	1807.41	-21.036%
B5	1792.812	1773.852	1777.78	-22.330%

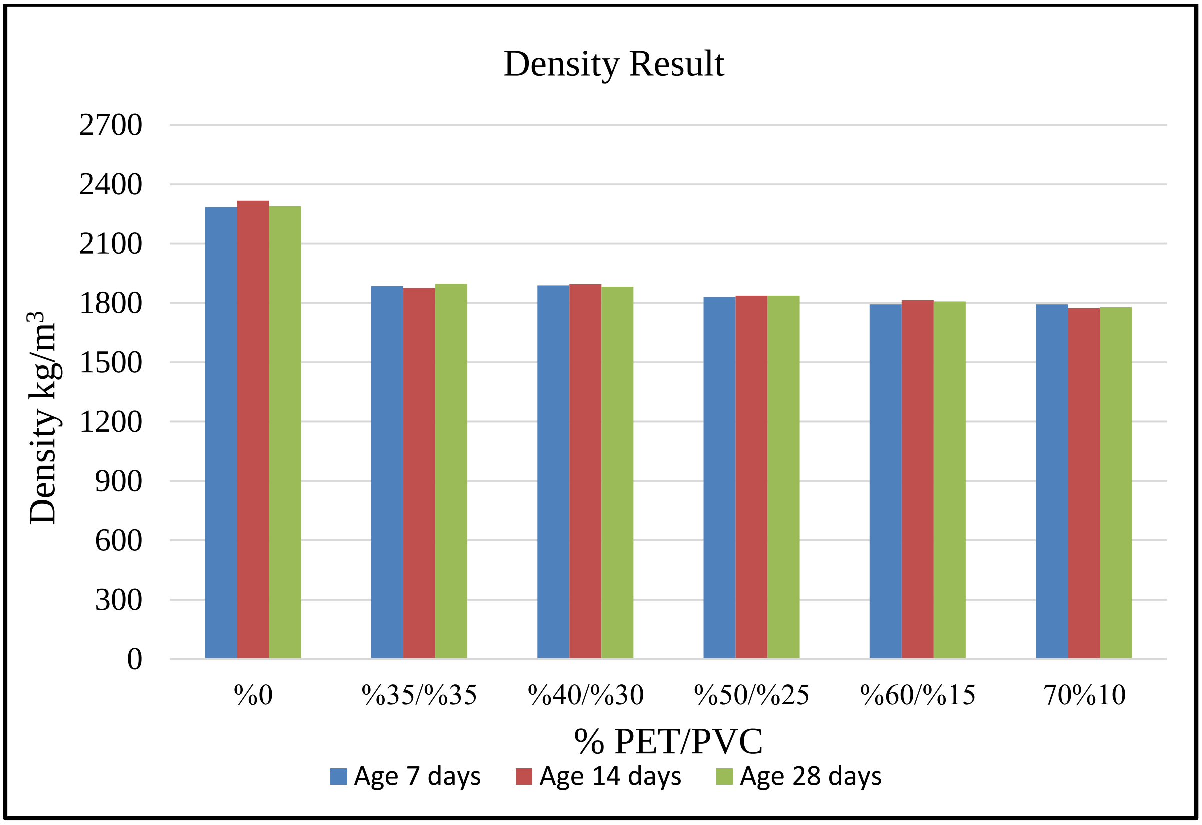


Figure 4.6 Density Result 7, 14 and 28 days

4.2.3.2 Absorption

Analysis was done on the absorption ratio findings in Table 4.6. and Figure 4.7 for various PET and PVC replacement ratios in concrete mixtures as shown in the table. These findings explain how different replacement percentages of PET and PVC impact the concrete's water-absorbing characteristics. In the reference mixture with the Replacement of 0% PET and 0% PVC, the absorption ratio of the control mix is 1.18%, providing a standard against which other mixes comprising PET and PVC substitutes can be assessed. The mix ratio of B1, the absorption ratio of the 35% PET and 35% PVC replacement mix is significantly higher at 1.91%, suggesting a 62.1% increase over the control mix. This implies that the material's ability to absorb water is increased by utilizing the PET and PVC waste in the concrete. For the B2 mixture with the replacement of 30% PET and 40% PVC The replacement ratio is a little different, but the absorption ratio stays at 1.91%.

The modest variance in the percentage change from the prior mix indicates that the absorption characteristics are not greatly affected by a small change in the PET and PVC content. In regard third ratio of B3 which contains the 25% PET & 50% PVC replacement, the absorption ratio drops to 1.72%, indicating that a higher PVC component combined with a lower PET percentage leads to less water absorption. Again the fourth ratio is 15% PET and 60% PVC substitution, the absorption ratio is reduced to 1.62% when the PET content is further reduced and the PVC content is increased to 60%. Since the percentage difference is just 37.1%, it can be concluded that a larger PVC concentration substantially lowers water absorption. Replacement of 70% PVC and 10% PET the change is % 33.6% and this replacement level causes the absorption ratio to rise to 1.57% once more.

This implies that the absorption ratio and the replacement levels of PET and PVC have a nonlinear relationship.

Table 4.6 Absorption results for PET and PVC percentages

Beam ID	**Dry weight (D.W)kg**	**Wet weight (W.W)kg**	**W.W-D.W**	**%Absorption ratio**	**% Changing**
R	7.635	7.725	0.090	1.18%	
B1	6.280	6.400	0.12	1.91%	62.1%
B2	6.231	6.350	0.119	1.91%	62.0%
B3	6.089	6.200	0.111	1.82%	54.6%
B4	6.003	6.100	0.097	1.62%	37.1%
B5	5.907	6.000	0.093	1.57%	33.6%

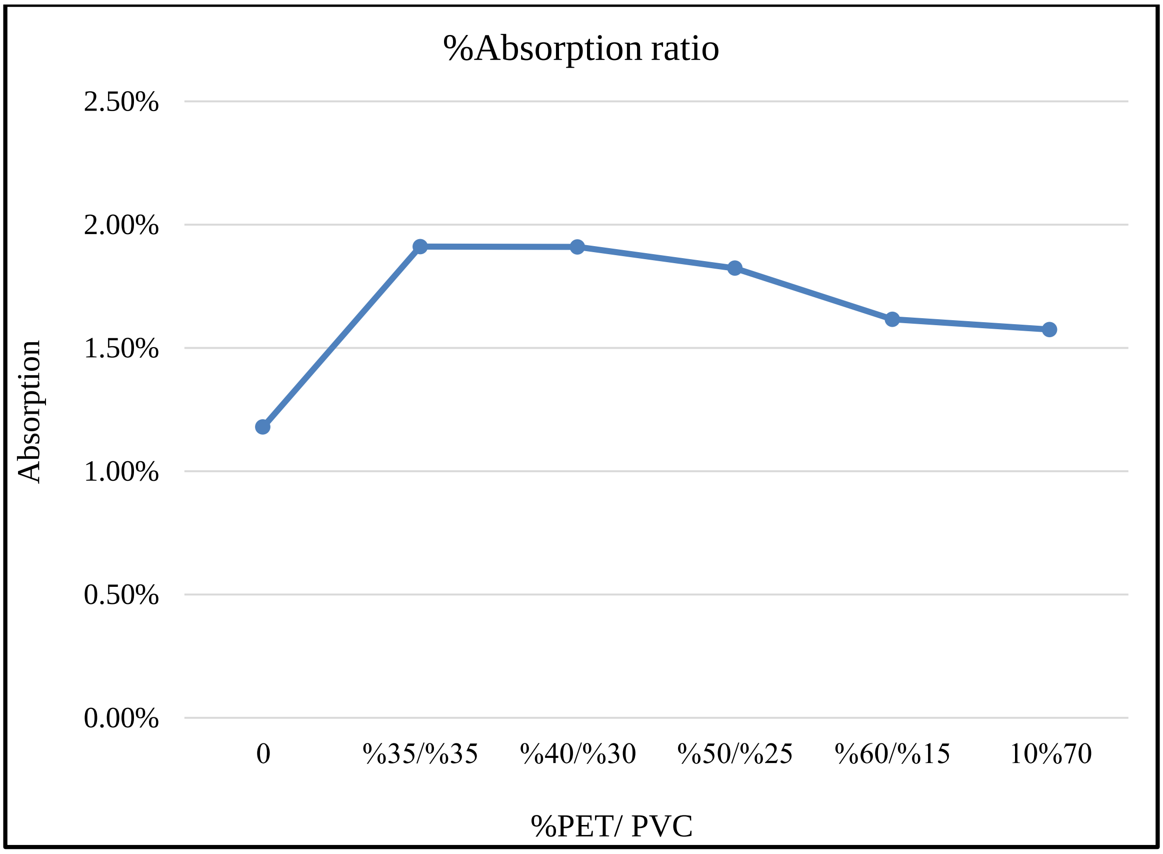


Figure 4.7 Absorption results for PET and PVC percentages

4.2.3.3 Ultrasonic pulse velocity test (UPV)

The results of the Ultrasonic Pulse Velocity (UPV) test for various percentages of PET (Polyethylene Terephthalate) and PVC (Polyvinyl Chloride) as illustrated in Figure 4.8 and Table 4.7, offer critical insights into the impact of these materials on the quality of the concrete mixtures. The UPV values, which measure the speed at which sound waves travel through the concrete, are directly correlated with the material's density, homogeneity, and overall structural integrity. The baseline sample, with no PET or PVC, exhibits the highest UPV, indicating a highly dense and uniform concrete matrix. The very good quality rating suggests that the concrete is free from significant internal defects, with strong bonding and minimal voids. Introducing 35% PET and 35% PVC leads to a marked reduction in UPV, reflecting a decrease in the density and uniformity of the concrete. Despite this reduction, the quality is still classified as good, indicating that the material retains adequate structural integrity, though the presence of PET and PVC may introduce some level of heterogeneity or minor voids. As the PVC content increases to 40%, the UPV continues to decrease, resulting in a medium quality classification. This reduction suggests that the concrete's internal structure may be becoming more porous or less uniformly bonded, likely due to the higher PVC content. At 50% PVC, the UPV further decreases, maintaining a medium quality rating. The close alignment of UPV values across both axes suggests that the distribution of PET and PVC within the concrete is relatively uniform, though the material's overall structural integrity is compromised compared to lower PVC concentrations. With 60% PVC, the UPV drops to the lower end of the medium quality spectrum. This significant reduction in velocity indicates increased internal weaknesses, such as voids or poor bonding, leading to reduced overall material performance. The highest PVC content (70%) combined with the lowest PET content (10%) yields the lowest UPV, categorizing the concrete as poor quality. This substantial decline in velocity is indicative of significant structural deficiencies, likely due to excessive void formation, weakened bonds, or other internal flaws caused by the high PVC content.

Table 4.7 Ultrasonic Plus Velocity results for PET and PVC percentages

Beam ID	Axis1	Axis2	Average	Quality
R	5185	5048	5116.5	Very good
B1	3512	3508	3510	Good
B2	3367	3312	3339.5	Medium
B3	3242	3245	3243.5	Medium
B4	3004	3010	3007	Medium
B5	2879	2742	2810.5	Poor

- Pulse Velocity Range and Quality of Concrete [64]

Above 4500 m/s: Generally indicates excellent quality concrete with good density and homogeneity.

3500 - 4500 m/s: Indicates good quality concrete.

3000 - 3500 m/s: Indicates moderate quality, which may have some defects or lower density.

Below 3000 m/s: Indicates poor quality concrete, potentially with significant voids, cracks, or other defects

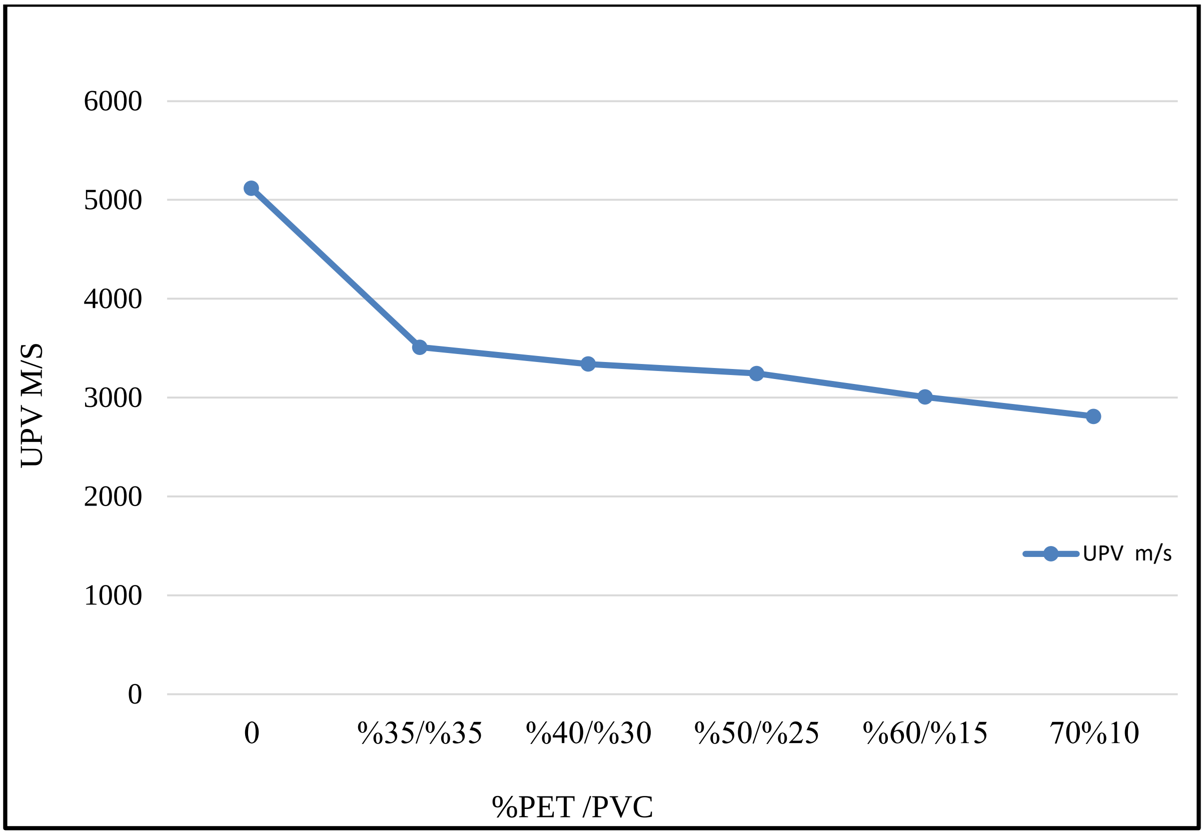


Figure 4.8 Ultrasonic Plus Velocity results for PET and PVC percentages

4.3 Part Two: Structural Behavior of Reinforced Lightweight Concrete Beams Contained Recycled Waste

4.3.1 General Behavior of Lightweight Beams

The study entailed conducting tests on five lightweight reinforced concrete beams, both with and without recycled plastic waste. The recycled plastic waste was composed of various ratios of PET and PVC. These beams were subjected to static stresses until they reached the point of failure during testing, as shown in Figure 4.9 The results demonstrated that the achieved strengths ranged from 141.5 to 164 kilonewtons, with deflection ranging from 30.59 to 61.34 millimeters, The variability in the maximum load capacity was attributed to fluctuations in the replacement ratio. Discussing the results solely in terms of the ultimate load of the beams will not provide a comprehensive understanding of their behavior. Therefore, many computations are employed for the discussion. These calculations accurately depict the beams' behavior in different aspects, including as stiffness, energy absorption, and ductility index.

Figure 4.9 The Lightweight Concrete Beams under the load.

4.3.2 Failure mode

Figure. 4.10 shows the representative failure mode in each beam which is observed during the tests. Flexural failure occurred for the beams that had flexural strength lower shear than strength and the flexural force exceeded the flexural capacity of the beam. Regarding the control beam (R) which was fabricated with normal concrete, at the middle of the beam's span, the first flexural cracks developed. Which widened and extended towards the loading zone. It should be noted that the flexural cracks were less than those of the lightweight concrete beams with PET and PVC. The control concrete beam showed missing shear cracks. Regarding the concrete beams with PET and PVC, the beams showed initiating of small shear cracks which appeared due to the lack of bonding between the concrete particles as a result of the existence of PET and PVC. Flexural cracks first developed at the mid-span with a huge amount. Larger and wider cracks were initiated at the mid-span and the crack size depends on the replacement ratio of the recycled plastic waste. For the beam B1, the crack propagation was higher than those of the normal concrete as seen in Figure 4.10. The concrete beam B2 with replacement ratios of 30 and 40 for PET and PVC showed that the increase of replacement ratio increased the deformation of the damaged zone. Varying the percentage of the PET and PVC affect the deformation and crack mode of the flexural beams, beam B3 revealed that the varying of the PET and PVC to 25 and 50 percent demonstrated that the cracks number was reduced with a reduction in the deformed area due to the increase of PET more than PVC. Beams B4 and B5 which included a higher percentage of PET and PVC showed little wide cracks because of the high percentage of PVC and PET the increase of recycled plastic waste reduced the bonding strength of the concrete.

Side view Crack Width

Top view Bottom view

Figure 4.10 Failure Mode of the lightweight Concrete

4.3.3 Ultimate Load

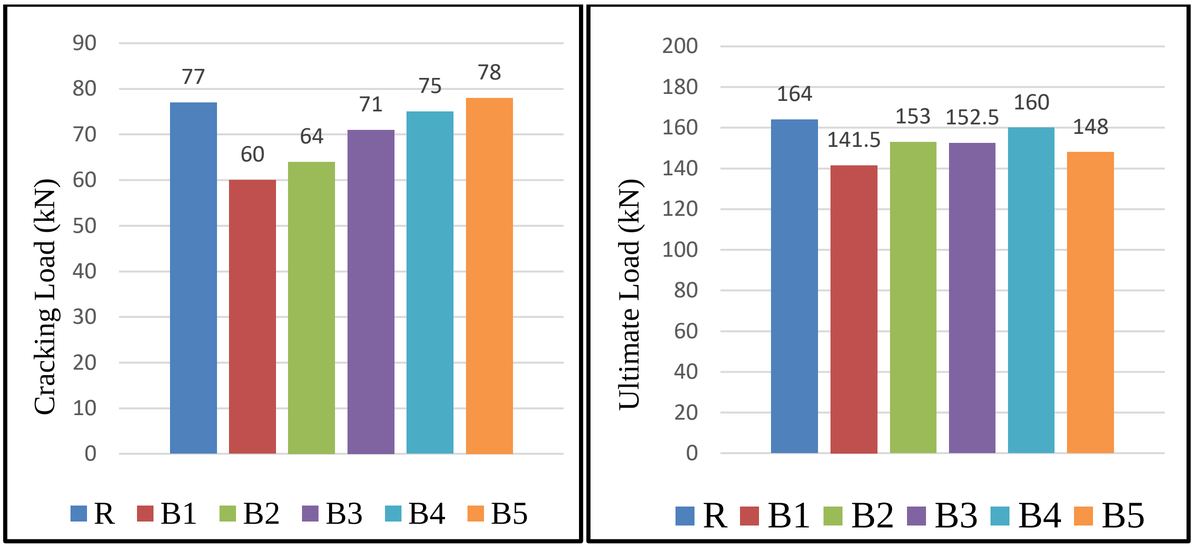
The study found that the replacement ratio of recycled waste significantly influenced the ultimate load-carrying capacity more than the control beam made of conventional concrete. The models exhibited flexural failure at a load of 164 kN, which diminished when fine and coarse aggregates were substituted with recycled plastic waste, specifically PET and PVC. The lightweight beam (B1) produced using a combination of PET and PVC in a 35% ratio showed a reduction in ultimate load to 141.5 kN, which is equivalent to a 13.7% decrease compared to the reference beam (R). The lightweight beam (B2) that was created with a greater replacement ratio of PVC and smaller of PET (30% and 40%) showed a reduction of 6.7% compared to the control beam. The beams B3, manufactured from PVC and PET with replacement ratios of 25% and 50% respectively, showed a decrease in ultimate flexural load of 7%. This load decrease is explained by how the behavior of the RC lightweight beams is affected by the different ratios of replacement with recycled plastic. In beam B4, increasing the PVC content to 60% and reducing the PET content to 15% resulted in improved flexural resistance for the recycled plastic waste lightweight concrete beam, with only a slight reduction of 2.44%. Conversely, in beam B5, with a higher PVC content (70%) and lower PET content (10%), the ultimate flexural strength decreased to 148 kN, representing a reduction of 9.76%, as shown in as demonstrated in Fig. 4.11 B. This indicates that increasing the amount of coarse aggregate at the expense of fine aggregate negatively impacts the ultimate flexural strength when PET content is reduced and PVC content is increased.

4.3.4 The Impact of the Replacement Ratio of Recycled Plastic Aggregate

To examine the effect of the recycled waste replacement ratio, the control beam which fabricated from normal concrete demonstrated that the cracks appeared at 77 kN of the ultimate load which decreased when the fine and coarse aggregate was replaced with recycled plastic waste (PET and PVC). For beam (B1) made with PET and PVC with a ratio of 35% for both of them revealed that the cracking load reduced to 60 kN which is equal to 22% when compared with the reference beam (R). For lightweight beam (B2) which was fabricated with a higher replacement ratio for PVC and a lower ratio for PET (30% and 40%) revealed that the reduction was 16.88% when In contrast to the control beam. Regarding the lightweight beams B3 which are made from PVC and PET of replacement ratio (25% and 50%) exhibited that the cracking load was reduced by 7.79% and the way the regenerated plastic debris was substituted had an impact on how the RC beams behaved. For lightweight beams B4Further reduction in PET and increase in PVC to 60% results in a performance very close to the reference, with only a slight reduction in Pcr by 2.60%. Pcr/Pu ratio of 46.88% suggests that this mix maintains a strong resistance to cracking. and B5 This mixture exhibits a slight increase in Pcr by 1.30%, indicating an improvement in crack resistance over the reference. The higher Pcr/Pu ratio of 52.70% suggests that with 10% PET and 70% PVC, the material is more resistant to cracking relative to its ultimate load, making it potentially more suitable for applications where cracking as demonstrated in Fig. 4.11 A. and Table 4.8.

Table 4.8 The First Crack Results for the lightweight Concrete Beams.

Beam No.	**Pcr (kN)**	**Pu (kN)**	**Pcr/Pu**	**Variation in Pcr %**
R	77	164	46.95%	----
B1	60	141.5	42.40%	-22.08%
B2	64	153	41.83%	-16.88%
B3	71	152.5	46.56%	-7.79%
B4	75	160	46.88%	-2.60%
B5	78	148	52.70%	1.30%



(A) (B)

Figure 4.11 RC beams' ultimate load capacity and cracking.

4.3.5 Load deflection Behavior

Concerning the load-displacement relationship, the normal concrete beam (R) showed higher stiffness than concrete made with recycled plastic waste with comparable ductility as seen in Figure 4.12 and Table 4.9 For beam B1, the curve of the load defection curve was less stiffness than the control one with higher deflection which the increased by 151% which equal to a double value. This increment was due to the existence of the PVC and PET which reduced the bond strength between concrete particles allowing for more deflection in the tension zone. For the lightweight beam B2 with a higher percentage ratio of recycled plastic waste showed more displacement but less than the B1 beam. The increase in the deflection was 165% when compared with the control beam. For beams B3 and B4, the load-deflection curve has comparable stiffness with the control beam which offered evidence of the possibility of use of the plastic waste in the flexural beam. Regarding beam B5, the curve indicated that the high ratio of replacement for the PVC with a decrease in the PET showed a Reduction in stiffness and an increase in deflection by 200%. It should be mentioned that, despite a slight improvement in the final load-carrying capability, the strain hardening observed in the concrete beams formed from recycled plastic wastes is regarded as a good indicator for this kind of concrete since it indicates a greater capacity for deformation.

Table 4.9 Maximum deflection for beams specimens

Beam ID	Pu	Δu (mm)	% Δu
R	164	30.599	-----
B1	141.5	46.312	51.35%
B2	153	50.49	65.02%
B3	152.5	55.31	80.77%
B4	160	58.81	92.22%
B5	148	61.34	100.46%

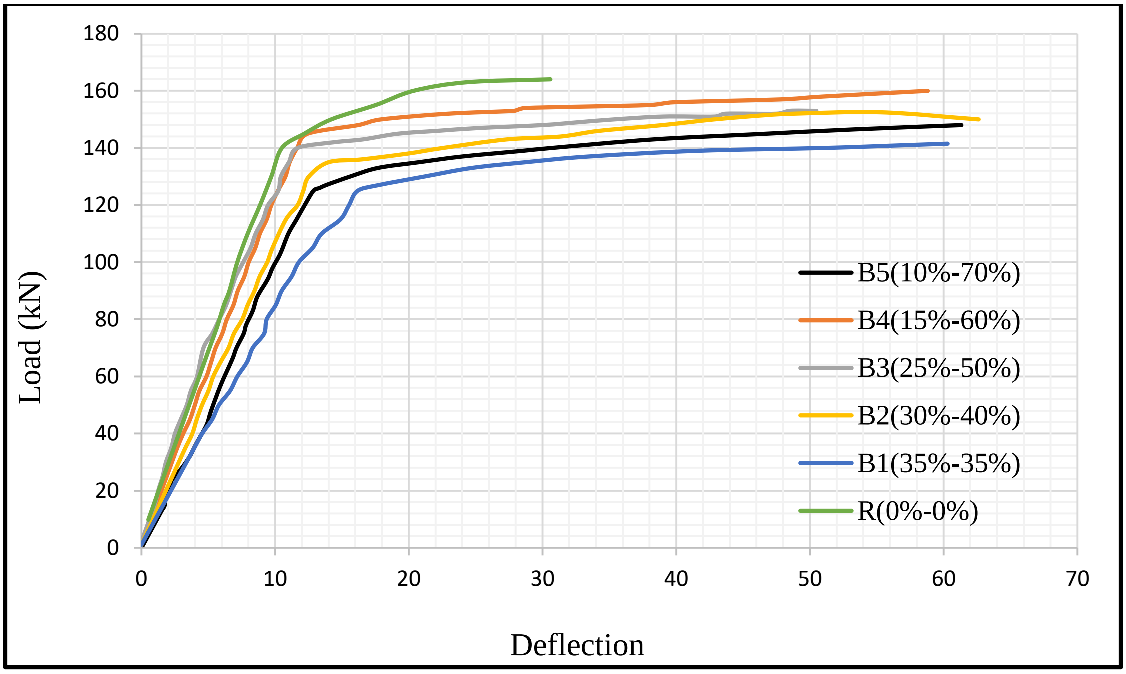


Figure 4.12 load-deflection relationship for LWRC beams.

4.3.6 Ductility Index

The term "ductility index" in relation to concrete refers to the material's ability to tolerate substantial deformation without experiencing sudden failure. Constructions composed of ductile concrete can exhibit visible deformations, such as cracking and bending when exposed to elastic loads. The inclusion of steel fibers is a component that can greatly enhance the ductility of concrete. Therefore, it aids in the control and allocation of cracking, enhances durability, and reduces sudden failure. Ductility can be quantified by determining the ratio between the maximum deflection (Δu) and the deflection at the yield point (Δy) [60]. To examine the impact of the replacement ratio of recycled waste, a control beam made of regular concrete was used.

The ductility of this beam was measured at 4.93532. The ductility altered when the fine and coarse aggregate were replaced with recycled plastic waste, specifically PET and PVC. The beam (B1) constructed using a combination of PET and PVC, with a ratio of 35% for each material, exhibited an improvement in ductility to 5.203, This, when compared to the reference beam (R), represents an increase of 5.44%. The beam (B2) made with a greater replacement ratio (30% and 40%) showed a 6.02% gain over the control beam. It was discovered that the ductility of the lightweight PET and PVC beams, with replacement ratios of 25% and 50%, respectively, was comparable. The variation in the percentage of plastic trash used affected the behavior of the reinforced concrete beams. Beams B4 and B5, which had a higher percentage of replacement ratio of PVC, showed that increasing the amount of recycled coarse aggregate and decreasing the amount of recycled fine aggregate resulted in approximately similar ductility compared to lightweight beams with different percentages of replacement.

However, when the percentage of PVC increased to 70%, the ductility increased by 5.576, which is equivalent to a 12.99% increasing, as shown in Fig. 4.13.and Table 4.10

Table 4.10 Ductility Index

Beam ID	Pu	Δu (mm)	Δy (mm)	D.I	% D.I Changing
R	164	30.59	6.20	4.93	-----
B1	141.5	60.31	8.90	5.20	5.44%
B2	153	50.49	9.65	5.23	6.02%
B3	152.5	55.31	10.20	5.42	9.88%
B4	160	58.81	10.70	5.49	11.38%
B5	148	44.95	11	5.57	12.99%

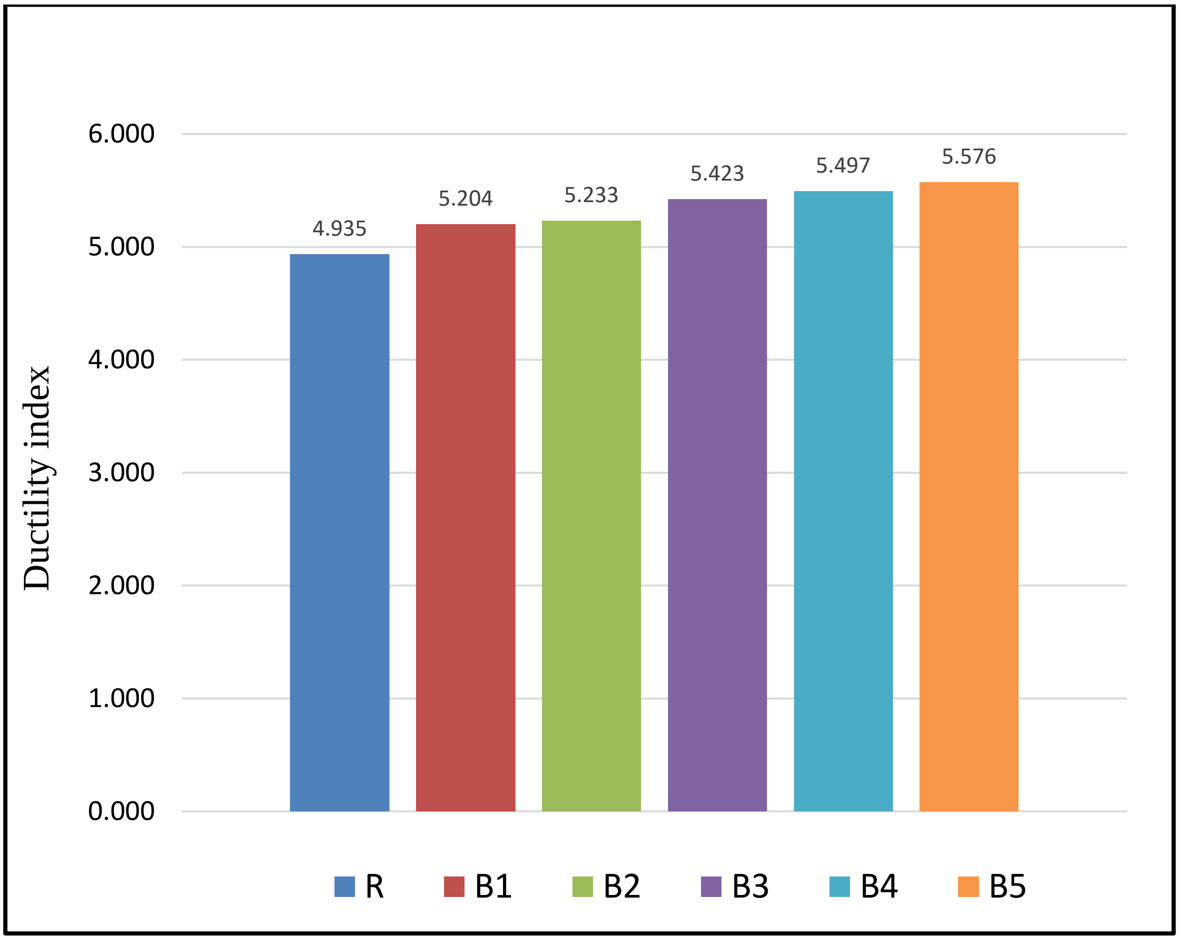


Figure 4.13 Result of ductility index.

4.3.7 Energy Absorption

Calculating the integral of the load-deflection curve is a method that may be utilized to quantify the amount of energy that is absorbed. The findings on the energy absorption are presented in Figure 4.13, respectively. To assess the replacement ratio of the recycled waste, the control beam that was produced from regular concrete indicated that the energy absorption was 3913.23 kN.mm.

This value changed depending on whether the fine and coarse aggregate were replaced with recycled plastic waste (PET and PVC). When the reference beam (R) was compared to the lightweight beam (B1) that was generated using PET and PVC with a ratio of 35% for both of them, it was discovered that the energy absorption increased to 5171.26 kN.mm, which is equivalent to 132% When the control beam was compared to the beam that was created with a higher replacement ratio of PVC and less for PET (30 percent and 40 percent), it was found that the increase was 170%. Regarding the beams B3, which were constructed from PET and PVC with a replacement ratio of twenty-five and fifty percent respectively, it was observed that the energy absorption was equivalent to 180%.

Furthermore, the behavior of the RC beams was affected by the fluctuation in the amount of fine and recovered plastic debris. The energy absorption of the lightweight beams B4 and B5, which have a higher percentage of PVC replacement ratio, was enhanced by an increase in the coarse aggregate due to the fine aggregate. This was observed at two approximate percentages.

This was the sole exception to the rule. The energy absorption was diminished by 7641.43 kN.mm, which is equivalent to 11.3%, when the PVC was increased to 70%, as illustrated in Figure 4.14 and Table 4.11.

Table 4.11 The Energy Absorption Results

Beam ID	Energy Absorption kN.mm	% Energy Abs.
R	3913.23	----
B1	5171.26	132.1%
B2	6650.69	170.0%
B3	7040.97	179.9%
B4	8113.67	207.3%
B5	7641.43	195.3%

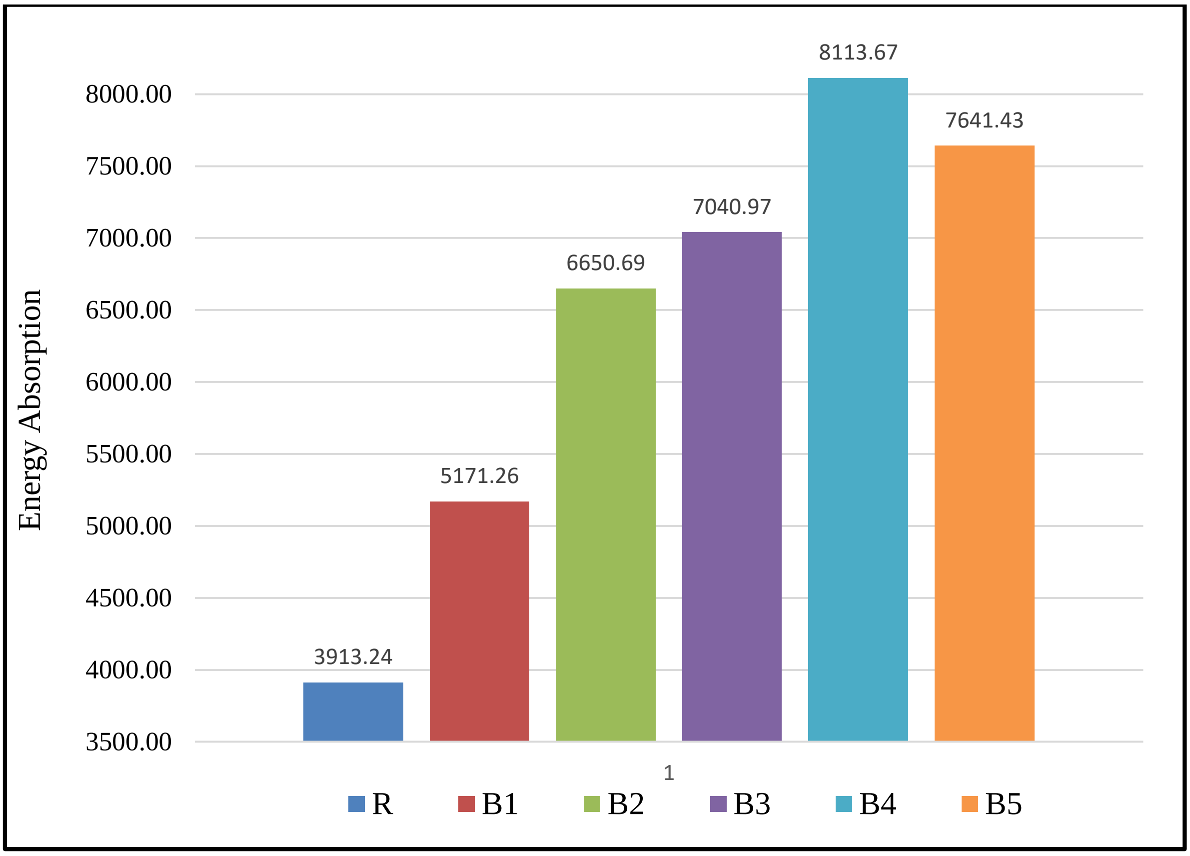


Figure 4.14 Energy absorption

4.3.8 Initial Stiffness

A material's initial stiffness can be described by its load-deflection curve slope. To calculate it, take the yield load (Py) and divide it by the yield deflection (Δy) [61]. Results for the starting stiffness are shown in Figure 4.13. The control beam, made of regular concrete, had an initial stiffness of 24.2 kN/mm and became less stiff after having the fine and coarse aggregates replaced with recycled plastic waste (PET and PVC), allowing researchers to examine the impact of the recycled waste replacement ratio. The initial stiffness decreased to 14 kN.mm, or 58%, when compared to the reference beam (R) for beam (B1) produced of PET and PVC at a 35% ratio for both materials. Compared to the control beam, a 59.7% reduction was seen for lightweight beam (B2) that was manufactured with a higher replacement ratio of 30% and 40%. Beams B3 and B4, constructed from a mixture of PET and PVC at a 25% and 50% replacement ratio, respectively, showed that the RC lightweight beams' behavior was impacted by the variance in the fine and coarse plastic waste, even though their beginning stiffness was comparable. Beams B5 with a larger replacement percentage resulted in a 50.7% reduction in initial stiffness, as shown in Fig. 4.15 and Table 4.12.

Table 4.12 The Initial and Secant Stiffness Results

Beam	Initial stiffness kN/mm	Variation in initial stiffness %	Secant stiffness kN/mm	Variation in secant stiffness %
R	24.19		5.35	----
B1	14.04	58.05%	3.05	57.01%
B2	14.50	59.97%	3.03	56.53%
B3	13.72	56.73%	2.75	51.44%
B4	13.55	56.01%	2.72	50.76%
B5	12.27	50.73%	2.41	45.02%

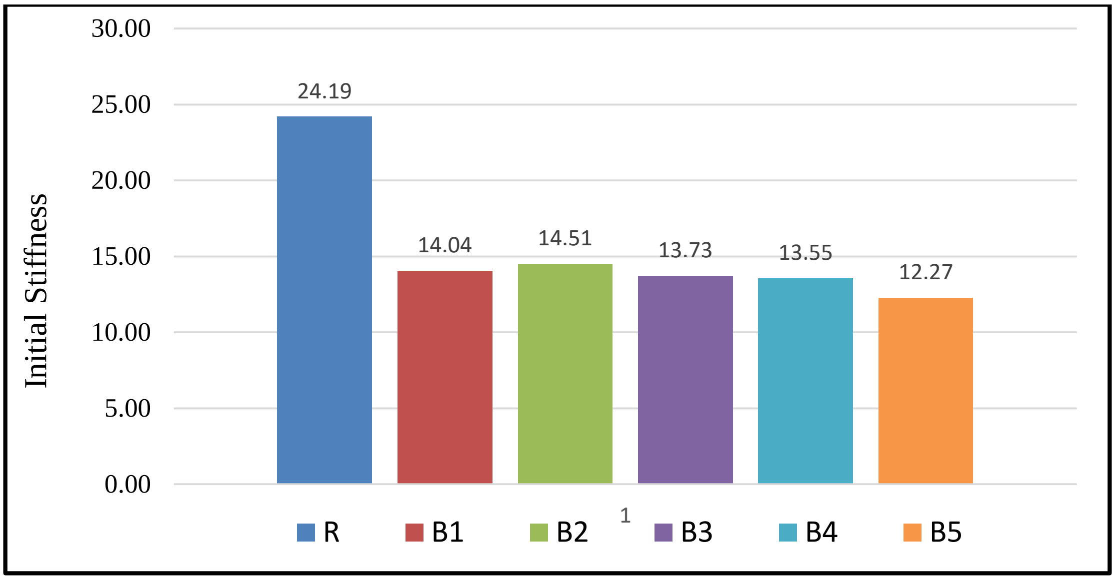


Figure 4.15 Initial stiffness.

4.3.9 Flexural Compression and tension Strain at Failure Load

Figure 4.16, which illustrates the compressive strain in the concrete beams from this study, provides valuable insights into the behavior and stress distribution of the beams. The reference beam shows higher load capacity and reduced compressive strain at the midpoint, with lower stress in the compression zone. In contrast, beams containing recycled materials exhibit reduced load capacity and significantly higher compressive strain, reaching up to 200% of that in the reference beam (R), exceeding the maximum strain limit for concrete. This is attributed to the lower stiffness, weaker bonding, and higher deformability of PET and PVC aggregates, which lead to greater deformation under load. The weaker bond with the cement matrix and the more ductile nature of the recycled materials further increase strain, highlighting their impact on the structural performance of the beams.

In Figure 4.17, the tension strain results in the reference beam experiencing the lowest strain and stress compared to the other beams. This is due to the decrease in compressive strength caused by the addition of PET and PVC material. Consequently, the strain gauge reading rises, the load capacity falls, and the tensions along the beams increase. The study found that beams with unbalanced material replacement had the lowest load resistance and experienced early failure, as seen in beams B5 and B1.

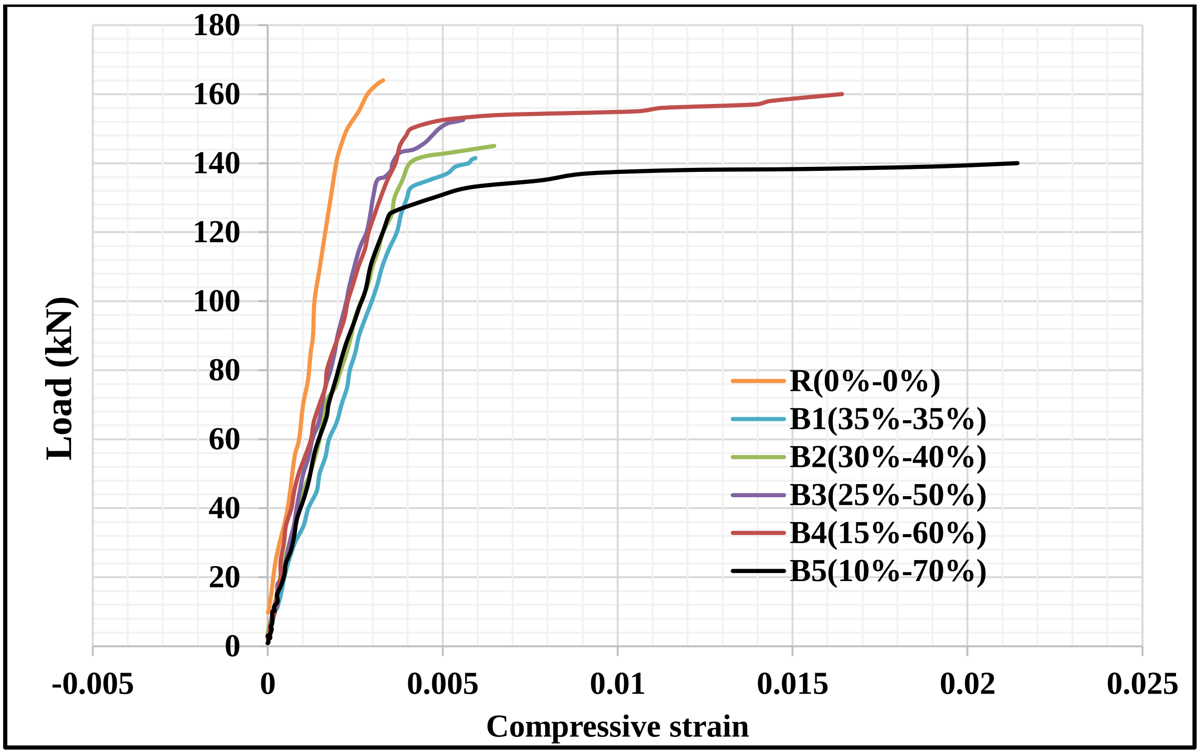


Figure 4.16 Compression strains

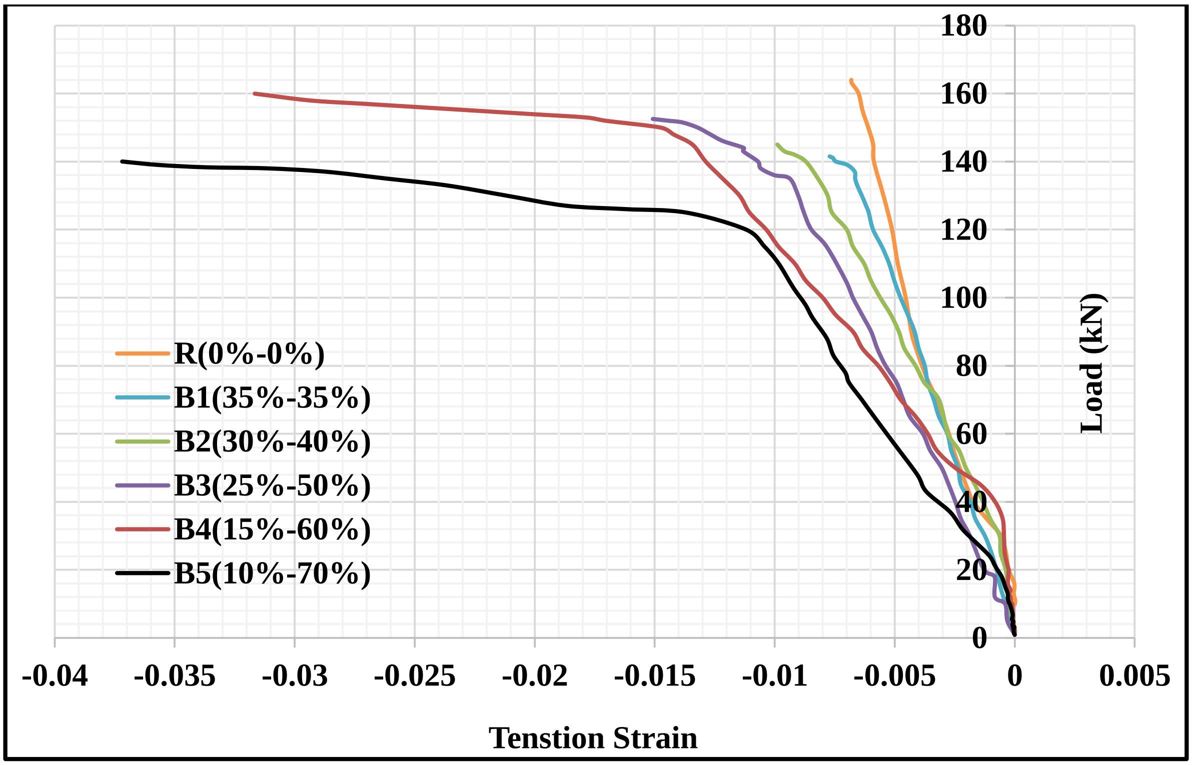


Figure 4.17 Tension strains

However, sample B4's tension strain and stress significantly increased, exceeding the concrete's maximum limit. This implies that the addition of the replacement material improved the concrete's mechanical characteristics in both tension and compression. The shear strain behavior of the beams, as shown in Figure 4.18, further demonstrates this. On the behavior and mode of failure of the beams, certain conclusions can be drawn. The results indicate that the strain did not reach 0.003, suggesting that the failure is not due to shear, except for the reference beam in the later stages. Additionally, the shear resistance improved when PET and PVC materials were used, as they absorbed the stresses. The strain gauge readings showed that beams B4 and B2 performed the best

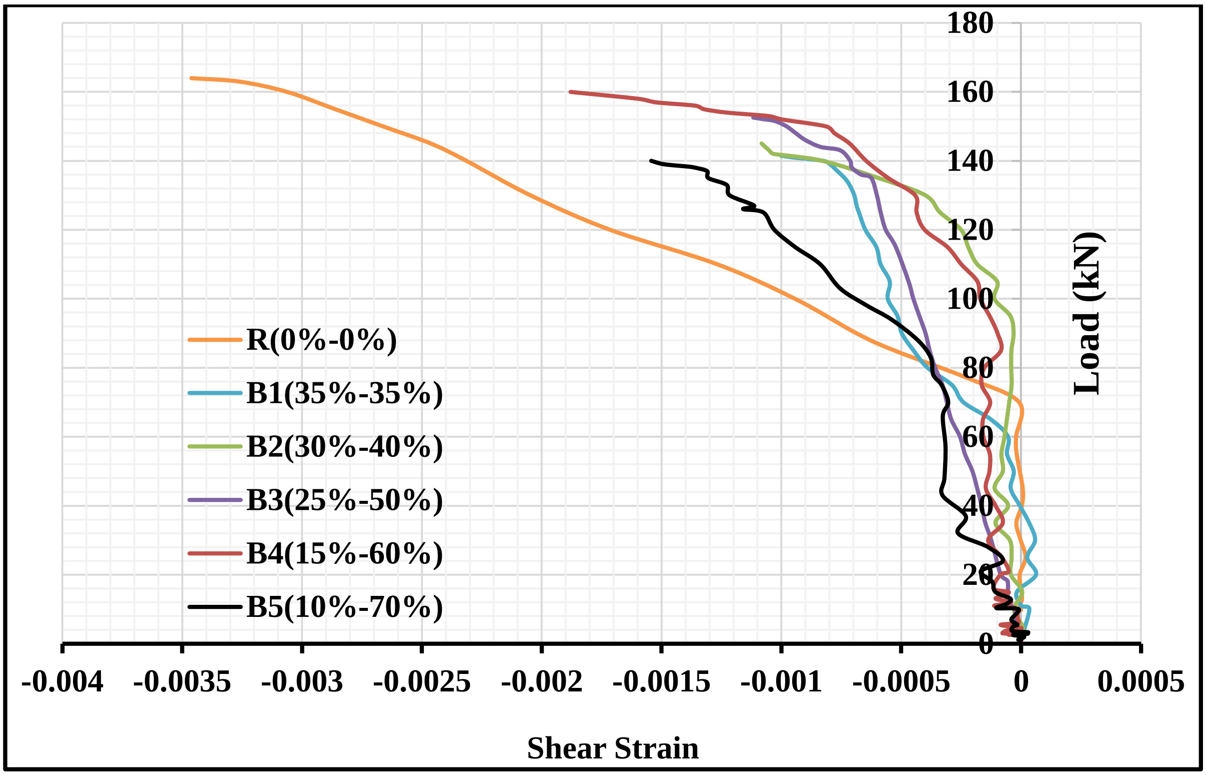


Figure 4.18 Shear strains

To achieve a thorough understanding of the impact of different replacement percentages, it is necessary to analyze the strains in the beams individually. This can be achieved by plotting strain-type curves for several scenarios in the same figures, as depicted in Figures 4.19-4.24. This approach allows for the extraction of distinct findings.

Figure 4.19 displays the strain curves of the reference beam, specifically highlighting the highest value in the tension region, which indicates the beam's flexural behavior. Furthermore, it is important to mention that the shear strain occurred following the initial formation of the first fracture, and the subsequent characteristics are associated with the typical process of strain formation in the concrete beam.

The initial beam, with a composition of 35% PET tension strain and 35% PVC compression strain, had a minor alteration in tension strain. However, significant improvement was observed in shear strain and additional strain in the compression zone, in comparison to the reference beam, as depicted in Figure 4.20.

The beam with a composition of 30%-40% waste material exhibits a much higher tension strain of 350% compared to the reference material. However, it experiences a decrease of 69% in shear strain, indicating the impact of the waste material utilised. Additionally, there is a slight alteration in the compression zone when comparing it to the reference beam, as depicted in Figure 4.21.

The beams B3 and B5 experienced a similar increase in enhancement in relation to tension and shear strains, with tension strains increasing by 145% to 545% and shear strains decreasing by 69% to 55%. However, in terms of compression, the rate of change was lower compared to the strain gauge reading of the reference beam in the study. On the other hand, beam B4 showed lower results due to a higher percentage of PVC replacement, resulting in reduced load capacity and lower strain compared to the other beams, as depicted in Figures 4.22 and 4.24 respectively.

However, Figure. 4.23 illustrates that the beam with a (15%-60%) composition achieved superior results compared to the reference beam in terms of compression, shear, and tension strains. The tension strains were enhanced by 465% and there was a significant improvement in shear resistance.

Upon analyzing Beam B3 in Table 4.16, it is apparent that the first crack load (Pcr) is 71 kN, and the ultimate load (Pu) reaches 152.5 kN. Upon analyzing the strain data, it is observed that at 20% of the ultimate load (30.5 kN), the compression strain at the top side is measured to be 0.0013, while the tension strain at the bottom side is recorded as -0.0019. As the load increases, the Strain gauge measurement gradually climbs, showing favorable ductility and yielding behavior. At the maximum load of 100%, the compression strain achieves a peak value of 0.0083, while the tension strain reaches a minimum value of -0.0151. Significantly, the neutral axis, originally positioned 100 mm from the top, moves downwards to 88.4 mm when subjected to full load.

This shift indicates alterations in the distribution of internal stress as the beam experiences greater deformation due to tension. Beam B4 demonstrates a marginally distinct behavior, as illustrated in Table 4.17. The beam's initial fracture load is measured at 75 kN, while its ultimate load is 154 kN. At 20% of the maximum load (32 kN), the compression strain is 0.0011, and the tension strain is -0.0011. The Strain gauge reading steadily increases when the load is applied, and when the load reaches 96% of its maximum capacity, the compression strain abruptly rises to 0.0150, while the tension strain increases to -0.0288. The displacement of the neutral axis in Beam B4 is more significant compared to B3, with a movement from 129.9 mm to 85.8 mm occurring as the load increases. This notable change signifies a major redistribution of stress inside the beam, indicating that Beam B4 experiences considerable deformation when subjected to high loads, resulting in an increasing strain in the tension zone.

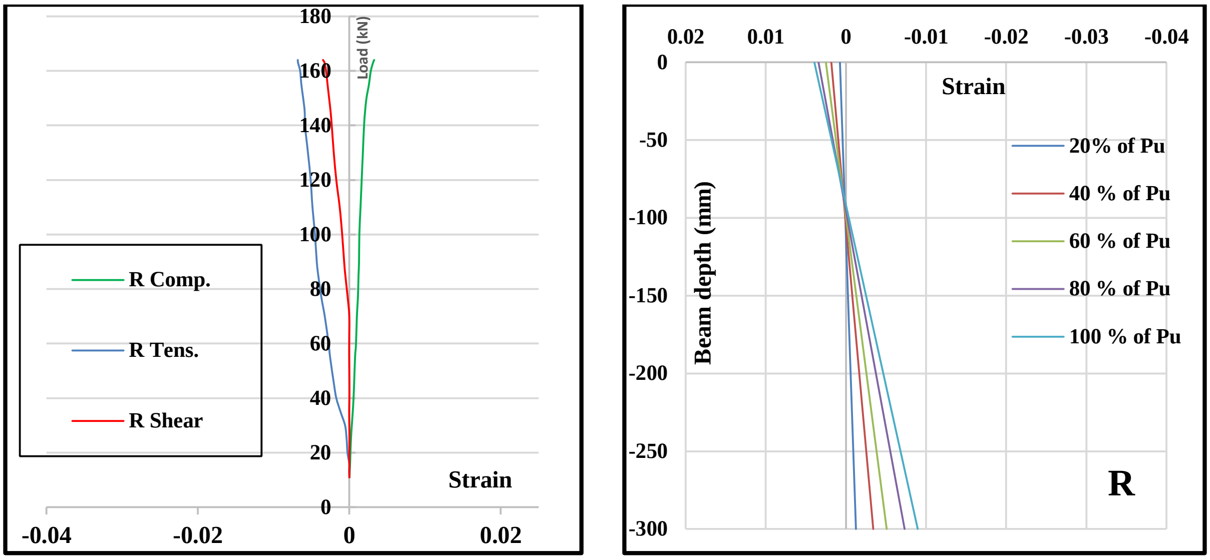
Upon examining Beam B5, Table 4.18, the investigation determined that its initial crack load is 78 kN, and it has the capacity to withstand an ultimate load of 126 kN. At 20% of the maximum load (28 kN), the compression strain is

0.0012, and the tension strain is -0.0016. As the load increases, the readings of these Strain gauges also increase. The compression strain reaches 0.0086 and the tension strain reaches -0.0162 at 90% of the ultimate load. The neutral axis, which was originally positioned at 109 mm, has shifted to 86.5 mm, suggesting a moderate redistribution of load in comparison to the other beams. Beam B5 exhibits a significant rise in strain when subjected to heavier loads, resembling the behavior of Beam B3, albeit with slightly lower peak strain values.

Overall, these beams' behavior under loads can be better understood by examining them. As the load increases, the neutral axis of all beams shifts downward, indicating greater deformation and stress redistribution in the tension zone. The strain behavior exhibits a linear correlation with the applied load, although the rates of growth and maximum strain values varied among the beams, indicating variations in material properties. Out of all the beams, B4 has the highest strain values at ultimate load, indicating greater ductility. Furthermore, Beam B4 has the highest ultimate load capacity of 160 kN, signifying its greater ability to withstand loads in comparison to Beams B3 and B5.

The remaining beams results are illustrated in Tables (4.13, 4.14 and 4.15) and show similar behavior with lower strains, and for lowest strains appears in the reference beam.

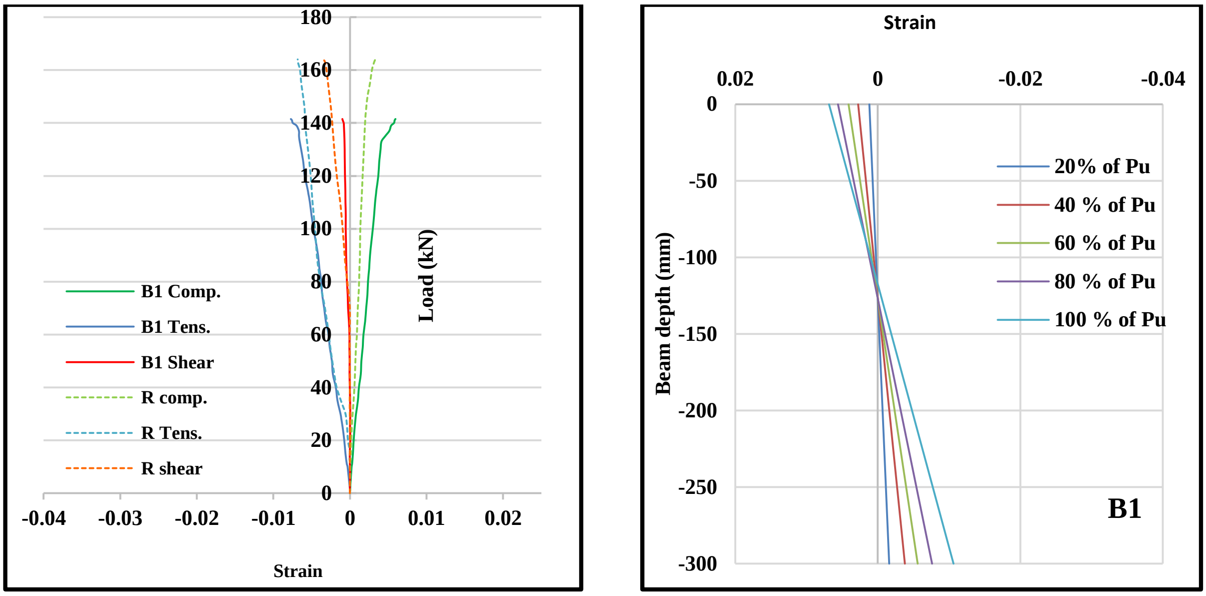
The strain gauge measurement provides a clear indication of both the strain and the presence of a crack in the tension zone, occurring after the elastic range.



a- Load-Strain Curve

b- Strain diagram through the depth

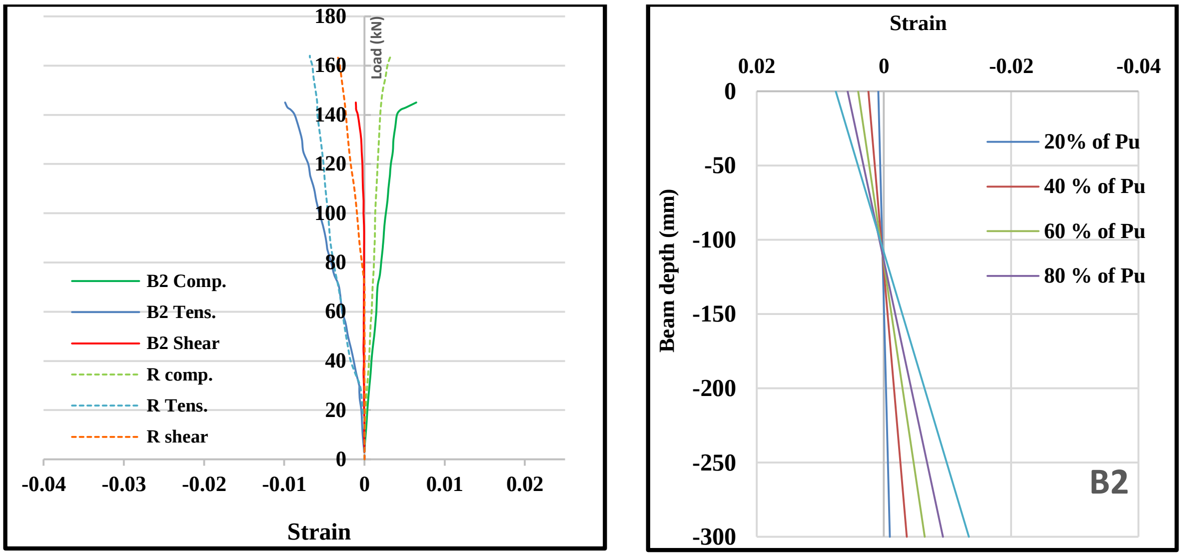
Figure 4.19 Load-Strain curves for beam R



a- Load-Strain Curve

b- Strain diagram through the depth

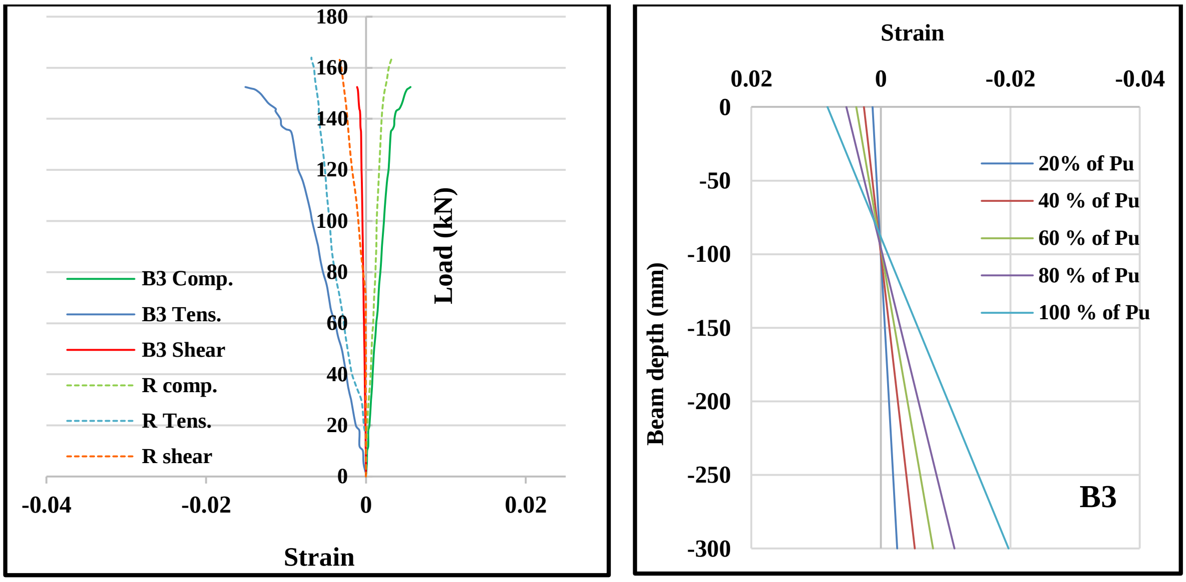
Figure 4.20 Load-Strain curves for beam B1



a- Load-Strain Curve

b- Strain diagram through the depth

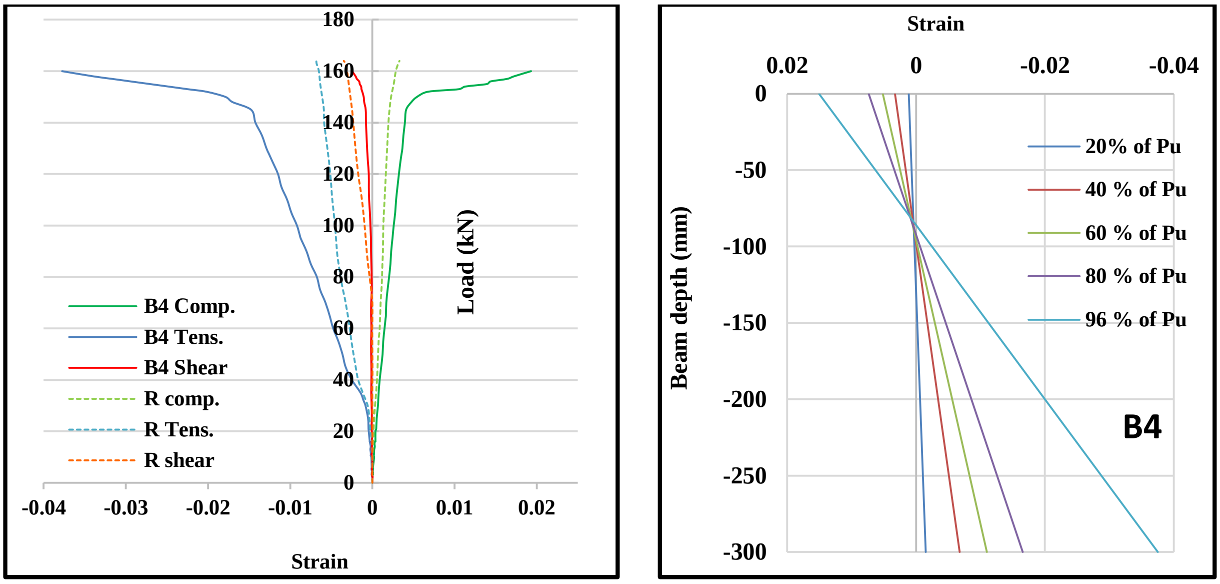
Figure 4.21 Load-Strain curves for beam B2



a- Load-Strain Curve

b- Strain diagram through the depth

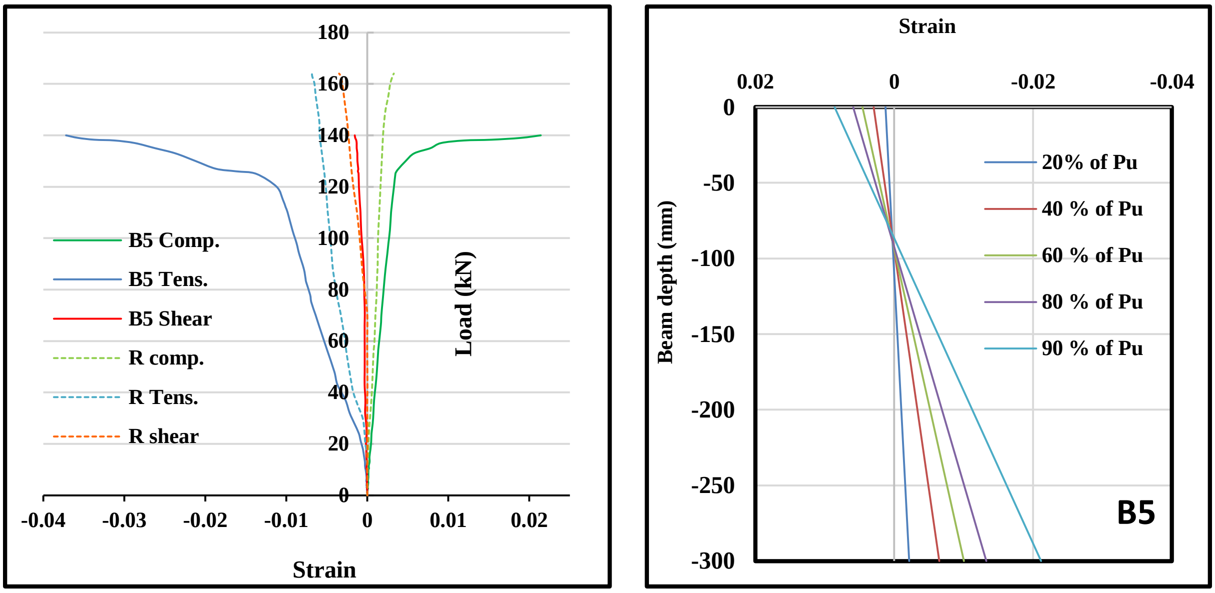
Figure 4.22 Load-Strain curves for beam B3



a- Load-Strain Curve

b- Strain diagram through the depth

Figure 4.23 Load-Strain curves for beam B4



a- Load-Strain Curve

b- Strain diagram through the depth

Figure 4.24 Load-Strain curves for beam B5

Table 4.13 Experimental results of load and strain for beam R

Beam No.	Pcr (kN)	% 0f Pu	Level of loads (kN)	Top side	Compression Strain gauge	Tension Strain gauge	Bottom Side	Measured NA from Top (mm)
R	77	20%	32.8	0.0007	0.0004	-0.0009	-0.0012	111.9
		40 %	65.6	0.0018	0.0010	-0.0025	-0.0034	105.0
		60 %	98.4	0.0025	0.0012	-0.0038	-0.0051	98.8
		80 %	131.2	0.0034	0.0016	-0.0055	-0.0073	95.4
		100 %	164	0.0040	0.0018	-0.0068	-0.0090	91.8

Table 4.14 Experimental results of load and strain for beam B1

Beam No.	Pcr (kN)	% 0f Pu	Level of loads (kN)	Top side	Compression Strain gauge	Tension Strain gauge	Bottom Side	Measured NA from Top (mm)
B1	60	20%	28.3	0.0012	0.0007	-0.0011	-0.0016	126.9
		40 %	56.6	0.0028	0.0017	-0.0027	-0.0038	126.9
		60 %	84.9	0.0041	0.0025	-0.0040	-0.0056	126.9
		80 %	113.2	0.0056	0.0034	-0.0054	-0.0076	126.9
		100 %	141.5	0.0068	0.0039	-0.0077	-0.0106	117.5

Table 4.15 Experimental results of load and strain for beam B2

Beam No.	Pcr (kN)	% 0f Pu	Level of loads (kN)	Top side	Compression Strain gauge	Tension Strain gauge	Bottom Side	Measured NA from Top (mm)
B2	64	20%	30	0.0009	0.0006	-0.0006	-0.0009	147.3
		40 %	61	0.0024	0.0014	-0.0026	-0.0036	121.0
		60 %	91	0.0040	0.0023	-0.0047	-0.0064	115.9
		80 %	122	0.0057	0.0032	-0.0068	-0.0093	113.9
		100 %	153	0.0076	0.0041	-0.0099	-0.0134	108.3

Table 4.16 Experimental results of load and strain for beam B3

Beam No.	Pcr (kN)	% 0f Pu	Level of loads (kN)	Top side	Compression Strain gauge	Tension Strain gauge	Bottom Side	Measured NA from Top (mm)
B3	71	20%	30.5	0.0013	0.0006	-0.0019	-0.0025	100.0
		40 %	61	0.0026	0.0013	-0.0039	-0.0052	100.0
		60 %	91.5	0.0038	0.0018	-0.0061	-0.0081	96.2
		80 %	122	0.0054	0.0026	-0.0086	-0.0114	96.0
		100 %	152.5	0.0083	0.0036	-0.0151	-0.0197	88.4

Table 4.17 Experimental results of load and strain for beam B4

Beam No.	Pcr (kN)	% 0f Pu	Level of loads (kN)	Top side	Compression Strain gauge	Tension Strain gauge	Bottom Side	Measured NA from Top (mm)
B4	75	20%	32	0.0011	0.0007	-0.0011	-0.0015	129.9
		40 %	64	0.0033	0.0016	-0.0051	-0.0068	97.9
		60 %	96	0.0052	0.0025	-0.0083	-0.0110	95.9
		80 %	128	0.0073	0.0034	-0.0126	-0.0166	92.1
		96 %	154	0.0150	0.0063	-0.0288	-0.0375	85.8

Table 4.18 Experimental results of load and strain for beam B5

Beam No.	Pcr (kN)	% 0f Pu	Level of loads (kN)	Top side	Compression Strain gauge	Tension Strain gauge	Bottom Side	Measured NA from Top (mm)
B5	78	20%	29.6	0.0012	0.0007	-0.0016	-0.0022	109.0
		40 %	59.2	0.0030	0.0014	-0.0049	-0.0065	94.0
		60 %	88.8	0.0046	0.0021	-0.0076	-0.0100	93.8
		80 %	118.4	0.0059	0.0027	-0.0101	-0.0133	92.3
		90 %	133.2	0.0086	0.0036	-0.0162	-0.0211	86.5

CHAPTER FIVE: CONCLUSION & RECOMMENDATION

In this study, comprehensive investigation was performed to investigate the effect of the plastic waste on the stress and stain characteristics of flexural RC beams. The conclusions of the study

5.1 Conclusion

1. The inclusion of PET and PVC in the concrete mix effectively reduces its density and leads to a reduction in the weight of concrete, resulting in lightweight concrete with a negligible drop in the ultimate compression strength. The mixture with 10% PET and 70% PVC shows the most significant reduction in density.
2. The use of PET and PVC material improves some attributes of concrete, such as shear resistance, at all levels of replacement.
3. The incorporation of recycled plastic wastes into the lightweight concrete beams resulted in a redistribution of the internal stresses, which in turn influenced the ultimate strength, load-carrying capacity, ductility, and energy absorption of the concrete members.
4. The 10% PET and 70% PVC replacement ratio demonstrated the most favorable outcomes in terms of compression, shear, and tension strains. Specifically, tension strains improved by 554%, and there was a notable enhancement in shear resistance, indicating a substantial overall benefit in the mechanical performance of the concrete with this mix ratio.
5. The slump values show a trend of slightly improving workability as the PET content decreases and PVC content increases, but overall, any combination with these materials significantly reduces the workability compared to the control mix.

6. A decrease in the bonding strength between the concrete particles was brought about as a consequence of the presence of PVC and PET materials, which led to an increase in the amount of deflection.
7. The UPV test results demonstrate a clear trend: as the percentage of PVC in the concrete mixture increases, the UPV values decrease, leading to a corresponding decline in material quality. While PET also influences these outcomes, its impact appears less pronounced compared to PVC.
8. As the amount of PET falls and PVC increases, the beams' resistance to the initial break improves. The sample containing 10% PET and 70% PVC exhibits the best crack resistance performance, outperforming the reference sample. Higher PET concentration, on the other hand, tends to diminish the beam's cracking resistance, making those blends unsuitable for applications where early cracking could jeopardize structural integrity.
9. The ductility and energy absorption were affected by the used variables and the ductility decreased especially when the replacement ratio increased to 70%.
10. Despite these differences, the strain hardening observed in the recycled plastic waste concrete beams is a good indicator, implying that this type of concrete has a higher capacity for deformation, which could be useful in some applications. This finding lends credence to the use of recycled plastic waste in concrete, especially in applications requiring enhanced deformability.

5.2 Recommendations

1. Study different type of structural members such as slabs, columns, spandrel beams in order to observe the punching shear, torsion resistance and other forces effect
2. Study the shear resistance in the beams and other members which is not fully covered in the present thesis.

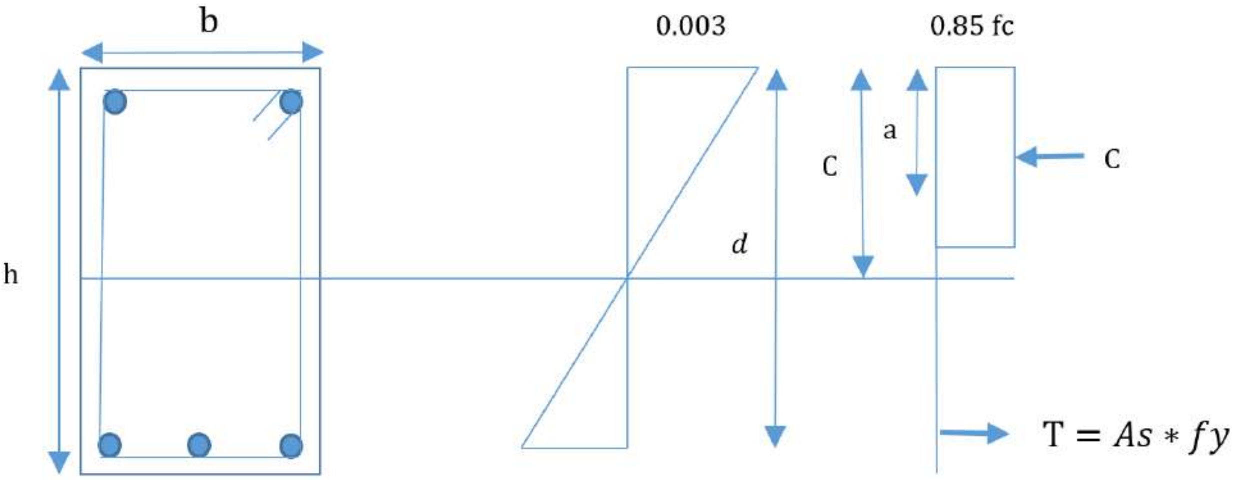
3. Applying Finite Element Analysis to fully understand and deep investigate the internal part behavior and elements that are not obvious for the researcher and difficult to reach in the real world
4. Investigate the impact of these materials on cracking patterns, load-bearing capacity, and deformation under different loading conditions.

APPENDICES

APPENDIX A

Flexural reinforcement for LWC

Beam LWC were designed according to ACI318-14 Code. The steps of analysis of the reference beam as follows:



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

$d = h - cover - ds - db/2$

Let concrete cover = 25 mm.

So, d =300-25-10-6= 259 mm

$As = 3 * \frac{\pi}{4} * d^2 = 339.3$

$\therefore \rho = 339.3/150 * 259 = 0.0087$

$\because \rho_{max} = 0.75 * \rho_b = 0.75 * \left[0.85\, \beta 1 * \frac{f`c}{fy} * \frac{600}{600+fy} \right]$

$\beta_1 = 0.85$ for 17 > f `c > 25 MPa

∵ Concrete strength f`c equal to 23.15 MPa and yield strength of reinforcement equals 568 MPa

∴ $\beta_1 = 0.85$

∴ $\rho_{max} = 0.0113$

∵ $\rho < \rho max$

∴ Ignore the compression reinforcement and analysis as simply reinforced beam

∵ $\rho = 0.0087$

And $\rho b = 0.85\, \beta 1 * \frac{f`c}{fy} * \frac{600}{600+fy} = 0.015$

So, $\rho < \rho b$

From Whitney Block

C = T

∴ $0.85 * f`c * b * a = As * fy$

∴ $a = 65.3\, mm$

∵ $Mn = C\,(d - a/2) = 0.85 * f`c * b * a * (d - a/2) = 40.73\, kN.m$

$ML = Mn - Md$

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

$Wu = 1.2 * Wbeam = 1.2 * density * volume$

$= (1.2 * 2289 * 0.15 * 0.3 * 2.3) * 9.81 * 10 - 3 = 2.79\, kN$

$Md = 2.79 * 2.32\ /8 = 1.85\, kN.m$

$ML = 40.73 - 1.85 = 38.88\, kN.m$

$$ML = \frac{p}{2} * 0.66$$

∴ $P_{flexural} = 117.8\, kN$

APPENDIX B

BUILDING TRUST

PRODUCT DATA SHEET

Sika® ViscoCrete®-180 GS

Set retarding, high range water reducing & superplasticizing admixture

DESCRIPTION

Sika® ViscoCrete®-180 GS is a Set retarding, high range water reducing & superplasticizing admixture for Concrete & Mortar utilizing Sika's 'ViscoCrete®' polycarboxylate polymer technology **(3rd Generation)** .

USES

1. High-performance Concrete (HPC).
2. Flowing Concrete.
3. Durable Concrete.
4. Pumped Concrete.

CHARACTERISTICS / ADVANTAGES

1. High water reduction, resulting in higher density, higher strength and reduced permeability.
2. Easier and faster pumping of concrete.
3. Increased workability and easier placeability.
4. Increased concrete durability and uniformity.
5. Reduced shrinkage and cracking.
6. Reduced rate of carbonation of the concrete.

PRODUCT INFORMATION

Composition	Aqueous solution of modified **polycarboxylates**
Packaging	1000 LTRs IBC 20 kg Pail
Shelf life	12 months from date of production if stored properly in undamaged unopened, original sealed packaging.
Storage conditions	In dry conditions at temperatures between +5°C and +35°C. Protect from direct sunlight. It requires recirculation when held in storage for extended periods.
Appearance and colour	Light brownish
Specific gravity	1.070 ± (0.02) g/cm3
pH-Value	4 - 6

TECHNICAL INFORMATION

Concreting guidance	The standard rules of good concreting practice, concerning production and placing, are to be followed. Laboratory trials shall be carried out before concreting on site, especially when using a new mix design or producing new concrete components. Fresh concrete must be cured properly and curing applied as early as possible.

APPLICATION INFORMATION

Recommended dosage	**(0.5 % - 2 %) by weight of total cementitious materials.**
Dispensing	Sika® ViscoCrete®-180 GS is added to the gauging water or added with it into the concrete mixer. To take advantage of the high water reduction, a wet mixing time, which is depending on the mixing conditions and mixer performance, of at least 3 mins. per cubic meter after the admixture addition is recommended. Sika® ViscoCrete®-180 GS shall not be added to dry cement.
Compatibility	Sika® ViscoCrete®-180 GS can be used in conjunction with : 1. Sika®Aer 2. Sika ViscoFlow® 3. Sika® ViscoCrete® 4. SikaPlast® 5. Sika® Retarder IQ 6. SikaFiber® 7. Sika® Plastocrete® N IQ All admixtures must be added separately. Trials are always recommended before combining products . For additional information, please contact Sika technical personnel.

BASIS OF PRODUCT DATA

All technical data stated in this Product Data Sheet are based on laboratory tests. Actual measured data may vary due to circumstances beyond our control.

IMPORTANT CONSIDERATIONS

1. A suitable mix design has to be taken into account.
2. Do not use Sika® ViscoCrete®-180 GS with naphthalene based admixtures.
3. Over dosage of Sika® ViscoCrete®-180 GS with excess water will cause :

- Increase in air entrainment.
- Bleeding & Segregation.
- Extend Initial & Final setting time.

ECOLOGY, HEALTH AND SAFETY

For information and advice on the safe handling, storage and disposal of chemical products, users shall refer to the most recent Safety Data Sheet (SDS) containing physical, ecological, toxicological and other safety-related data.

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LOCAL RESTRICTIONS

Please note that as a result of specific local regulations the declared data for this product may vary from country to country. Please consult the local Product Data Sheet for the exact product data.

LEGAL NOTES

The information, and, in particular, the recommendations relating to the application and end-use of Sika products, are given in good faith based on Sika's current knowledge and experience of the products when properly stored, handled and applied under normal conditions in accordance with Sika's recommendations. In practice, the differences in materials, substrates and actual site conditions are such that no warranty in respect of merchantability or of fitness for a particular purpose, nor any liability arising out of any legal relationship whatsoever, can be inferred either from this information, or from any written recommendations, or from any other advice offered. The user of the product must test the product's suitability for the intended application and purpose. Sika reserves the right to change the properties of its products. The proprietary rights of third parties must be observed. All orders are accepted subject to our current terms of sale and delivery. Users must always refer to the most recent issue of the local Product Data Sheet for the product concerned, copies of which will be supplied on request.

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الخلاصة

تبحث هذه الدراسة في إمكانية دمج المواد البلاستيكية المعاد تدويرها - بولي إيثيلين تيريفثالات (PET) وبولي فينيل كلوريد - (PVC) كبدائل جزئية لكل من الكتل الخرسانية الناعمة والخشنة في الخرسانة خفيفة الوزن. تم استخدام PET ، المأخوذ من الزجاجات البلاستيكية المهملة، و PVC، المشتق من أنابيب البناء المجزأة، لاستبدال الرمل والحصى على التوالي. كان الهدف الأساسي هو تطوير مزيج خرساني بكثافة أقل من 1900 كجم / م 3 وقوة ضغط تتجاوز 21 ميجا باسكال أثناء تقييم التأثيرات على الخصائص الفيزيائية والميكانيكية للخرسانة وتحليل سلوك الانحناء لعوارض الخرسانة خفيفة الوزن المسلحة. تم إعداد سلسلة من الخلطات الخرسانية بنسب متفاوتة من PET و PVC. على وجه التحديد، تم استبدال الكتل الخشنة (الحصى) جزئيًا بـ PVC ، وتم استبدال الكتل الدقيقة (الرمل) بـ PET. شمل البرنامج التجريبي خلطات بنسب التالية: B1 (35% PET و35% PVC)، B2 (30% PET و40% PVC)، B3 (25% PET و50% PVC)، B4 (15% PET و60% PVC)، و B5 (10% PET و70% PVC). كما تم اختبار خليط تحكم لا يحتوي على PET أو PVC. حافظت جميع الخلطات على نسبة ثابتة 1:1.1:2 للركام.

أظهرت قابلية التشغيل، التي تم تقييمها من خلال اختبارات الركود، انخفاضًا ملحوظًا يصل إلى 56% في الخلطات التي تحتوي على 35 % PET و35 % PVC، ويرجع ذلك في المقام الأول إلى الكثافة المنخفضة والترابط الضعيف للبلاستيك المعاد تدويره. في حين أن محتوى PVC الأعلى عزز قابلية التشغيل قليلاً، إلا أنه كان لا يزال أقل بكثير من خليط التحكم.

أشارت اختبارات قوة الضغط إلى انخفاض عام مع إضافات PET و PVC، حيث أظهر خليط B1 (35% PET و35 % PVC) انخفاضًا بنسبة 26.3% بعد 28 يومًا. كما انخفضت قوى الشد والانحناء، مع انخفاض يصل إلى 42.1% في قوة الشد و38.2% في قوة الانحناء مقارنة بمزيج التحكم.

انخفضت قياسات الكثافة مع ارتفاع محتوى البلاستيك، حيث حقق مزيج B5 (10% PET و70 % PVC) انخفاضًا بنسبة 22% مقارنة بمزيج التحكم. وهذا يشير إلى فعالية PVC في إنشاء خرسانة خفيفة الوزن. كما زادت نسبة الامتصاص، حيث أظهر مزيج B1 ارتفاعًا بنسبة 62.1% إلى 1.91%، في حين أدى أعلى محتوى PVC (70%) مع 10 % PET إلى نسبة 1.57%، مما يدل على وجود علاقة غير خطية بين الامتصاص ومحتوى البلاستيك.

أشارت قياسات سرعة النبض بالموجات فوق الصوتية (UPV) إلى انخفاض في جودة الخرسانة مع زيادة محتوى البلاستيك. كان لمزيج التحكم أعلىUPV ، مما يعكس كثافة وتوحيدًا متفوقين. أدى زيادة محتوى البلاستيك إلى انخفاض قيمUPV ، مما يدل على انخفاض الكثافة والتوحيد الداخلي. حافظ مزيج B1 على تصنيف جودة جيد، في حين أظهرت الخلطات ذات المحتوى الأعلى من بولي كلوريد الفينيل على سبيل المثال B5 تصنيفات جودة أقل بسبب عيوب داخلية كبيرة.

أظهر الاختبار الهيكلي لعوارض الخرسانة خفيفة الوزن تحت الأحمال الثابتة قدرات تحمل الحمل القصوى تتراوح من 141.5 كيلو نيوتن إلى 164 كيلو نيوتن وانحرافات بين 30.59 ملم و61.34 ملم. أظهرت العوارض ذات المحتوى الأعلى من بولي كلوريد الفينيل ليونة وامتصاصًا محسنين للطاقة، حيث أظهر مزيج B5 زيادة بنسبة 12.99٪ في مؤشر الليونة وزيادة بنسبة 180٪ في امتصاص الطاقة مقارنة بحزمة التحكم. ومع ذلك، تم تحقيق هذه الفوائد على حساب انخفاض قوة الضغط والصلابة

أظهر سلوك الانحراف في الحمل أن العوارض المصنوعة من نفايات البلاستيك المعاد تدويرها أظهرت عمومًا صلابة أقل وانحرافًا متزايدًا مقارنة بحزمة التحكم. على سبيل المثال، أظهر مزيج B5 زيادة بنسبة 200٪ في الانحراف. بشكل عام،

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التصرف الانشائي للجسور الخرسانية خفيفة الوزن المتضمنة مخلفات بلاستيكية

من قبل

مصطفى محمد عبد الحسن

بكالوريوس هندسة مدني 2014

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