University of Southern Queensland
Faculty of Health, Engineering & Sciences

CONCRETE MIX DESIGN USING RECYCLED PET PLASTIC AS A PARTIAL REPLACEMENT OF THE NATURAL FINE AGGREGATE

A dissertation submitted by
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Abstract

In this study feasibility of using recycled PET plastics as a partial replacement for natural fine aggregates in concrete mixes was investigated by analysing workability, durability, mechanical properties and fire resistance. Three trial mixes were prepared a control mix with 0% PET, 5% PET replacement mix, and 10% PET replacement mix. The samples were cured for 7, 14 and 28 days and were tested to analyse the various properties.

Workability tests indicated that replacing natural fine aggregates with PET improved the workability of the concrete, particularly in mixes with higher PET content. Ultrasonic pulse velocity (UPV) tests displayed that while the control mix was of the excellent quality, the mixes with PET content were also of the good quality and were improving with the curing and 5% PET replacement mix almost nearing excellent quality.

The mechanical properties were analysed using compressive strength, split tensile strength, and flexural strength tests. The results revealed that PET replacement mixes reduced strength with the increase in the PET content, however both mixes improved with curing. Fire resistance tests showed that PET replacement mixes, experienced significant reductions in strength and durability after exposure to high temperatures.

The study concluded that partial replacement of the natural fine aggregate in concrete with recycled PET plastic is suitable for applications requiring high workability and low structural demands. The 5% PET replacement mix showed the most promise for non-critical applications, but its use in load-bearing structures or fire-prone areas is not recommended.

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Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Majid Ali

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1. Introduction

The following chapter introduces the massive problem of the waste and role of the plastics, especially PET plastics. It discusses how PET plastics can be collected from waste and effectively incorporated as a partial replacement for fine aggregate in concrete mix. This approach can result in reduced mining and procurement of the natural resources, thus preserving the eco-system. Additionally, it motivates the waste collection and management efforts. The chapter also analyses the background and aims of this project, identifying specific objectives that will be the central focus of the research.

1.1. Project Background

The improvement in socio-economic condition has eased the life, which resultantly has reduced the health and security issues thus improving the quality of life. This improvement has increased the average lifespan of the general population around the world. However, with the growth in the population then comes the increase in general municipal waste generated around the globe. It is projected that the waste produced by 2050 is around 3.40 billion tons as compared to the 2.01 billion tons in 2016(Kaza et al. 2018)

There are various contributors in generation of municipal waste and plastics are one of the major contributors in the municipal waste and a nuisance in its management because of the slow degradation of the plastics. Since 1950's almost 1 billion tons of the plastics have been discarded which can take up to hundreds or even thousands of the years to degrade(Subramanian 2019).

Global plastic production has surged due to its versatile applications and desirable properties, particularly its widespread use in single-use products. Thus, plastic waste has become a significant global challenge, with approximately 60% of post-consumer plastic waste ending up in the environment, landfills, or oceans. Polyolefins, HDPE, LDPE, LLDPE, and PP constitute about 60% of plastic waste, while PET, PVC, PS, and other minor polymers make up the remaining 40%. Despite efforts, only 12% of plastic waste is recycled, while 25% is incinerated, leaving the majority unmanaged(Lange 2021)

PET plastics offer excellent properties such as temperature resistance, strength, and chemical resistance, making them versatile but also significant contributors to plastic waste accounting for around 26.8% of total plastic waste (Bernat 2023). To address PET waste, various recycling methods exist, including mechanical, chemical, and bio recycling, as well as upcycling. One innovative approach being explored involves incorporating waste PET into concrete mixtures as a partial replacement for fine aggregate, offering a cost-effective solution that could mitigate environmental impact and conserve natural resources.

1.1.1. Natural Resources

Natural resources, such as sand, gravel, and stone, are important in construction activities and infrastructure development. However, excessive extraction of these resources has adverse environmental impacts, including landscape degradation, loss of biodiversity, and resource depletion. Sustainable construction practices are increasingly looking for ways to reduce the dependence on natural resources by substituting them with alternative materials.

1.1.2. Natural Resources used in Construction Industry

The construction industry is one of the largest consumers of natural resources, particularly in producing concrete. The production of concrete requires vast amounts of aggregate materials, including both coarse and fine aggregates. The mining and quarrying of these materials contribute to environmental degradation, air pollution, and a disruption of ecosystems. Thus, finding alternatives to traditional aggregates can significantly benefit the environment.

1.1.3. Natural Resources used as fine aggregate

Fine aggregates, such as natural sand, are vital components of concrete. However, excessive sand extraction from rivers and other natural habitats leads to erosion, depletion of water resources, and ecological imbalances. Substituting fine aggregates with waste materials like PET plastics can not only reduce the demand for natural sand it can also provide a sustainable waste management solution.

1.2. Research Aims

The aim of this research is to investigate the potential of using recycled PET plastics as a partial replacement for fine aggregate in concrete mix design. By doing so, the study aims to:

- Evaluate the possibility of replacing fine aggregates with PET plastics in terms of workability, mechanical properties, and durability of the concrete.

- Contribute to sustainable construction practices by incorporating recycled materials into conventional concrete designs without compromising performance.

1.3. Research Objectives

The specific objectives of this research are as follows:

- To calculate the compressive strength, flexural strength, and split tensile strength of concrete mixes with varying percentages of PET plastic as a replacement for fine aggregates.

- To analyse the durability of PET replacement mix, in terms of fire resistance, and ultrasonic pulse velocity.

- To contribute to the development of eco-friendly concrete mixes by encouraging the use of waste materials like PET in construction applications.

1.4. Conclusion

This chapter outlines the growing concern surrounding plastic waste, particularly PET plastics, and presents the potential solution of incorporating these plastics into concrete. By replacing fine aggregates with PET, the research aims to address the double challenges of plastic waste management and natural resource conservation. The following chapters will dig into the detailed methodology, experimental results, and analysis that will support or challenge the feasibility of this innovative approach.

2. Literature Review

The following chapter provides a review of existing academic research undertaken in the waste management, including types of the waste, types of the plastic waste and particularly Polyethylene Terephthalate (PET) plastic waste. Moreover, a review of the procurement of the natural resource, their uses in the construction industry and especially their use as fine aggregate in concrete mix. Furthermore, peer-reviewed academic papers will also be analysed to gather information relevant to the partial replacement of the various recycled materials, various recycled plastics, and PET plastics as a fine aggregate in concrete mix.

The knowledge argued below delivers the essential background detail to supplement resulting methodology and data analysis. The information analysed was acquired through review of published works and relevant technical papers in this field of research. The purpose of this literature review is to achieve a detailed understanding of prior research, not only to establish prospects for research progress but also to accomplish the key understanding essential to sufficiently devise noticeable results from the following research methodology.

2.1. Municipal Solid Waste Management

The term waste as described by Merriam-Webster dictionary," "refuse from places of human or animal habitation, damaged, defective, or superfluous material produced by a manufacturing process". there are various types of waste, nuclear waste, hazardous waste, medical waste, Municipal Solid Waste (MSW).

The MSW can be described as the solid portion of the waste (not classified as hazardous or toxic) generated by households, commercial establishments, public and private institutions, government agencies, and other sources(National Research et al. 2000).

Municipal solid waste management is a severe issue worldwide. The massive waste generation, insufficient collection, inefficient transportation, treatment, and disposal poses severe environmental issue. It is projected that approximately 3.40 billion tons of waste will be generated annually around the globe by 2050(Kaza et al. 2018).

The MSW comprises of the organic waste which is waste produced from plants, waste food and animals and inorganic waste such as glass, metal, leather etc. The MSW can also be either biodegradable or non-biodegradable. However, MSW does not include construction or demolition waste, automobile waste, non-hazardous industrial waste, combustion ashes and municipal sludges(Yakah et al. 2023).

The composition of MSW can be very informative in understanding the different types of the waste that are the major contributors in generation of MSW and will help in its management and disposal.

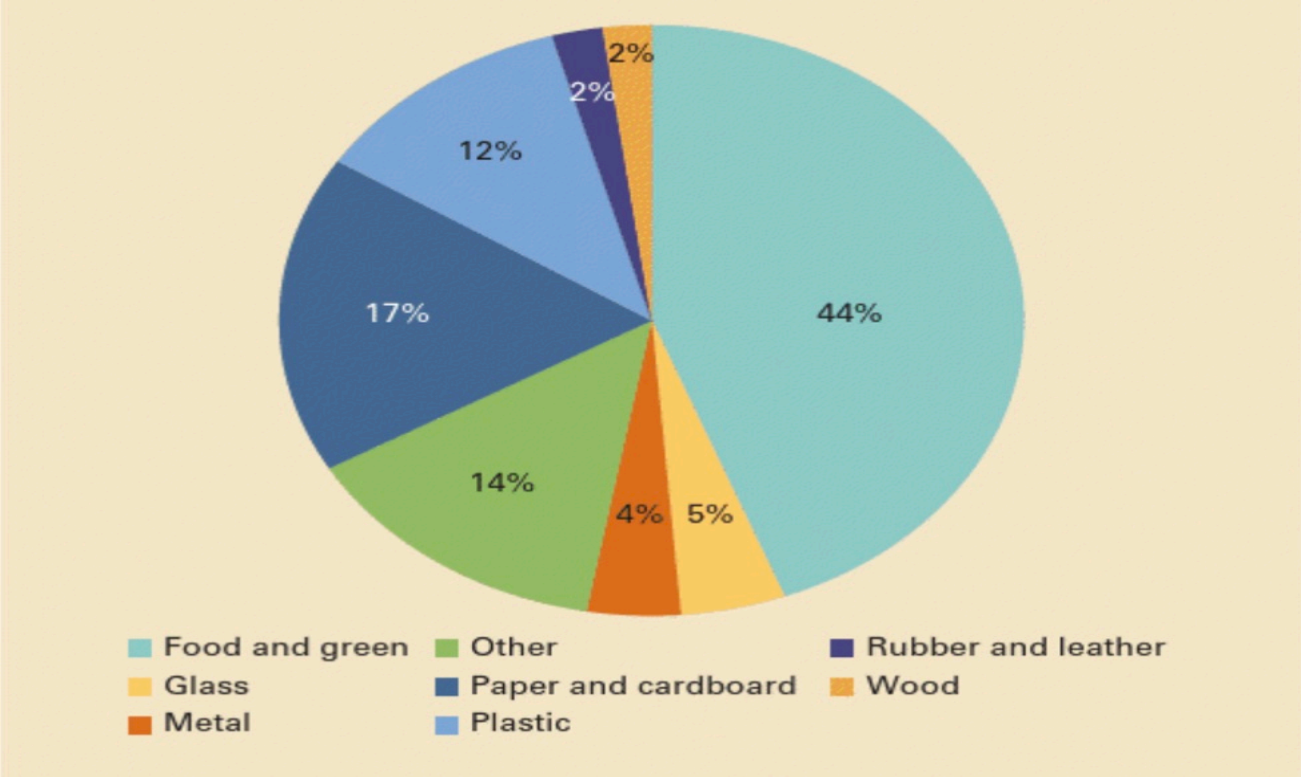

Figure 2.1: Global Waste Composition(Kaza et al. 2018)

The figure no 1 can help us understand what the global waste composition was in 2018. Almost 44% of the total generated MSW is of food and green, the next major contributor is paper and cardboard waste with 17% followed by plastics with a huge chunk amounting to 14%, wood and metal comes in next with 5% and 4% respectively, while glass, rubber and leather are at 2% each with the remaining 14% is other different kinds of waste.

2.1.1. Plastic Waste

Global production of the plastics has gone up from 230 million tonnes in 2005 to 335 million tonnes in 2016 because of its wide range of application and possession of excellent high characteristics plastics are an attractive manufacturing material. Moreover, almost 50% of all the plastics produced globally are for single use only which resultantly makes plastics as one of the top three contributors of the global MSW. Furthermore, with its high resistance to degradation plastic waste is a huge nuisance to properly manage and dispose of(Subramanian 2019).

The plastic waste produced globally is composed of various types of plastics, with approximately 60% being polyolefins, HDPE, LDPE, LLDPE, and PP the remaining 40% comprises of PET, PVC, PS along with some other minor polymers. Unfortunately, only 12% of the waste plastic is recycled, and a 25% of the waste plastics also find its way for the incarnation, while a huge chunk approximately 60% ends up in the environment, landfills, unmanaged dumps or in oceans, rivers and on land(Lange 2021).

The large portion of the post-consumer waste contains plastic waste which is generally packaging waste and is essentially diverse in content thus, quality is unclear. It comprises of different types of polymers primarily PE, PP and PET. This type of waste regularly includes some amount of foreign materials like foreign polymers, additives, and other containments. Post-consumer plastic bottles, trays and films are usually comprised of a dominant 75% to 90% polymers i.e. PE, PP, and PET along with 5% to 15% foreign polymers and papers, with 5% to 15% residue. This can be usually found on labels and caps or lids(Roosen et al. 2020).

To deal with the menace of the plastic waste we must stop manufacturing the plastics and find different ecofriendly alternatives meanwhile recycling is what we must focus on, and we must ensure through strict legislations and regulations that no plastic waste go unmanaged.

2.1.2. PET Plastic Waste

To understand the challenges faced in managing the post-consumer plastic waste from packaging let's consider the most dominant type of polymers which are PET polymers with almost 26.8% share in total these types of polymers are primarily used for the bottling of various types of beverages and are widely used(Bernat 2023).

PET plastics with its excellent properties are one of the widely used plastic for packaging especially for the bottling of various types of beverages. PET plastic can withstand temperature up to 80 °C, and are strong and durable with high tensile strength, high dimensional stability, and excellent chemical resistance making it one of the most versatile type of plastics with various application in numerous industries. However, with all these qualities the demand is also significant thus making it one of the major contributor of the post-consumer plastic waste(Muringayil Joseph et al. 2024).

To reduce the wase generated from the PET plastic proper collection and recycling is necessary. To recycle the PET plastics various recycling methods are used. The most common method of recycling is the mechanical recycling which involves collecting and shredding the waste PET plastics in minor pieces, then washing and separating them from the containments and then melting them to create molten PET resin, which can be used to manufacture wide range of products. The other process of recycling is known as chemical recycling, it is an emerging technology in which chemical reaction is used to break down waste PET into monomers which can used to manufacture new products. Bio recycling is another method with which PET waste can be recycled it is a new method of recycling PET, and the monomers produced are of high quality almost identical to virgin PET. There is another method of recycling PET know as upcycling which is a more innovative way of recycling waste PET, in this method the waste PET is recycled and used to create more valuable items like clothing, furniture or decorative items. (Muringayil Joseph et al. 2024).

However, to reduce and reuse the waste PET we must find more creative methods, one such method which can be cost effective and will also motivate the collection and management of the waste PET plastic is being researched in this paper which is incorporating waste PET into concrete mix as a partial replacement of fine aggregate. The reuse of waste PET in construction industry will not only lessen the burden of waste in a cost-effective manner but will also help saving millions of tons of precious natural resources from being mined.

2.2. Use of Natural Resources in Construction Industry

The planet Earth is rich with natural resources, which mankind is utilizing for various purposes. However, with the increase in population, the demand for extracting these resources has also surged. Despite the planet's abundance of resources, they are not infinite in number, and they are depleting at an alarming rate. This depletion not only threatens to deprive future generations of their benefits but also poses a serious harm to the ecosystem. Drastic measures are needed to prevent the continued depletion of natural resources.

The construction industry is one of the major consumers of the world resources. This industry alone consumes almost 32% of the total world resources, this includes 12% of the total fresh water supply and approximately 40% of the energy. Nearly 40% of the raw material extracted from earth is consumed by this industry along with approximately 25% of the virgin wood(Yeheyis et al. 2013).

An important component of the construction industry is concrete which comprises of cement, water, coarse aggregate, and fine aggregate. Globally the demand of the aggregates has reached an enormous 40 billion tons annually(Tam et al. 2018).

In construction almost everything used is made up of raw material extracted from earth for instance the concrete mix alone requires water, cement, aggregates. Where, cement is made up of limestone and clay, and aggregates which can be of different types either coarse aggregate or fine aggregate and both are extracted from earth.

2.2.1. Aggregates and their types

Aggregates are an important part of the concrete mix which provide structural integrity and stability and constitutes almost 60% to 80% of the total volume of the concrete. There are two primary types of the aggregates i.e. coarse aggregate and fine aggregate.

Coarse aggregates are large sized aggregates typically more than 4mm in particle size. They include materials such as gravel, crushed stone, and recycled concrete. Coarse aggregates are primarily responsible for providing bulk to the concrete mix, contributing to its strength and durability.

Fine aggregates are small size aggregates usually not larger than 4mm in particle size. They include materials such as sand, crushed stone dust, and recycled concrete fines. Fine aggregates fill the voids between coarse aggregates, improving the workability and cohesion of the concrete mix. They also play a crucial role in achieving a smooth surface finish.

2.3. Concrete Mix

Concrete mix is the combination of typically several key components, each playing a crucial role in determining the properties and performance of the final product. These components include cement, water, coarse aggregates, and fine aggregates, and sometimes admixtures.

Cement acts as the binding agent in concrete mixtures, providing cohesion and strength to the overall structure. The most common type of cement used in construction is Portland cement, which accounts for most cementitious materials in concrete mixtures.

Water is fundamental for the hydration process of cement, where it reacts chemically to form a strong, durable matrix. An optimal water-cement ratio is necessary to ensure proper hydration without compromising the integrity of the concrete.

Aggregates, including both coarse and fine particles, constitute the bulk of the concrete mix. The selection and proportioning of aggregates influence the strength, density, and durability of the concrete.

Admixtures are optional ingredients added to concrete mixtures to modify certain properties or enhance performance. These additives can improve workability, reduce water demand, increase strength, or enhance durability, depending on the specific requirements of the project.

2.3.1. Concrete Mix with Recyclable Materials as partial replacement of natural fine aggregate

The researchers around the world are working hard to find new combination of concrete mix incorporated with various waste materials with which not only we can produce a concrete mix with properties almost same to the structural grade concrete, but we can also reduce and reuse the solid waste to protect the environment.

In one such effort (Taner Yildirim & Pelin Duygun 2017) used waste electrical cable rubber as a partial replacement of the fine aggregate to develop the concrete mix. In this study, the total volume of fine aggregate was replaced with 5%, 10% and 15% of the waste electrical rubber. In this paper, the experimental studies were carried out on workability, unit weight, water absorption, compressive strength, flexural strength, ultrasonic pulse velocity, modulus of elasticity, and abrasion resistance of concrete. The experiments result shows that with the increase of the waste electrical cable rubber the workability of the concrete increased but the same reduced the mechanical properties of the concrete. The study concludes that the mix can be used with the replacement of waste electrical cable rubber up to 5% taking into the account that with the more replacement the reduction of the mechanical properties is very negative.

In an experimental study conducted by (Karthik & Saranya 2017) waste tires rubber was used as a partial replacement of the natural fine aggregate. The samples were prepared using the replacement of 2.5%, 5% and 7.5%. the samples were tested for compressive strength, split tensile strength and flexural strength. The concrete specimen with the partial replacement of up to 2.5% showed promising results and it was concluded that the waste tire rubber can be used to in a mix design of M40 grade concrete with replacement of natural fine aggregate with tire rubber up to 2.5%. However, the increase in the percentage of waste tire rubber decreased the mechanical properties of the concrete drastically.

A study conducted by (Bravo et al. 2020) used construction and demolition waste as a replacement of the fine natural aggregate in concrete mix design. The replace percentage of the fine natural aggregates were 10%, 25%, 50% and 100% with construction and demolition waste. The findings in this study were that the incorporation of construction and demolition waste up to 25% exhibits same mechanical properties as of the reference specimen with 0% construction and demolition waste. However, with the increase in content of construction and demolition waste the mix design shows significant decrease in the mechanical properties.

In a research conducted by (Mallick et al. 2023) a concrete mix design with the partial replacement of cement with fly ash and natural fine aggregate with industrial glass waste powder was developed. The specimens were produced using concrete mix with 25% replacement of cement with fly ash and natural fine aggregate with by 10%, 20% and 30% of industrial glass waste powder. The authors concluded that the high workability was received and after testing the specimen compressive strength of the concrete mix does not decrease significantly relative to each other. Overall, the findings were promising.

2.3.2. Concrete Mix with Recycled Plastics as partial replacement of natural fine aggregate

Studies are conducted regularly on reusing various types of waste plastics to reduce the plastic waste from finding its way to the landfills. the incorporation of various kinds of plastic waste in concrete mix design as a partial replacement of the natural fine aggregate are widely done around the globe each year. Some of these studies are reviewed here to better understand the incorporation of waste plastic concrete mix.

The study conducted by (Kou et al. 2009) used polyvinylchloride or PVC Plastics as partial replacement of the natural fine aggregate in concrete mix. The specimens were prepared using the replacement of the natural fine aggregate with 5%, 15%, 30% and 45% PVC plastic waste of the total volume of the natural fine aggregate. On the brighter side the test result shows that concrete prepared was lighter, more ductile, had lower drying shrinkage and had higher resistance to the chloride ion penetration. On the other hand, a significant reduction in workability, compressive strength, and splitting tensile strength were noticed.

An experimental study was conducted by (Harsojo & Nataadmadja 2022) in which crumb rubber and HDPE was used as partial replacement of the natural fine aggregate. The specimens were prepared with a partial replacement of 5%, 7.5%, 15% and 17.5% of total volume of the fine natural aggregate with crumb rubber and HDPE. The study concluded that with the increase in the content of the crumb rubber and HDPE the drop in compressive strength was notices, however, the compressive strength was higher with the replacement of HDPE as natural fine aggregate then the replacement of crumb rubber as natural fine aggregate.

2.3.3. Concrete Mix with Recycled PET Plastic

Numerous studies have been conducted on the incorporation of recycled PET plastic as a partial replacement for fine natural aggregate. This research area is of importance because of its potential in developing sustainable concrete mix designs. By utilizing recycled PET plastic, these designs contribute to waste reduction and help save the ecosystem by reducing the need for further extraction of natural aggregates. To gain understanding into the methodologies and findings of these studies, various papers were reviewed. The following section provides a summary of key research in this field.

In an experimental study conducted by(Marzouk et al. 2007), recycled PET bottles are used as a partial replacement for natural fine aggregate in concrete, with different volumes ranging from 2% to 100%. Three sizes of the PET plastics were used and classified as Type-A, Type-B, and Type-C with the maximum aggregate size of 0.5cm, 0.2cm, and 0.1cm respectively. The study evaluates the bulk density and mechanical properties of the mixes, while also studying the relationship between mechanical properties and concrete mix's microstructure using scanning electron microscopy SEM.

After the experiments results show that replacing sand with granulated PET up to 50% does not greatly affect the compressive and flexural strengths. However, beyond this level, bulk densities fall, and mechanical properties also decline heavily. Interestingly, when sand is replaced 100% with the PET, the resulting mix display high mechanical properties. Microstructural analysis reveals that mix with up to 50% PET maintain a high level of compactness, while those with higher percentage of the PET appear more cavernous. This difference in structure relates with observed decreases in bulk densities and mechanical properties.

The study also examines the effect of aggregate size distribution on mechanical properties. Mix containing different PET aggregate sizes display similar behaviour, with type-A aggregates maintaining high mechanical properties even with high percentage of the PET. Scanning electron microscopy confirms good matrix-aggregate adhesion regardless of aggregate type. Furthermore, the study examines durability factors and results suggest that mix with PET aggregates display favourable durability characteristics compared to conventional materials.

Overall, the research proves the possibility of using PET waste in concrete mix, a low-cost alternate material with good properties. This method not only tackles solid waste problems especially plastics but also contributes to protection of the natural aggregates and provides a sustainable option.

In a study by (Choi et al. 2005) waste PET bottles were used as a partial replacement of the natural fine aggregate. The waste PET bottles were cut in the size ranging from 5 to 15mm and used in the concrete mix as a fine aggregate. The water-cement ratios were 45%, 49%, and 53%, whereas the replacement ratios were 0%, 25%, 50%, and 75% of the total volume of the natural fine aggregate. The analysis of the concrete mix was conducted to check the fresh and hardened properties. Moreover, scanning electron microscopy SEM analysis was performed to inspect the microstructure and transition zone between the cement paste and aggregates.

The test results show that the specific gravity and bulk density was 50% lower of the PET aggregate then that of natural fine aggregate however, the workability of the concrete mix with the waste PET plastic increased with the increase in the replacement ratio and water-cement ratio. The improvements were 52%, 104%, and 123% than the reference concrete mix with 0% PET. However, the increase in water-cement ration and replacement ration of the natural fine aggregate affected the compressive strength, tensile strength, and modulus of elasticity. The 28-day compressive strength was 21% lower for the specimen with the replacement of 75%.

To summarize, the study findings suggest that waste PET plastics can be used as a partial replacement of the natural fine aggregate, to provide a sustainable option to design a concrete mix which can reduce the extraction of the natural resources and helps in reduction of the plastic waste.

In another study conducted by (Choi et al. 2009) PET plastics were used as a partial replacement of the natural fine aggregate. Three different mixes were prepared using the water-cement of 0.45,0.49, and 0.53 respectively. The specimens were prepared using the replacement ratio of 0%, 25%, 50%, and 75% of the total volume of the natural fine aggregate with PET plastics.

The test results show that the use of PET plastics as fine aggregate increased the workability with the increase in the replacement ratio. The air content of the concrete with PET plastic was lower than the reference mix. The reduction in the compressive strength was also observed with the increase of the PET content and at 3 day the specimens with the replacement ratio of 25%, 50%, and 75% had the compressive strength reduction of

4%, 7%, and 18% respectively. When the specimens were again tested after 7 days, the reduction of compressive strength of 6%, 13%, and 20% were noticed. However, at 28 day the specimen with the 75% replacement ratio shows the reduction of 30% in compressive strength.

However, the concrete mix with the water-cement ratio of 0.49 and the replacement ratio of 25% had the higher structural efficiency than the control mix with 0% PET plastics.

The study conducted by (Almeshal et al. 2020) used PET plastic as a partial replacement for sand in concrete mixes. Various tests were conducted to examine its impact on various physical and mechanical properties of the concrete. Concrete mixtures were prepared with PET replacement ratios of 0%, 10%, 20%, 30%,40%, and 50%.

The results of the study shown that the addition of PET decreased workability 31.6% for mix with the replacement ration of 50% was noticed. The unit weight of the concrete was also decreased indicating a reduction in density due to the lightweight nature of PET. However, as the substitution level of PET increased, there was a noticeable decline in the mechanical properties of the concrete. The 28-day compressive strength for the concrete with 10%, 20%, 30%, 40% and 50% PET had a reduction of 1.2%, 4.2%, 31%, 60% and 90.6%, respectively. The splitting tensile and flexural strengths were reduced by 10.5% to 85.5% and 2.4% to 84.2%, respectively, for replacement levels of PET 10% to 50%.

Furthermore, the study also examined the quality of the concrete using ultra sonic pulse velocity and it was observed that the pulse velocity was decrease from 4.5 km/s to 1.9 km/s. Moreover, the fire resistance of the PET concrete was also tested, and the results showed that concrete containing PET showed higher combustibility compared to the reference concrete without PET.

In summary, the study suggests that while PET can be effectively utilized as a partial substitute for sand in concrete, careful consideration must be given to its potential impact on mechanical properties and fire resistance. Moreover, the study also recommended that the concrete containing PET plastics can easily be used for non-structural elements that do not require high compressive strength.

In a study conducted by (Frigione 2010) used waste PET plastic as a partial replacement of the natural fine aggregate. The size of the waste PET plastic aggregate manufactured for the research was that of the natural sand with the size ranging from 0.1mm to 5mm. the mixes were prepared with the 5% replacement of the natural fine aggregate with waste PET plastic aggregate. However, the different cement content and water-cement ratio was used to prepare the specimens. The mixes were then tested for the fresh concrete properties and the mechanical properties of the mixes were analysed at 28 days and 365 days.

The results showed that the inclusion of the waste PET aggregate does not significantly affect the fresh concrete properties. However, a slight decrease in the compressive strength of the concrete was noticed. Moreover, the observations revealed that the decrease. However, was not significant and was only up to 2%. The results were almost the same for the splitting tensile strength, a slight decrease in splitting tensile strength was also recorded. The study suggested that the decrease in the compressive strength and splitting tensile strength may be due to weaker bond between the cement paste and the PET plastic aggregate.

Furthermore, the investigation of the stress-strain curve revealed that the concrete mix with waste PET plastic had a slightly softer behaviour which reduced the brittleness and increased the ductility. A slight increase in the drying shrinkage was also recorded which may be associated with the reduced modulus of elasticity in the specimen with the PET plastic aggregate.

Overall, the study concluded that replacing natural sand with PET in concrete could be a possible option, offering benefits in waste disposal and reducing environmental impacts. However, the study noticed that the slight decrease in mechanical properties and increase in drying shrinkage should be considered in structural applications.

An experimental study was conducted by (Azhdarpour et al. 2016) using waste PET plastic as a partial replacement of the sand. The first gradation of the plastics was 2 to 4.9 mm, and the second gradation was finer with their diameter size ranging from 0.5mm to 2 mm. The specimens were prepared using waste PET as a replacement of the sand with the replacement ratio of 5%, 10%, 15%, 20%, 25%, and 30% of the total volume of the natural fine aggregate. the water-cement ratio was constant with 1:2.

The test results showed that with the increase in the PET content the fresh and dry densities of the mix was reduced, with the maximum loss of 9% observed in the mix with the Pet content of 30%. Interestingly, the compressive strength of the mix with replacement ratio of the 5% and 10% was higher with 39% and 7.6% respectively, however when the replacement ratios were increased the decrease in the compressive strength was notice. Furthermore, the tensile strength also improved for the replacement ratio of 5% and 10% and a reduction in tensile strength was also observed when the PET content was increased. The slight increase in the flexural strength was also recorded at lower replacement ratios but as the replacement ratio increased the decrease in flexural strength was also detected.

Overall, the study concluded that the PET can be utilized as a partial replacement of the fine aggregate which can lead to reduction in the waste and preservation of the natural resources. However, to ensure performance and strength optimal replacement ration needs to be studied.

The study by (Rahmani et al. 2013) investigates the fresh and hardened properties of the concrete mix with the partial replacement of the natural fine aggregate with waste PET plastic. The waste PET plastic was collected washed and grinded to the maximum size of 4.75mm. the specimens were prepared with two waster-cement ratios of 0.42 and 0.54. The replacement ratio for the both eater-cement ratios were ranging from 0% to 15%, with an increment of 5%.

The tests results revealed that with the increase in the replacement of PET particles the workability of the concrete decreased. However, the promising results were observed at lower percentage of the PET replacement when the samples were tested for the compressive strength. The 28 days compressive strength for the mix with 5% replacement of the PET at the water-cement ratio of 0.42 and 0.54 led to an increase of 8.865 and 11.97%. The results were almost like that of the control mix when the replacement ratio was at 10%, but the decrease in the compressive strength was noticed when the samples with the replacement ratio of 15% were tested. this positive trend was also observed while testing for flexural strength, for instance, for the ratio of 5% replacement of sand with PET and with water-cement ratio of 0.42 and 0.54 the increase in flexural strength was of 6.71% and 8.02% respectively. However, when the replacement ratios were increased the decline in flexural strength was noticed.

Moreover, the results for the splitting tensile strength were on the decreasing trend with the increase in the ratio of PET, for example, at the water-cement ratio of 0.42 and 0.54 with the replacement rate of 15% the reduction in tensile strength were 15.9% and 18.06% respectively. The modulus of the elasticity was also lower than the control mix and the reduction in the ultrasonic pulse velocity was also observed with the increase in the PET content.

To summarize, study showed promising results and potential of the waste PET plastics as an alternate to the natural resources if replaced partially. The study concluded that the waste PET can be utilised as the partial replacement of the natural fine aggregate which can create a sustainable mix design, thus leading to the preservation of the natural resources and reusing of the waste plastics.

In an experimental study conducted by (Thorneycroft et al. 2018) used various kinds of the plastics as partial replacement of the natural fine aggregate. The aim of the study was to test that weather the plastics can replace the natural fine aggregate in high performance concrete. The PET plastic used was 0.05mm to 5mm in size. The mixes were prepared using 10% replacement ratio of the natural fine aggregate. The 11 mixes were manufactured using different kind of plastics with different grading. To enhance the bonding some of the PET aggregates were chemically treated. The details of the plastic and their grading is presented in the table no:1 below.

	Mix code	Base mix design	Mix description
1	Ref	R1	Reference mix
2	PET1	P1	PET fragments graded to match the sand replaced
9	PET2	P1	PET fragments between 0.5 and 2 mm in size
8	PET3	P1	PET fragments between 2 and 4 mm in size
7	PET4	P1	PET fragments between 2 and 4 mm in size and treated with sodium hydroxide and sodium hypochlorite
10	PET5	P1	PET fragments between 2 and 4 mm in size and treated with sodium hydroxide and sodium hypochlorite and washed
3	HDPP1	P1	Smooth spherical polypropylene pellets 3 mm diameter
4	HDPE1	P1	Shredded high-density polyethylene carrier bags passing through a 4 mm sieve
6	PPS1	P1	Virgin polypropylene strips (aspect ratio 6.7)
5	PPF1	P1	Virgin polypropylene fibres (aspect ratio 400)
11	PPF2	P1	0.64% substitution of sand with virgin polypropylene fibres

Table 2.1:Test Mixes(Thorneycroft et al. 2018)

To analyse the specimen various tests were conducted to test the mechanical properties of the concrete mixes. The results of the compressive strength and tensile strength of all the 11 concrete mixes tested are presented in the table no:2 below.

	Mix code[1]	Average Density (kg/m^3)	Average Compressive Strength (N/mm^2)	% Change in Compressive Strength compared to Mix 1	Average Tensile Strength (N/mm^2)	% Change in Tensile Strength compared to Mix 1
1	Ref	2300	53.8	–	3.26	–
2	PET1	2273	54.4	+1.2	4.07	+25.0
9	PET2	2272	51.8	−3.7	3.70	+13.7
8	PET3	2282	51.6	−4.1	3.31	+1.5
7	PET4	1861	11.8	−78.1	1.55	−52.4
10	PET5	2269	52.7	−1.9	2.88	−11.5
3	HDPP1	2244	47.0	−12.5	3.05	−6.3
4	HDPE1	2242	45.6	−15.1	3.77	+15.8
6	PPS1	2266	52.2	−2.9	2.41	−26.0
5	PPF1	2111	33.5	−37.7	3.77	+15.7
11	PPF2	2288	54.5	+1.5	4.04	+24.0

Table 2.2: Compressive and tensile strength test results(Thorneycroft et al. 2018)

Apart from PET4, the results obtained for the compressive and tensile strength of the various concrete mixes with the PET as 10% replacements of the natural fine aggregate show promising results, with mix PET1, containing PET particles graded to match the natural fine aggregate even outperforming the reference mix by +1.2% in compressive strength and +25% in tensile strength.

The study also investigated and recorded the effect of the chemical treatment of the plastics on the mechanical properties. It was observed that when the plastic particles for mix-7 PET4 were chemically treated with common household bleach (sodium hypochlorite) and caustic soda (sodium hydroxide), in which the plastic particles were immersed for one hour and then drained and dried performed very badly. However, for the mix-10 PET5, when plastic particles were treated with bleach (sodium hypochlorite), then with caustic soda (sodium hydroxide) and finally were washed with water performed better, and even outperformed the mix-8 PET3, which has same grading as mix-10 PET5.

The results showed that if the appropriate plastic particle size and replacement ratio is used it is viable to use plastic aggregates in designing a structural grade concrete. The study concluded that the waste plastics can be used as a partial replacement of the natural fine aggregate to design a high-performance concrete mix, however, long term durability cost implications of using plastic in concrete construction may further be researched.

2.4. Challenges and Considerations

In the quest of sustainable concrete mix, the replacement of recycled PET plastic aggregate into concrete mix design in place of natural fine aggregate has gained huge attention, because it has the potential for proper waste disposal and environmental protection. However, the utilization of recycled PET plastics as a partial replacement for natural fine aggregate in concrete has several challenges and considerations that must be addressed to ensure the successful incorporation of this new material developing the concrete mixes. The issues related to optimal particle shape and size distribution, optimal replacement ratios, lower workability, lack of bonding, lower mechanical properties, high fire combustibility, and other economic and environmental implications. Understanding and addressing these challenges are crucial for incorporation of recycled PET plastics.

Determining the optimal particle shape and size of the recycled PET plastics is critical for achieving the desired properties in concrete. (Nevile 2011) suggests that the surface texture and shape of the aggregates have significant effect on the strength of the resulting concrete mix, the affect is especially higher in terms of flexural strength in comparison with the compressive strength. Furthermore, (Marzouk et al. 2007) suggests that finer particles tend to improve mechanical properties such as compressive strength and durability. However, larger particles may lead to difficulties in achieving proper dispersion within the concrete mix, potentially resulting in segregation and reduced workability.

Maintaining acceptable workability in concrete containing recycled PET plastics presents challenges. PET particles can significantly affect the properties of the concrete mix, influencing its flowability, cohesiveness, and ease of placement. Workability of the concrete was significantly affected with the increase in the content of PET plastics as reported by (Rahmani et al. 2013; Azhdarpour et al. 2016; Almeshal et al. 2020). However, study conducted by (Choi et al. 2005) achieved increase in the workability with reference to the control mix and attributed the increase in the workability with the smooth and spherical shape of the replace PET particles.

The absence of chemical bonding between recycled PET plastics and the cement paste poses challenges for achieving adequate interfacial bond strength. Unlike natural aggregates, which form strong bonds with the cement paste, PET particles lack this which can result in reduced bond strength, thus, decreasing the mechanical properties of the resulting mix. (Naik et al. 1996) suggest that the plastic particles should be chemically treated to improve the bonding between the plastic particles and cement paste. (Thorneycroft et al. 2018) treated the PET aggregates with sodium hydroxide and sodium hypochlorite and then washed the particles before using it in the development of the concrete mix. The results showed that the resulting mix showed only 1.9% decrease in compressive strength from the reference mix, but more importantly it showed a 2% increase from the mix in with same percentage of PET particles were used but were not chemically treated.

One of the most significant concerns associated with the replacement of the recycled PET plastics in place of natural fine aggregate to develop a sustainable concrete mix is the potential reduction in mechanical properties. Most of the studies reviewed suggests that with the increase in the replacement ratio of the natural fine aggregate with the PET plastic the resulting mixes tend to decrease the mechanical properties. This reduction is attributed to factors such as poor bonding, increased porosity, and the heterogeneous nature of the plastic aggregates. However, on the bright side some studies reviewed presented promising results and (Marzouk et al. 2007) even recorded increase in compressive strength even at 100% replacement ratio of the natural fine aggregate with the recycled PET plastic aggregate.

The most significant challenge is selecting the appropriate replacement ratio of natural fine aggregate with recycled PET plastics aggregate in concrete mix design. While higher replacement ratios offer the potential for greater waste disposal and environmental benefits, they can also lead to negative effects on concrete performance. Studies have shown that excessive replacement ratios may compromise mechanical properties, such as compressive strength and modulus of elasticity. Therefore, finding a right balance between replacement ratio and maintaining concrete performance is essential and one of the main purposes of this study.

2.5. Summary

To conclude, after reviewing various previous studies on the topic, it has been observed that while, PET plastics can partially replace the natural fine aggregate in concrete mix but there are several challenges, and they must be addressed to ensure the success of the study.

Choosing right particle size and shape is very important, because the size and shape effects seriously on the fresh and hardened properties of the concrete mix. Furthermore, the optimal replacement ratio also requires the careful consideration because most of the studies reviewed suggested that the increase in the PET content decreases the mechanical properties of the concrete mis heavily.

However, after reviewing the literature it is clear that waste PET plastics can be used as a partial replacement of the natural fine aggregate, which will not only help in mitigating the issue related to waste management but will also reduce the extraction of the natural resources, and a sustainable option for manufacturing of the concrete can be attained.

3. Methodology

This chapter outlines the experimental methods and specimen preparation techniques used in this research. A wide range of technical equipment was used throughout the project, all of which are discussed in this chapter. The methodology for preparing recycled Polyethylene Terephthalate (PET) plastic as a fine aggregate, along with the preparation of specimens for compressive, split tensile and flexural strength tests, is detailed to provide a complete understanding of the practical experimentation involved.

3.1. Materials Used

3.1.1. Cement

In this study, locally available Ordinary Portland Cement (OPC) is used as the binding agent for preparation of the samples. The cement used is manufactured by the Lucky Cement Factory, Pakistan and the OPC product used is Lucky Star.

Figure 3.1: OPC Lucky Star, supplied by Lucky Cement Factory, Sindh, Pakistan.

3.1.2. Natural Coarse Aggregate

Coarse aggregate is the key element used in concrete mix design with the particle size of greater than 4.75mm. The quality of the coarse aggregate significantly influences the durability and strength of the concrete. The properties which should be under key consideration to ensure the quality of the coarse aggregate are, size and particle distribution, the shape and texture must be angular and rough, the specific gravity ranges must be between 2.5 to 2.8, the bulk density between 1400 to 1600 Kg/m^3 , the water absorption ranges from 0.5% to 2.5% , while the abrasion resistance , impact and crushing values should be less than 30%. The most used natural materials as coarse aggregates are crushed stone and gravel.

In this study crushed stone is used as natural coarse aggregate, with two different sizes one with the maximum particle size of 10mm and the other with maximum particle size of 19mm. The coarse aggregate was sourced from a local concrete batching plant, D-Ready Mix.

Figure 3.2: Coarse Aggregate 19mm, supplied by D-Mix, Karachi, Pakistan.

Figure 3.3:Coarse Aggregate 10mm, supplied by D-Mix, Karachi, Pakistan.

The blend was made with 30% of the aggregate of 10mm size and 70% of the aggregate from 19mm. the sieve analysis of the coarse aggregate and the blended aggregate is shown in table 1 and 2 respectively and the other properties like specific gravity, water absorption, soundness of aggregates, degradation of small size coarse aggregates, Bulk Density, and percentage of fractured particles are shown in table 3 below.

Table 3.1: Sieve Analysis Coarse Aggregate.

Aggregate Size	25mm	19mm	9.5mm	4.75mm	2.36mm
19mm	100	89.5	22	5.1	0.3
10mm	100	100	93.8	18.7	3.4

Table 3.2: % Passing of Blended Coarse Aggregate.

	% Used	25mm	19mm	9.5mm	4.75mm	2.36mm
Coarse Aggregate 19 mm	70	70	62.7	15.4	3.6	0.2
Coarse Aggregate 10 mm	30	30	30	28.1	5.6	1
Combination	100	100	92.7	43.5	9.2	1.2
Mid-Point		100	95	37.5	5	2.5

Table 3.3: Various Properties of the Coarse Aggregate.

<table>
<tr><th colspan="2" rowspan="2"></th><th colspan="2">Aggregate Size</th></tr>
<tr><th>19 mm</th><th>10 mm</th></tr>
<tr><td rowspan="3">Specific Gravity</td><td>Bulk Oven Dry</td><td>2.643</td><td>2.634</td></tr>
<tr><td>Bulk Saturated Surface Dry</td><td>2.664</td><td>2.658</td></tr>
<tr><td>Apparent</td><td>2.701</td><td>2.697</td></tr>
<tr><td>Absorption %</td><td rowspan="3"></td><td>0.826</td><td>0.879</td></tr>
<tr><td>Soundness</td><td colspan="2">5.80%</td></tr>
<tr><td>Abrasion</td><td colspan="2">28.40%</td></tr>
<tr><td rowspan="2">Bulk Density</td><td>By Shovelling</td><td>1.423</td><td>1.429</td></tr>
<tr><td>By Dry Rodded</td><td>1.532</td><td>1.54</td></tr>
</table>

3.1.3. Natural Fine Aggregate

Natural fine aggregate is another key component used in concrete mix design with the particle size of less than 4.75mm. Natural fine aggregate contributes to the workability and cohesion of the concrete mix, by filling the voids made by the coarse aggregates thus providing a smoother finish. The quality of the fine aggregate significantly influences the workability, durability and strength of the concrete. The properties which should be under key consideration to ensure the quality of the fine aggregates are, size and particle distribution, the shape and texture must be angular and rough, the specific gravity ranges must be between 2.5 to 2.8, the bulk density between 1500 to 1700 Kg/m^3, the water absorption ranges from 0.1% to 2%.

In this study, Bolari sand was used as the fine aggregate. Bolari sand is a type of natural river sand sourced from the Bolari area near Thatta, Sindh, Pakistan. Due to its fine grain size and uniform texture, Bolari sand is widely used in the Karachi region for concrete and construction applications. It is known for its ability to provide workability and cohesion in concrete mixes, making it a suitable choice for various construction purposes. The Bolari sand was provided by the local concrete batching plant, D-Ready Mix.

Figure 3.4: Bolari River Sand used as fine Aggregate, supplied by D-Mix, Karachi, Pakistan.

The sand was sieved to ensure a uniform particle distribution, with maximum particle size being 4.75mm. Table 4 provides sieve analysis of the sand and table 5 provides information of the various properties of the sand.

Table 3.4: Sieve Analysis of Bolari Sand used as Natural Fine Aggregate.

Fine Aggregate Bolari	**9.5mm**	**4.75mm**	**2.36mm**	**1.18mm**	**0.6mm**	**0.3mm**	**0.15mm**	**0.075mm**
	100	97	82.4	60.4	37.5	22	7	3

Table 3.5: Bolari Sand Properties.

<table>
<tr><th colspan="2"></th><th>Fine Natural Aggregate Bolari</th></tr>
<tr><td rowspan="3">Specific Gravity</td><td>Bulk Oven Dry</td><td>2.663</td></tr>
<tr><td>Bulk Saturated Surface Dry</td><td>2.697</td></tr>
<tr><td>Apparent</td><td>2.757</td></tr>
<tr><td>Absorption %</td><td rowspan="2"></td><td>1.282</td></tr>
<tr><td>Soundness</td><td>6.80%</td></tr>
<tr><td>Bulk Density</td><td>By Shovelling</td><td>1.68</td></tr>
</table>

3.1.4. Recycled Polyethylene Terephthalate (PET) plastic

Recycled Polyethylene Terephthalate (PET) plastic was used as a partial replacement for natural fine aggregate in this study. PET is a synthetic polymer commonly used in packaging, particularly for plastic bottles. Due to its abundance as waste material and its non-biodegradable nature, PET plastics is utilized in concrete as a sustainable alternative to reduce environmental pollution. The incorporation of recycled PET in concrete offers potential benefits, such as reducing the consumption of natural resources and enhancing the motivation for the collection of the PET plastic thus contributing to reduction in the waste in environment. However, PET particles, do not exhibit the same mechanical strength or density as traditional fine aggregates.

In this study, recycled PET was used as a partial replacement for natural fine aggregate. The recycled PET was acquired from a local plastic recycling plant, Shazil Pakistan Private Limited. The sieve analysis of the PET plastic is provided in Table 6.

Figure 3.5: Recycled PET plastic being air dried.

Table 3.6: Sieve Analysis of the Recycled PET Plastic as Fine Aggregate.

Fine Aggregate PET	9.5mm	4.75mm	2.36mm	1.18mm	0.6mm	0.3mm	0.15mm	0.075mm
	100	100	97.9	41.6	14.1	6.6	2.6	1

3.1.5. Micro Silica

Micro Silica, also known as silica fume, is an ultrafine material that is a byproduct of silicon and ferrosilicon alloy production. It is finer than ordinary Portland cement with particles composed of spherical shape with an average diameter of less than 1 micron. When added to concrete, micro silica considerably enhances the mechanical properties and durability of the concrete due to its high pozzolanic reactivity.

In this study, micro silica Expan Silica, which is provided by FOSPAK Private Limited, is used as an additive to improve the compressive strength and durability of the concrete mix. Its main advantages include improving the cement matrix's density, enhancing bonding properties, and reducing porosity. In this study, micro silica was added at 5% by weight of cement.

Figure 3.6: Expan Micro Silica.

3.1.6. Admixture

In this study, Expanplast Super40 by FOSPAK Private Limited, is used as a high-performance admixture. Expanplast Super40 is a plasticizing and water-reducing admixture designed to improve workability, reduce water content, and enhance the overall durability and strength of concrete. Its application leads to better hydration of the cement and improved mechanical properties. The primary benefits of using Expanplast Super40 includes water reduction, early strength gain, shrinkage reduction. In this study, Expanplast Super40 was added to the concrete mix at 1% by weight of cement.

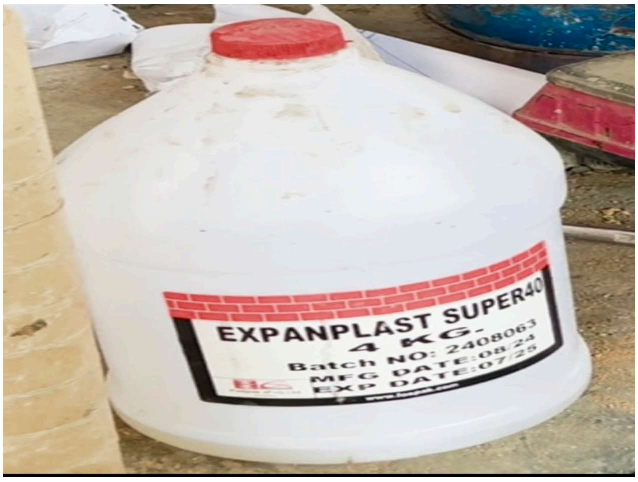

Figure 3.7: Expanplast Super40, Admixture.

3.1.7. Water

For this study, potable water was used, supplied by Karachi Water & Sewerage Board, a local government authority for water supply.

In this study, the water-cement ratio was kept at 0.27, ensuring a balance between workability and strength.

3.2. Equipment's Used

In this study various equipment's were used for preparation of materials, casting of specimens, and testing of the concrete samples. The main equipment used includes:

3.2.1. Sieve Set

A sieve set was used to determine the particle size distribution of the natural coarse aggregates, natural fine aggregates and recycled PET fine aggregates. The sieves ranged from 75 µm to 19 mm, ensuring the aggregates met grading requirements.

Figure 3.8: Sieve Set.

3.2.2. Weighing Scale

A weighing scale with a precision of ±0.01 kg was used to measure materials such as cement, aggregates, recycled PET plastic, micro silica, and water.

Figure 3.9: Weighing Scale

3.2.3. Concrete Mixer

A mechanical concrete mixer was used to prepare the concrete mix, ensuring homogeneous mixing of cement, aggregates, water, micro silica, recycled PET plastic, and admixture.

Figure 3.10: Concrete Mixer.

3.2.4. Moulds for Specimens

In this Study two types of moulds were used for the casting of the concrete samples.

Cylindrical moulds (152.4 mm x 304.8 mm) for compressive strength and split tensile strength.

Rectangular moulds (152.4 mm x 152.4 mm x 457.2 mm) for flexural strength testing.

Figure 3.11: Moulds Being Poured with Concrete to prepare Samples

3.2.5. Mallet and Scoops

A mallet was used to lightly tap the moulds to remove any trapped air bubbles, ensuring a dense, void-free concrete mix. Scoops were used to handle and place concrete into the moulds with accuracy, ensuring precise layering and preventing segregation.

Figure 3.12: Mallet & Scoop

3.2.6. Slump Cone, Base Plate and Tamping Rod

For the slump test and concrete casting, a slump cone, base plate, and tamping rod were used. The base plate was used because it provides a flat, stable surface for the cone during the test, ensuring accurate measurement. The tamping rod, with a diameter of 16 mm and length of 600 mm, is employed to tamp the concrete in layers while the slump test and casting the samples, ensuring uniform compaction and the removal of trapped air to enhance the concrete's strength.

Figure 3.13: Slump Cone, Base Plate, Tamping Rod.

3.2.7. Curing Tanks

Concrete samples were cured in water curing tanks, samples were cured for 7, 14, and 28 days to monitor the strength development over time.

3.2.8. Compression Testing Machine (CTM)

A compression testing machine (CTM) was used for several mechanical tests:

Compressive strength of cylindrical specimens.

Split tensile strength of cylindrical specimens, using a split tensile test fixture.

Flexural strength of rectangular specimens, using a four-point loading fixture.

The CTM provided accurate load application and measurement across all these tests.

Figure 3.14:Compression Testing Machine.

Figure 3.15: CTM setup for Compressive Strength.

Figure 3.16: CTM setup for Split Tensile Strength.

Figure 3.17: CTM setup for Flexural Strength Testing.

3.2.9. Ultrasonic Pulse Velocity (UPV) Tester

A UPV tester was used to assess the quality and durability of the concrete samples.

Figure 3.18: Ultrasonic Pulse Velocity Testing.

3.2.10. Furnace

A furnace was used to expose cylindrical samples at 28 days curing stage to temperatures of up to 950°C for 60 minutes, replicating fire conditions. After exposure, these samples were tested to assess changes in strength and durability.

Figure 3.19: Furnace.

3.3. Material Preparation

3.3.1. Polyethylene Terephthalate PET plastic preparation

In this study, recycled PET plastics in shredded form were acquired from Shazil Pakistan Private Limited. The plastic was first washed with caustic soda (sodium hydroxide) for 2 hours, then drained and then washed with household bleach (sodium hypochlorite) for another 2 hours. The plastics were drained and thoroughly washed with water afterwards, as done by(Thorneycroft et al. 2018).

The recycled PET was air-dried for 2 days, after which it was collected in a bag and stored in a dry location for use in the concrete mix design. The recycled and chemically treated plastic was then analysed using a sieve set.

Figure 3.20: Caustic Soda.

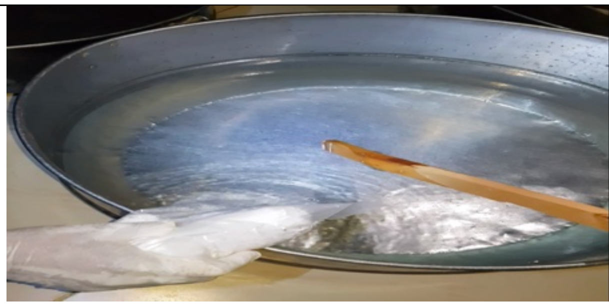

Figure 3.21: Caustic Soda being Poured in the Tub.

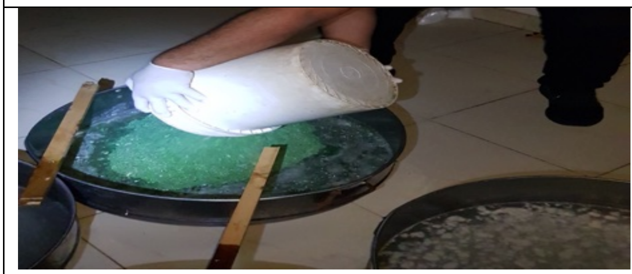

Figure 3.22: Plastic bring immersed in Caustic Soda.

Figure 3.23: Bleach.

Figure 3.24: Bleach being Poured in Tub.

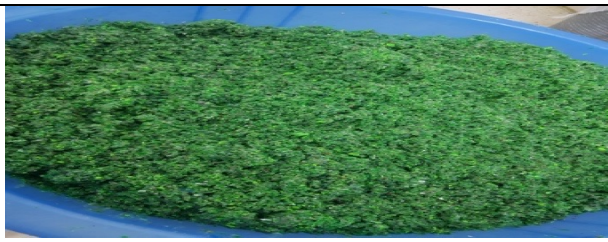

Figure 3.25: Plastic after Washing with water.

Figure 3.26: Plastic being Air Dried.

Figure 3.27: Plastic inside the concrete mixer being used as aggregate.

3.3.2. Concrete Mix Preparation

The concrete mix preparation involved blending several materials like, cement, fine aggregate, coarse aggregate, recycled PET plastic, water, micro silica, and admixture. Three mix designs were then prepared. The first mix was with all the natural aggregates for referencing. The second mix was with 5% replacement of the fine natural sand with recycled PET plastic, while the third mix had 10% replacement of the natural fine sand with recycled PET plastics.

To mix the concrete, a mechanical concrete mixer was used. The following steps were taken to obtain the concrete mix:

1. The mixer was cleaned thoroughly with water and dried.

2. The natural coarse aggregate with 10mm size was measured using weighing scale and poured into the mixer.

3. The natural coarse aggregate with 19mm size was measured using weighing scale and poured into the mixer.

4. The mixer was started, and the coarse aggregates were dry mixed for approximately 1 minute.

5. The natural fine aggregate was measured using weighing scale and poured into the mixer.

6. The mixer was again started, and the coarse aggregates and fine aggregates were dry mixed for approximately 1 minute.

7. In the case of trail mixes with recycled PET plastic replacement recycled PET was measured using weighing scale and poured into the mixer.

8. The mixer was again started, and the coarse aggregates and fine aggregates along with recycled PET plastics were dry mixed for approximately 1 minute.

9. Cement and Micro Silica was weighted using weighting scale and added to the mixer.

10. The mixer was again started, and the coarse aggregates and fine aggregates along with recycled PET plastics, cement and micro silica were dry mixed for approximately 1 more minute.

11. Water and admixture were gradually added at the regular intervals and mixer was run for additional 4-5 minutes, until the uniform consistency was achieved.

Figure 3.28: 10mm Coarse aggregate added.

Figure 3.29: 10mm and 19mm coarse aggregates are being mixed.

Figure 3.30: Coarse and Fine aggregate.

Figure 3.31: OPC.

Figure 3.32: Recycled PET for Preparing Trial Mix.

3.4. Fresh Concrete Properties

3.4.1. Slump Test

The slump test was conducted to assess the workability and consistency of the fresh concrete mix. The procedure followed was:

1. The slump cone, base plate, and tamping rod were cleaned and checked for any debris or damage.

2. The base plate was placed on a level, non-absorbent surface. The cone was then placed and filled with fresh concrete in three layers. Each layer was approximately one-third of the height of the cone.

3. Each layer was compacted with 25 strokes of the tamping rod, ensuring that the concrete was evenly distributed and free from air voids.

4. After compacting the third layer, the surface of the concrete was struck off with a straightedge to remove any excess material and ensure a level surface.

5. The cone was carefully lifted vertically upward, and the concrete was allowed to settle. The difference between the height of the cone and the highest point of the settled concrete was measured.

6. The slump value was recorded in millimetres.

Figure 3.33:Slump Test Being Conducted.

3.5. Sample Preparation Method

In this study, a total of 30 concrete samples were prepared to be tested at various curing stages i.e., 7, 14, and 28 days. Two types of moulds were used, cylindrical and rectangular. The cylindrical moulds were used for casting samples intended for compressive strength, split tensile strength, and fire tests, while the rectangular moulds were used for casting samples to undertake flexural strength testing. At each curing stage, 3 samples were cast from the each mix, control mix, 5% recycled PET mix, and 10% recycled PET mix. Additionally, for fire rating tests, 3 extra cylindrical samples were cast one from each mix design, to be tested after 28 days of curing. For all other tests, 3 samples were cast to obtain an average of the results.

The moulds were first cleaned thoroughly and lubricated with oil to ensure smooth demoulding. The bolts were then tightened to prevent leakage during casting.

After measuring the fresh concrete properties, the mix was poured into the moulds in three layers, each representing approximately one-third of the total height of the mould. Each layer was compacted using a 16 mm diameter tamping rod by tamping 25 times per layer to remove air voids and ensure uniform density. After filling and compacting the third layer, the surface of the concrete was levelled using a hand trowel to achieve a smooth finish.

The moulded samples were left undisturbed for 24 hours before demoulding. After demoulding, the samples were placed in a curing tank with water, until they reached their respective curing periods 7, 14, or 28 days. This ensured proper hydration and strength development in the samples. The average of three samples was taken at each testing stage to ensure reliable results.

Figure 3.34: Rectangular Mould being Lubricated.

Figure 3.35: Moulds Poured with Concrete.

Figure 3.36: Moulds being Demoulded.

Figure 3.37: Samples ready to be placed in curing tank.

3.6. Ultrasonic Pulse Velocity (UPV)

The UPV test was performed to assess the internal quality of the concrete. The steps followed are:

1. Cylindrical samples were surface-dried after curing for 7, 14, and 28 days.
2. A pulse transducer was placed on opposite sides of the specimen.
3. A pulse was sent through the specimen, and the travel time was measured.
4. The velocity was calculated using the formula:

$$UPV = \frac{L}{T}$$

where L is the path length and T is the travel time of the pulse.

The results were used to assess the homogeneity, presence of cracks, and voids within the concrete.

Figure 3.38: Ultrasonic Pulse Velocity Testing.

3.7. Hardened Properties

3.7.1. Compressive Strength

The compressive strength test was conducted on cylindrical concrete specimens. The following procedure was followed:

1. After curing for 7, 14, and 28 days, the specimens were removed from the curing tank and allowed to surface dry.
2. The samples were then placed in a Compression Testing Machine (CTM), the load was applied along the longitudinal axis, until the sample failed, and the maximum load was recorded.
3. The compressive strength was calculated using the formula:

$$Compressive\ Strength = \frac{P}{A}$$

where P is the maximum applied load and A is the cross-sectional area.

Figure 3.39: Compressive Strength Testing.

3.7.2. Flexural Strength

Flexural strength tests were conducted on rectangular beam to test the capacity of the concrete to resist against the bending force. The testing procedure is as follows:

1. After curing, the beams were removed from the tank and surface dried.
2. The beams were placed in the CTM with a four-point loading setup to simulate bending.
3. A constant load was applied until the beam failed, and the maximum load was recorded.
4. The flexural strength was calculated using the formula:

$$Flexural\ Strength = \frac{PL}{bd^2}$$

where P is the maximum load, L is the span, b is the width, and d is the depth of the beam.

Figure 3.40:Flexural Strength Testing.

3.7.3. Split Tensile Strength

The split tensile strength of concrete was tested using cylindrical specimens. The procedure involved:

1. After 7, 14, and 28 days, the samples were surface dried and placed horizontally in the CTM.
2. A compressive load was applied along the vertical diameter of the cylinder at a uniform rate until failure occurred.
3. The split tensile strength was calculated using the formula:

$$Split\ Tensile\ Strength = \frac{2P}{\pi LD}$$

where P is the maximum load, L is the length, and D is the diameter of the cylinder.

Figure 3.41: Split Tensile Strength Testing.

3.7.4. Fire Resistance

The fire resistance test was conducted to assess the performance of the concrete under extreme heat conditions. The procedure followed is as below:

1. Cylindrical specimens for all three mix designs were cured for 28 days.
2. The samples were exposed to a temperature of 950°C in a furnace for 60 minutes.
3. After cooling, the samples were tested for compressive strength using the CTM, and UPV was measured to evaluate any deterioration in internal structure.

Figure 3.42: Sample Placed in Furnace for Fire Testing.

Figure 3.43: Sample after Fire Testing.

Figure 3.44: Compressive Strength Testing after removing from Furnace.

Figure 3.45: After Compressive Strength Testing.

3.8. Summary

This chapter presented a detailed methodology for preparing and testing concrete specimens using recycled PET plastic as a partial replacement for fine aggregates. It outlined the materials, including OPC cement, natural coarse aggregates, Bolari sand as fine aggregate, recycled PET plastics, micro silica, and admixtures. The concrete mix designs were discussed, emphasizing the replacement percentages of PET plastic, and the mechanical and chemical treatments applied to the plastic.

The preparation of concrete involved blending the materials in a mechanical mixer. The methodology covered both fresh and hardened concrete tests, including slump tests for workability, compressive strength, flexural strength, split tensile strength, all conducted with a Compression Testing Machine (CTM). Additional, testing equipment like curing tanks, an ultrasonic pulse velocity tester, and a furnace for fire tests were also employed.

The procedures described are important for assessing the effect of recycled PET plastic on the strength and durability of concrete, with the aim of promoting sustainable construction practices.

4. Data Analysis

4.1. Introduction to Data Analysis

This chapter presents an overview of the results obtained from the testing of the concrete samples. The tests were conducted to investigate the workability using slump test, durability through ultrasonic pulse velocity and mechanical properties through compressive strength, flexural strength and split tensile strength testing. Additionally, three samples were subjected to extreme conditions by placing them in a furnace at a temperature of 950°C for 1 hour to assess the effect of fire using pulse velocity and compressive strength test. The results from these tests provide insights into the quality and mechanical properties of recycled PET when used as a partial replacement for fine aggregate in concrete, highlighting its effects on the overall mix design.

4.2. Fresh Concrete Properties

The fresh concrete properties of the three trial mixes were evaluated to understand the workability of the concrete when natural fine aggregates were partially replaced with recycled PET plastics. The slump test was conducted to investigate the consistency and ease of handling of the concrete. This method provides understandings into how the replacement of fine aggregates affects the overall workability of the concrete mix.

4.2.1. Slump Test

The table and figure below, provides the results obtained from the slump test conducted on the three trial mixes, control mix which had 0% PET, 5% PET replacement mix and 10% PET replacement mix. The result for the control mix was 100 mm slump value, while for the 5% PET replacement mix and 10% PET replacement mix had slump values of 150 mm and 180 mm respectively.

Table 4.1: Slump Test Results.

Mix Type	**Slump (mm)**
Control Mix (0% PET)	100
5% PET Mix	150
10% PET Mix	180

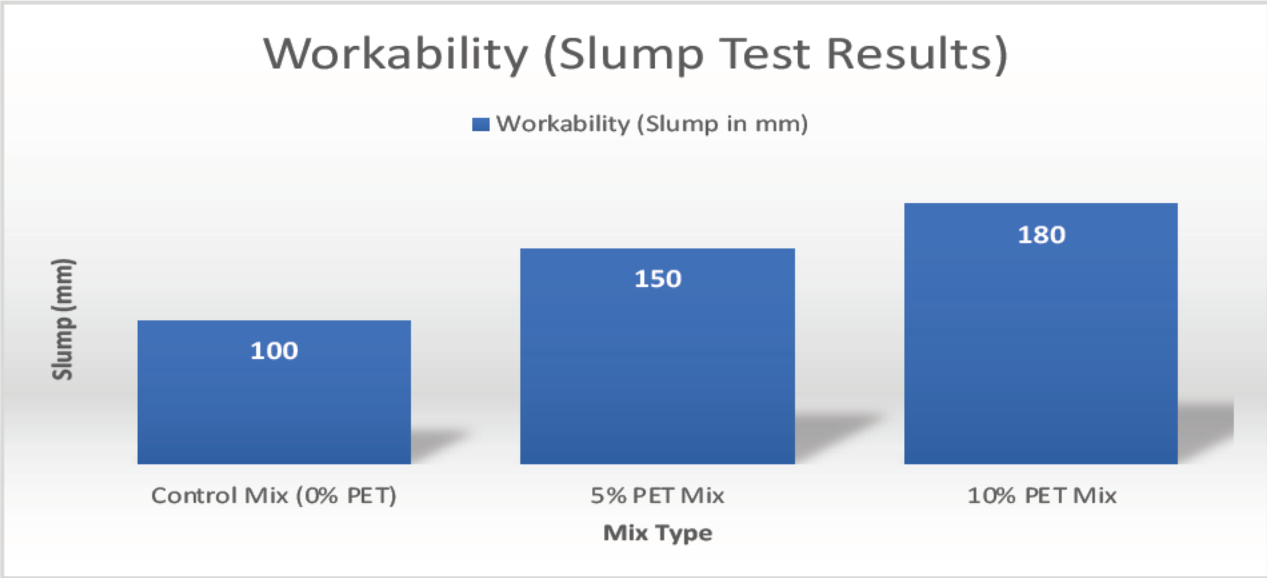

Figure 4.1: Slump Test Results.

The increasing slump value with the increase in replacement percentage of natural fine aggregate with recycled PET indicates that the workability improves with the addition of the PET plastics. The increase in workability of the concrete may be because of the smoother surface and lower water absorption of the PET particles, which make the concrete easier to mix and handle.

The findings are consistent with previous studies. (Choi et al. 2005) observed that incorporating PET as a partial replacement for fine aggregates increased the slump value, indicating improved workability. They attributed this to the smooth and hydrophobic nature of PET particles, which reduces water demand in the mix. Similarly, (Frigione 2010) reported that the addition of PET aggregates enhanced the workability of concrete due to their shape and surface characteristics.

However, while improved workability is beneficial for ease of placement, it is essential to monitor the mix to prevent segregation and ensure uniformity. Adjustments in mix design for example using admixtures might be necessary to maintain the desired consistency without compromising the concrete's structural integrity.

4.3. Ultrasonic Pulse Velocity (UPV) Analysis

The ultrasonic pulse velocity test was conducted on the concrete samples from all the three trial mixes at each curing stage of 7, 14, and 28 days, to assess the durability and internal integrity of the concrete. The ultrasonic pulse velocity test measures the velocity of sound waves passing through the concrete, with higher velocities implying denser and higher-quality concrete, while lower velocities suggest the presence of voids, cracks, or other imperfections. The ultrasonic pulse velocity values provide the breakdown about the concrete quality and usually higher values above 4.5 mm/µs are for the excellent quality concrete. The concrete with the ultrasonic pulse velocity values between 3.5 mm/µs and 4.5 mm/µs is termed as good quality concrete and concrete below 3.5 mm/µs is termed as poor-quality concrete.

The table and figure below show the ultrasonic pulse velocity test results for the control mix, 5% PET replacement mix and 10% PET replacement mix at the curing stage of 7 days, 14 days and 28 days.

Table 4.2: Ultrasonic Pulse Velocity Test Results.

Type of Mix	Curing Period (Days)	Diameter (mm)	Height (mm)	PET Content (%)	Ultrasonic Pulse Velocity (mm/µs)
Mix 1 (Control Mix)	7	152.4	304.8	0	4.58
Mix 2 (5% replacement of natural Fine Aggregate with recycled PET)	7	152.4	304.8	5	3.82
Mix 3 (10% replacement of natural Fine Aggregate with recycled PET)	7	152.4	304.8	10	3.22
Mix 1 (Control Mix)	14	152.4	304.8	0	4.57
Mix 2 (5% replacement of natural Fine Aggregate with recycled PET)	14	152.4	304.8	5	4.24
Mix 3 (10% replacement of natural Fine Aggregate with recycled PET)	14	152.4	304.8	10	3.68
Mix 1 (Control Mix)	28	152.4	304.8	0	4.73
Mix 2 (5% replacement of natural Fine Aggregate with recycled PET)	28	152.4	304.8	5	4.38
Mix 3 (10% replacement of natural Fine Aggregate with recycled PET)	28	152.4	304.8	10	3.9

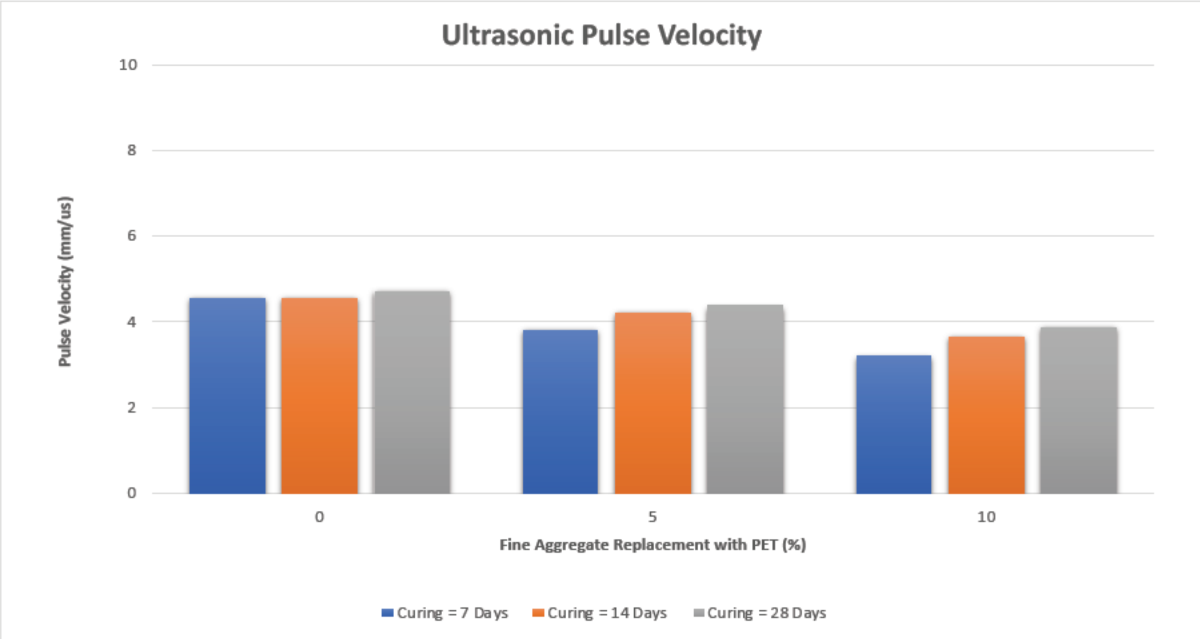

Figure 4.2: Ultrasonic Pulse Velocity Test Results.

The control mix which had 0% PET plastic, had the UPV value of 4.58 mm/µs at 7-days of curing, suggesting it as an excellent quality concrete, while at 14 day curing stage the UPV value was 4.57 mm/µs a slight decrease of 0.01 mm/µs was noticed here, although the values still suggested that the concrete is of excellent quality. However, after 28 days of curing the UPV value was 4.73 mm/µs. The UPV values suggests that the control mixes at all the curing stages were of excellent quality concrete.

The 5% PET replacement concrete had the UPV value of initially 3.82 mm/µs at the 7-day curing stage suggesting a good quality concrete, which further improved with curing and at 14 day curing stage the result was 4.24 mm/µs. However, by the 28th day of curing the results were promising with 4.38 mm/µs making the 5% mix at 28 days curing stage almost excellent quality concrete. The trend for the 5% PET replacement mix suggests that the quality of the concrete increases with the increase in curing period.

In contrast the 10% PET replacement concrete, at the 7-day curing had the UPV value of 3.22 mm/µs, indicating poor quality of the concrete, while at 14 days of curing the UPV values increased with 3.68 mm/µs, making it a fair quality concrete. The trend continued and at 28 days of the curing the UPV values further increased with 3.9 mm/µs but still the concrete with 10% PET replacement failed to attain the excellent quality. Moreover, the trend of increase in UPV values with the increase in curing time was also observed here.

The results show that the control mix continues to show excellent quality throughout all curing stages, while with the addition of the PET plastics the quality of concrete decreases, with 5% PET replacement mix displaying significant improvement, approaching excellent quality at 28 days. In contrast, the 10% PET replacement mix, although improving with curing, remains in the medium-to-low quality range, suggesting that higher PET content negatively affects the concrete's density and internal structure.

The UPV results in this study are consistent with previous literatures on PET mixed concrete, for example, (Almeshal et al. 2020) reported similar trends, noting that UPV values decreased as PET content increased, indicating a less dense and less homogeneous structure. In their study, PET replacement ratios of 10% showed lower UPV values, corresponding to the poor-to-fair quality rating found in the current study for the 10% PET mix. This correlation supports the conclusion that high PET content reduces internal concrete quality.

Moreover, (Thorneycroft et al. 2018) also recorded reduced UPV values in PET concrete, particularly when the PET was untreated or of larger particle sizes. The treatment process and particle gradation significantly influenced the quality of concrete, with higher UPV values reported for mixes with treated PET particles. While in this study PET was chemically treated to enhance bonding, but the UPV values remained lower for PET mixes compared to the control.

Another study conducted by (Marzouk et al. 2007) demonstrated that PET replacement, even up to 50%, maintained acceptable UPV values, provided that particle sizes were controlled. In this study the particle size of the PET was maintained below 4.75mm and it was observed that, though there was a decrease in UPV with PET inclusion, the 5% PET mix still achieved a good quality result by 28 days, which suggests that a low replacement level with proper particle grading could still yield durable concrete.

In summary, the current study's UPV results validate findings with the other previous literatures, showing that PET inclusion can impact internal integrity. However, lower PET replacement levels show potential to retain concrete quality, while higher levels may compromise durability and homogeneity.

4.4. Mechanical Properties

The mechanical properties of the three trial mixes, control mix, 5% PET replacement mix and 10% PET replacement mix at 7,14 and 28 days of curing were evaluated using, compressive strength, split tensile strength and flexural strength tests. These tests were conducted to analyse the behaviour and performance of the concrete incorporating recycled PET under various load conditions.

4.4.1. Compressive Strength

The compressive strength is one of the most important mechanical properties, determining the ability of the concrete to withstand compressive loads. The results of the compressive strength tests for each trial mix at each curing stage are presented in the table and figure below.

Table 4.3: Compressive Strength Results.

Type of Mix	Curing Period (Days)	Diameter (mm)	Height (mm)	PET Content (%)	Max. Load (kN)	Compressive Strength (MPa)
Mix 1 (Control Mix)	7	152.4	304.8	0	995.886	54.6
Mix 2 (5% replacement with recycled PET)	7	152.4	304.8	5	629.587	34.5
Mix 3 (10% replacement with recycled PET)	7	152.4	304.8	10	586.786	31.2
Mix 1 (Control Mix)	14	152.4	304.8	0	1110.603	60.9
Mix 2 (5% replacement with recycled PET)	14	152.4	304.8	5	752.17	41.2
Mix 3 (10% replacement with recycled PET)	14	152.4	304.8	10	550.644	30.2
Mix 1 (Control Mix)	28	152.4	304.8	0	1478.843	81.0
Mix 2 (5% replacement with recycled PET)	28	152.4	304.8	5	775.706	42.5
Mix 3 (10% replacement with recycled PET)	28	152.4	304.8	10	732.557	40.1

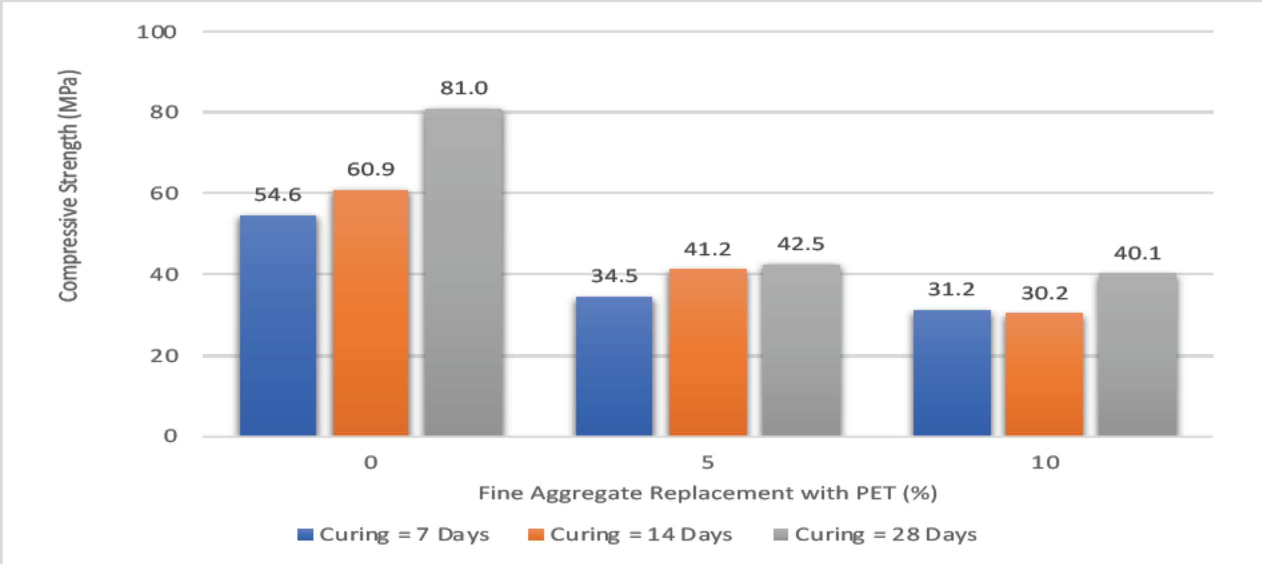

Figure 4.3: Compressive Strength Results

The concrete sample of control mix at the 7-day curing stage had a compressive strength of 54.6 MPa, while with the addition of the PET aggregate the decrease in compressive strength was observed. The 5% PET replacement mix had a compressive strength of 34.5 MPa, and 10% PET replacement had a compressive strength of 31.2 MPa. This indicates that the control mix had better early age compressive strength than the PET replacement mixes, while 5% PET replacement mix performed better than the 10% PET mix but still a reduced compressive strength in comparison to the control mix was noticed.

At the 14 days of the curing, the improvement in compressive strength of all the trial mixes was observed. The control mix outperformed the 5% and 10% PET replacement mixes, with a compressive strength of 60.9 MPa. The 5% PET replacement mix, and 10% PET replacement mix had the compressive strength of 41.2 MPa and 30.2 MPa respectively. However, with the curing the 5% PET replacement mix performed better but still was outperformed by the control mix.

By the 28th day of curing the control mix attained the compressive strength of 81 MPa confirming its superior performance. The 5% PET replacement mix improved from the 14-day curing stage and had a compressive strength of 42.5 MPa. Moreover, the improvement in the compressive strength of the 10% PET replacement mix was also recorded with almost 10 MPa gain from the 14-day curing stage with a compressive strength of 40.1 MPa. The compressive strength results from this study align with previous research, indicating that PET plastic replacement generally reduces compressive strength as PET content increases. For instance, (Choi et al. 2005) observed similar trends where PET replacement led to reduced compressive strength at higher replacement levels. Their findings showed that as the replacement ratio increased from 0% to 75%, compressive strength decreased by up to 21% by 28 days, comparable to the reduction observed in the 5% and 10% PET mixes in this study.

(Frigione 2010) also reported that replacing natural fine aggregates with PET plastic results in slight reductions in compressive strength, although their 5% replacement level only showed a minor decrease (around 2%) after one year. This aligns with the relatively better performance of the 5% PET mix in the current study.

(Rahmani et al. 2013) found that increasing PET content led to a decrease in compressive strength, with replacement levels beyond 10% resulting in significant strength loss. Findings of this study are similar, as the 10% PET mix consistently showed the lowest compressive strength across curing stages.

The findings from the current study align with these previous works, highlighting that the results of the compressive strength test suggested that the increase in the PET content decreases the compressive strength of the concrete however, with the curing the compressive strength increases. The 5% mix performed better than the 10% mix, but both the mixes showed reduced compressive strength in comparison to the control mix.

4.4.2. Split Tensile Strength

The split tensile strength tests assess the ability of the concrete to resist tensile forces, which is critical for concrete's performance when subjected to lateral or splitting forces.

The table and figure below present the results obtained from the split tensile strength test for the three mixes, control mix, 5% PET replacement mix, and 10% PET replacement mix at the curing stage of 7, 14, and 28 days.

Table 4.4: Split Tensile Strength Test Results.

Type of Mix	Curing Period (Days)	Diameter (mm)	Height (mm)	PET Content (%)	Max. Load (kN)	Split Tensile Strength (MPa)
Mix 1 (Control Mix)	7	152.4	304.8	0	352.059	5.0
Mix 2 (5% replacement with recycled PET)	7	152.4	304.8	5	280.47	3.8
Mix 3 (10% replacement with recycled PET)	7	152.4	304.8	10	277.038	3.8
Mix 1 (Control Mix)	14	152.4	304.8	0	453.558	6.2
Mix 2 (5% replacement with recycled PET)	14	152.4	304.8	5	281.451	3.9
Mix 3 (10% replacement with recycled PET)	14	152.4	304.8	10	259.876	3.6
Mix 1 (Control Mix)	28	152.4	304.8	0	537.859	7.4
Mix 2 (5% replacement with recycled PET)	28	152.4	304.8	5	318.226	4.4
Mix 3 (10% replacement with recycled PET)	28	152.4	304.8	10	299.103	4.1

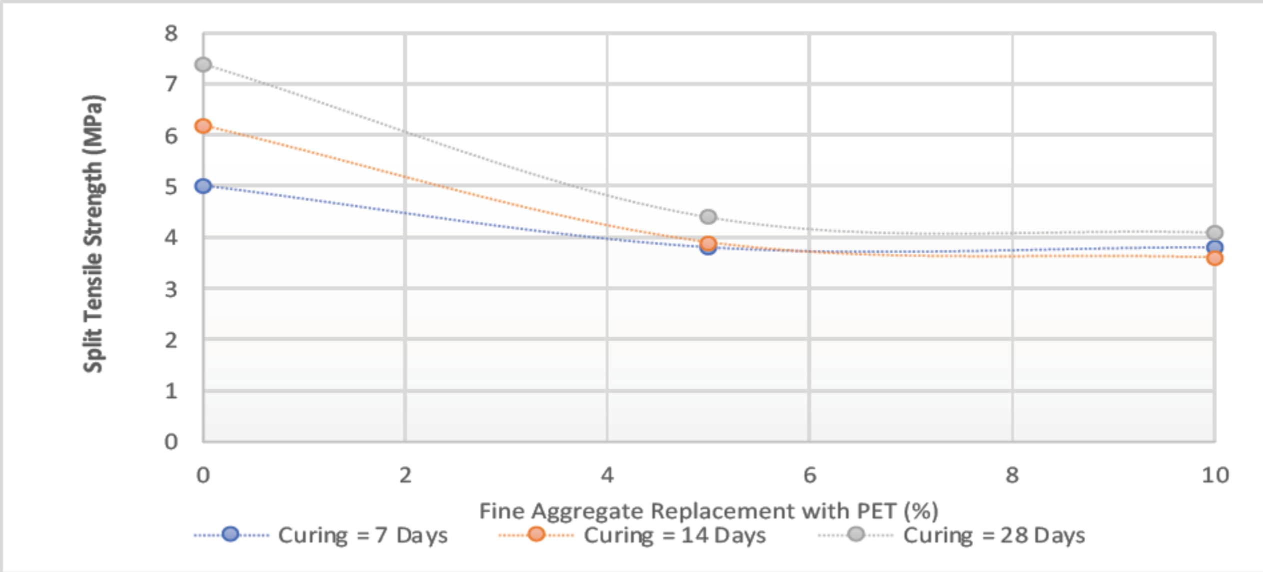

Figure 4.4: Split Tensile Strength Test Results.

At the 7-day curing stage, the control mix had the split tensile strength of 5 MPa, while the 5% PET replacement mix and 10% PET replacement mix both displayed the split tensile strength of 3.8 MPa.

The split tensile strength of the control mix and 5% PET replacement mix at the 14-day curing stage improved with control mix exhibiting a split tensile strength of 6.2 MPa and 5% PET replacement mix showing a slight increase of 0.1 MPa with a total of 3.9 MPa. However, for the 10% PET replacement mix a reduction in the split tensile strength was noticed with a drop of 0.2 MPa bringing it to a split tensile strength of 3.6 MPa.

However, all three trail mix at 28 day curing stage, recorded improvements in the split tensile strength, with control mix performing better than the other two mixes with a split tensile strength of 7.4 MPa, while the 5% PET replacement mix and 10% PET replacement mix displayed the split tensile strength of 4.4 MPa and 4.1 MPa respectively. These results align with findings from previous studies, where increasing PET content generally led to reduced split tensile strength. (Choi et al. 2005) similarly observed a decline in tensile strength with increased PET replacement. They found that PET replacements exceeding 25% significantly compromised tensile properties, which aligns with the current study's results, where the increase in PET content reduces the split tensile strength of the mixes.

(Frigione 2010) and (Rahmani et al. 2013) also reported that PET replacement concrete mix exhibited reduced split tensile strength compared to conventional concrete. Their study found that lower PET replacement percentages showed only minor decreases, comparable to the modest reduction in the 5% PET mix in this study. However, with the increase in PET content significant reduction was notices, similar trends were observed in this study.

The results of the split tensile strength tests confirms that the addition of PET content reduces the tensile strength of the concrete. However, with the curing improvement in the split tensile strength was recorded, with the 5% PET mix consistently performing better than the 10% PET mix, although both mixes were significantly outperformed by the control mix across all curing stages. Moreover, the result of the split tensile strength for both the 5% PET replacement mix and 10% PET replacement mix were almost 10% of the compressive strength at the 28 days curing stage suggesting that the mixes can be classified as good quality concrete in terms of split tensile strength.

4.4.3. Flexural Strength

The flexural strength test measures the concrete's ability to resist bending forces, which is critical in applications such as beams, slabs, and pavements where bending stresses occur. The flexural strength test results for the control mix, 5% PET replacement mix, and 10% PET replacement mix at curing stages of 7, 14, and 28 days are presented in the table and figure below.

Table 4.5: Flexural Strength Test Results.

Type of Mix	Curing Period (Days)	PET Content (%)	Max. Load (kN)	Flexural Strength (MPa)
Mix 1 (Control Mix)	7	0	50.504	6.5
Mix 2 (5% replacement of natural Fine Aggregate with recycled PET)	7	5	35.794	4.6
Mix 3 (10% replacement of natural Fine Aggregate with recycled PET)	7	10	25.007	3.2
Mix 1 (Control Mix)	14	0	57.859	7.5
Mix 2 (5% replacement of natural Fine Aggregate with recycled PET)	14	5	39.717	5.1
Mix 3 (10% replacement of natural Fine Aggregate with recycled PET)	14	10	31.381	4.1
Mix 1 (Control Mix)	28	0	70.608	9.1
Mix 2 (5% replacement of natural Fine Aggregate with recycled PET)	28	5	41.678	5.4
Mix 3 (10% replacement of natural Fine Aggregate with recycled PET)	28	10	38.246	4.9

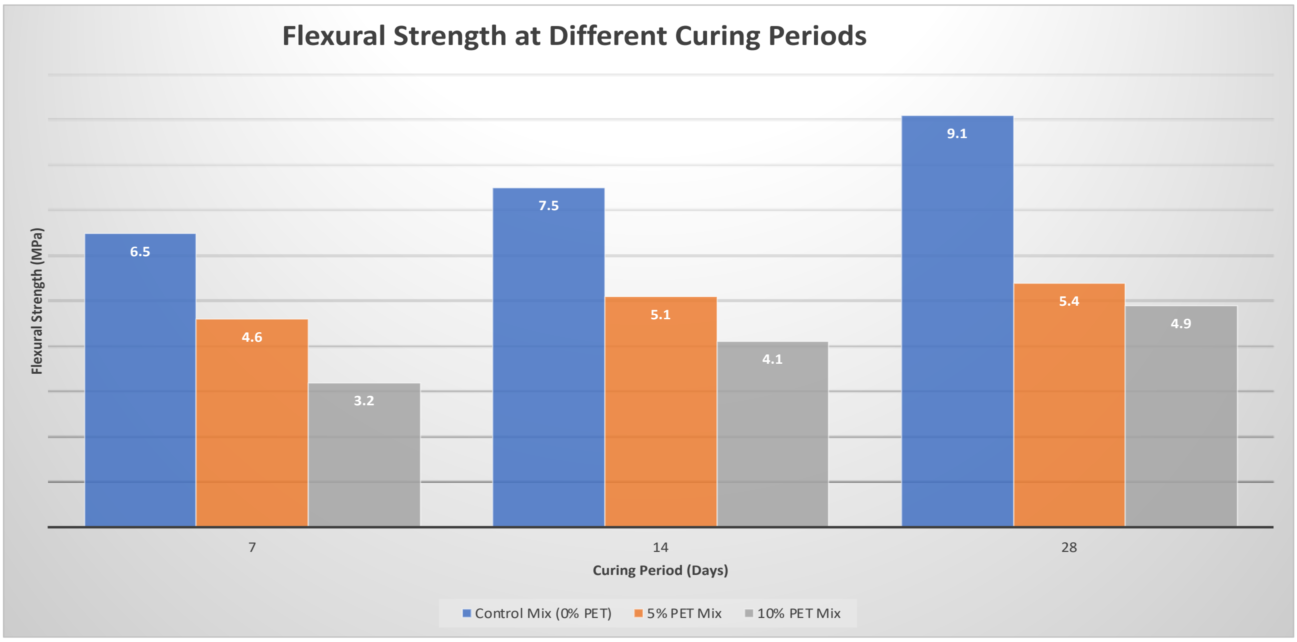

Figure 4.5: Flexural Strength Test Results.

At the 7-day curing stage, the control mix showed the flexural strength of 6.5 MPa, while the 5% PET and the 10% PET replacement mix had a value of 5.3 MPa, and 4.8 MPa respectively. These results suggest that the addition of PET affects the early-stage flexural strength of the concrete. However, the 5% PET mix still performed better than the 10% PET mix. But both PET mixes had lower flexural strength than the control mix.

At the 14-day curing stage, all mixes showed an increase in flexural strength. The control mix reached 6.7 MPa, while the 5% PET replacement mix improved to 5.5 MPa and the 10% PET replacement mix increased to 4.9 MPa. Despite the improvements across all mixes, the control mix continued to outperform the PET mixes.

By the 28^{th} day of curing, the control mix displayed a flexural strength of 7.2 MPa. The 5% PET replacement mix increased to 5.8 MPa, and the 10% PET replacement mix showed an improvement to 5.1 MPa. The results prove that the PET mixes improve the flexural strength with the curing. The flexural strength results of this study align with findings in previous studies, which indicate that PET inclusion generally reduces concrete's flexural performance

(Choi et al. 2005) found that PET replacement concrete displayed reduced flexural strength, particularly at replacement levels above 5%. Their results showed that higher PET contents reduced bending strength significantly, which is consistent with the current study, where the 10% PET mix displayed the lowest flexural strength at each curing stage.

(Frigione 2010) noticed similar results, reporting that concrete with PET aggregates experienced moderate reductions in flexural strength but remained within acceptable ranges. This aligns with the findings in this study, where the 5% PET mix maintained satisfactory flexural strength relative to the control mix.

(Thorneycroft et al. 2018) observed that PET replacement concrete could maintain acceptable flexural performance at lower replacement levels. This supports the trend observed in this study, where the 5% PET replacement mix performed better than the 10% PET mix.

The results in this study support previous research, indicating that while PET addition reduces flexural strength, however, all mixes still fall within acceptable ranges of 10% to 15% of the 28-day compressive strength according to Australian standards. The 5% PET replacement mix performs relatively well in comparison to the 10% PET replacement mix. This suggest that the 5% PET replacement mix may still be suitable for lower-stress applications.

4.5. Fire Test Results

Fire tests were conducted on the concrete samples to assess their performance under high temperatures. The concrete specimens were exposed to a temperature of 950°C for 1 hour to replicate fire conditions, after which the Ultrasonic Pulse Velocity (UPV) and compressive strength were measured. These tests provided understanding of the structural integrity and durability of the concrete when subjected to extreme heat.

The table and figure below present the ultrasonic pulse velocity and the compressive strength test results for the control mix, 5% PET replacement mix, and 10% PET replacement mix after exposure to extreme temperatures.

Table 4.6: Results for ultrasonic pulse velocity and compressive strength after extreme temperature conditions.

Type of Mix	Curing Period (Days)	Diameter (mm)	Height (mm)	PET Content (%)	Max. Load (kN)	Compressive Strength (MPa)	Ultrasonic Pulse Velocity (mm/µs)
Mix 1 (Control Mix) Burnt	28	152.4	304.8	0	139.745	7.7	1.7
Mix 2 (5% replacement with recycled PET) Burnt	28	152.4	304.8	5	75.511	4.1	1.65
Mix 3 (10% replacement with recycled PET) Burnt	28	152.4	304.8	10	44.13	2.4	1.52

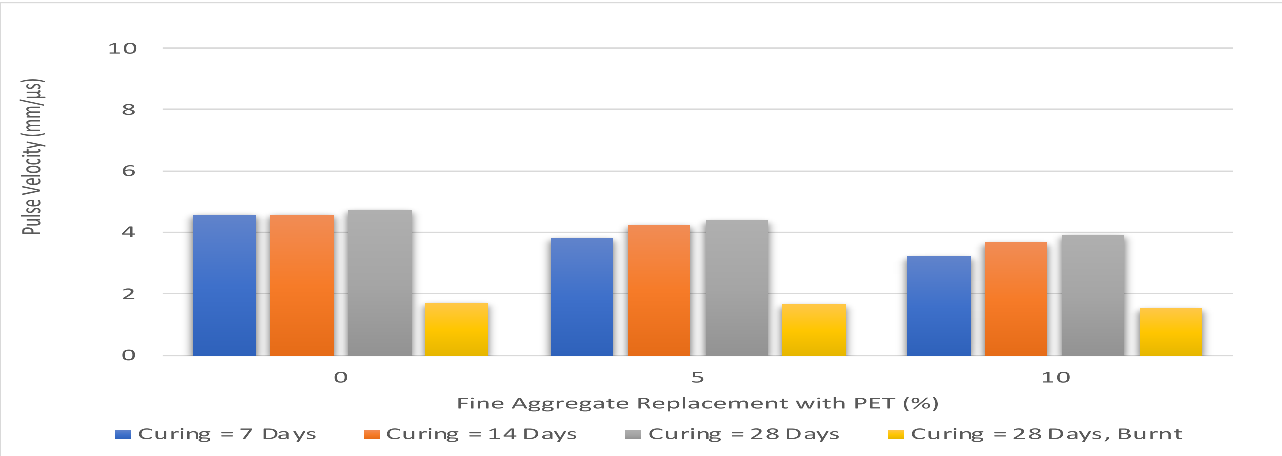

Figure 4.6: Results for ultrasonic pulse velocity after extreme temperature conditions.

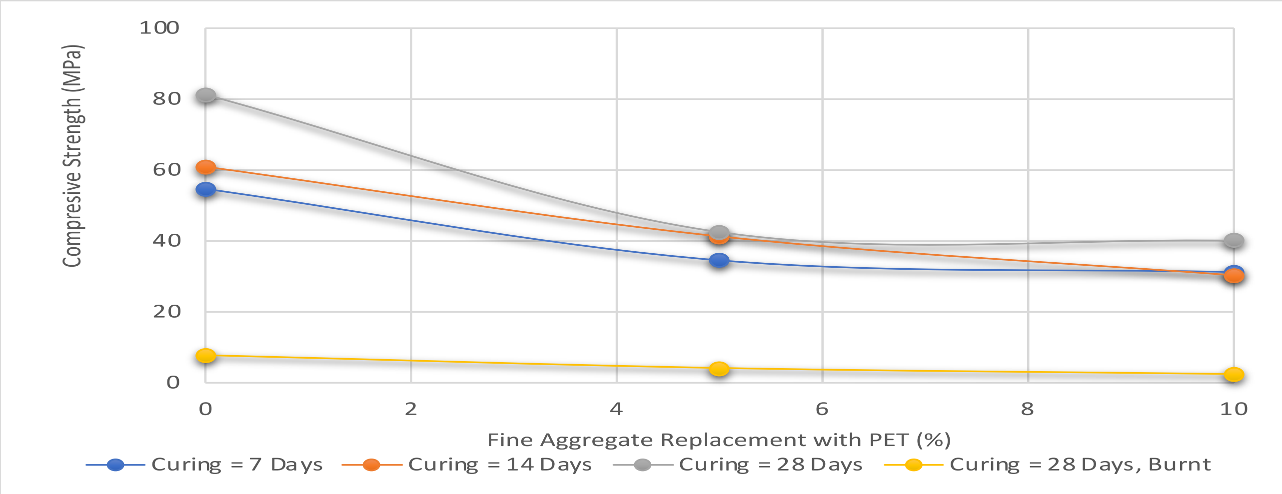

Figure 4.7: Results for compressive strength after extreme temperature conditions.

4.5.1. Ultrasonic Pulse Velocity

After removing the samples from furnace, they were cooled and then tested for the ultrasonic pulse velocity, the control mix displayed a UPV value of 1.7 mm/µs, significantly lower than its pre-fire value. For the 5% PET replacement mix, the UPV value dropped to a 1.65 mm/µs. The 10% PET replacement mix showed the lowest UPV value at a 1.52 mm/µs, indicating greater internal damage compared to the other mixes. The results show that while all mixes experienced reductions in UPV after fire exposure, the control mix retained relatively better internal integrity compared to the PET mixes.

4.5.2. Compressive Strength

The compressive strength of the concrete samples post exposure was heavily reduced with, the control mix displaying a compressive strength of 7.7 MPa, showing a significant reduction from its pre-fire strength. The 5% PET replacement mix recorded a compressive strength of 4.1 MPa, representing a larger reduction in strength, which suggests that the presence of PET aggregates compromised the concrete's ability to withstand extreme heat. The 10% PET replacement mix showed the highest reduction, with a compressive strength of 2.4 MPa, highlighting its vulnerability to fire exposure.

The results of this study align with findings from previous research, where concrete with PET replacements demonstrated reduced fire resistance. (Frigione 2010) reported that PET replacement concrete displayed reduced structural integrity under high temperatures, primarily due to the melting and decomposition of PET at higher temperatures. This supports the current study’s results, where both PET mixes showed considerable reductions in UPV and compressive strength, with the 10% PET mix displaying the lowest values.

(Almeshal et al. 2020) reported that PET replacement concrete exposed to temperatures above 600°C experienced significant degradation in mechanical properties. Their findings showed similar patterns with this study, where with the increase in PET content displayed greater weakness to thermal damage.

The results of the fire resistance test of this study agree with previous research, indicating that incorporating PET into concrete reduces its fire resistance, with increased PET content the greater degradation in both UPV and compressive strength was recorded. The control mix retained the most integrity post fire, while PET mixes, especially the 10% replacement, demonstrated higher weakness to fire damage, thus limiting their suitability in high-temperature environments.

4.6. Summary of Results

Various tests were conducted on the concrete samples of control mix, 5% PET replacement mix and 10% PET replacement mix to assess the fresh concrete properties, durability, mechanical properties, and fire resistance of the concrete mix when the natural fine aggregates are partially replaced with the recycled PET plastics. The results obtained were presented and discussed in this chapter.

The slump test results suggest that the incorporation of the PET increases the workability of the concrete mix, particularly at the higher PET content. This observation is consistent with previous literatures where it was noticed that PET particles tend to improve workability due to their smoother surface and low water absorption.

During the ultrasonic pulse velocity testing, it was noticed that the however, all the samples from the three trial mixes, control mix, 5% PET replacement mix and 10% PET replacement mix had values which suggest that the concrete was of good quality and was improving with the curing, but control mix was found to be of excellent quality. These results align with previous studies where mostly the findings were that the UPV values tend to be lower in PET replaced concrete compared to control mixes, however, PET mixes still retain reasonable integrity.

The mechanical properties were conducted to investigate the compressive strength test, split tensile strength test and flexural strength test. The results obtained were consistent with the previous works and suggested that the inclusion of the PET, concrete decreases the mechanical properties however, the curing benefited the PET mixes, and the mechanical properties found to be increasing with increase in curing, but PET mixes were still outperformed by control mix.

The exposure to high temperature suggested that the concrete losses its durability and strength heavily, but the PET mixes compromised the strength and durability drastically in contrast to the control mix.

To summarize, the results from all the tests suggested that the concrete with PET plastic mix at low replacement percentage still maintained enough durability and mechanical strength that it can be used in low preforming structural elements and applications or where higher workability is required but its use in the high-performance structural elements and fire prone area is not recommended.

5. Conclusion & Recommendations

In this study the feasibility of using recycled PET plastics as a partial replacement for natural fine aggregates in concrete mixes is investigated.

- Three trial mixes were prepared, the control mix with 0% PET, 5% PET replacement mix, and 10% PET replacement mix.
- The concrete mixes were initially assessed for the fresh concrete properties using slump test.
- Then the samples were prepared and placed in curing tank.
- The samples were then tested at 7, 14 and 28 days of curing for the durability, mechanical properties and fires resistance.
- The slump test showed that replacing fine aggregates with PET considerably improved the concrete's workability, particularly at the higher PET content.
- The improvement can be due to the smooth surface and low water absorption of PET particles, which reduce friction, hence increasing workability.
- Through ultrasonic pulse velocity (UPV) tests durability of the concrete samples was assessed.
- The control mix throughout all the curing stages maintained the excellent quality.
- However, the 5% PET replacement mix and 10% PET replacement mix demonstrated good results and improvements with the curing, particularly the 5% PET replacement mix nearing the excellent quality concrete values at the 28-day curing stage but, both the mixes still under performed in comparison to the control mix.
- The mechanical properties were analysed by conducting compressive strength, split tensile strength, and flexural strength tests.
- It was observed that they mechanical properties were decreasing with the increase in PET content.
- While curing benefited and the mechanical properties of the PET replacement mixes increased, but they still were outperformed by the control mix.
- The 5% PET mix performed better than the 10% mix, indicating that lower PET content is more suitable for maintaining structural integrity.
- The fire resistance tests revealed that all concrete mixes experienced significant reductions in both ultrasonic pulse velocity and compressive strength after exposure to high temperatures.
- However, the PET replacement mixes particularly at the higher PET content were affected the most.

In conclusion, the research determined that PET replacement mix can be used in applications where higher workability is required and structural performance is not critical. The 5% PET replacement mix offers the most promise, maintaining acceptable durability and strength for use in low-stress environments. However, its use in high-performance structural applications or fire-prone areas is not recommended.

5.1. Recommendations

1. Further research should be conducted to examine the long-term durability and performance of PET replacement mix, particularly under varying environmental conditions, such as freeze-thaw cycles and water exposure.

2. While the 5% PET replacement mix showed promising results, optimization of PET content below 5% could be explored to find an ideal balance between workability and mechanical properties, potentially improving its suitability for a broader range of applications.

3. To address the reduction in fire resistance observed in PET replacement mix, including fire-resistant additives or coatings could help mitigate the detrimental effects of high temperatures.

4. The use of PET replacement mix could be employed in non-load-bearing elements or applications requiring high workability, such as floor slabs, partition walls, and precast elements. However, its use in load-bearing and high-temperature environments should be limited.

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Appendix A

Specification and Work Plan

Specification and Work Plan

Title: Concrete Mix Design using Recycled PET Plastics as Partial Replacement of the Natural Fine Aggregate
Name: Majid Ali
Student ID: [redacted]
Supervisor: Belal Yousif

Introduction and Background:

The improvement in socio-economic condition has eased the life, which resultantly has reduced the health and security issues thus improving the quality of life. This improvement has increased the average lifespan of the general population around the world. However, with the growth in the population then comes the increase in general municipal waste generated around the globe. It is projected that the waste produced by 2050 is around 3.40 billion tons as compared to the 2.01 billion tons in 2016(Kaza et al. 2018).

There are various contributors in generation of municipal waste and plastics are one of the major contributors in the municipal waste and a nuisance in its management because of the slow degradation of the plastics. Since 1950's almost 1 billion tons of the plastics have been discarded which can take up to hundreds or even thousands of the years to degrade(Subramanian 2019).

Global plastic production has surged due to its versatile applications and desirable properties, particularly its widespread use in single-use products. Thus, plastic waste has become a significant global challenge, with approximately 60% of post-consumer plastic waste ending up in the environment, landfills, or oceans. Polyolefins, HDPE, LDPE, LLDPE, and PP constitute about 60% of plastic waste, while PET, PVC, PS, and other minor polymers make up the remaining 40%. Despite efforts, only 12% of plastic waste is recycled, while 25% is incinerated, leaving the majority unmanaged(Lange 2021)

PET plastics offer excellent properties such as temperature resistance, strength, and chemical resistance, making them versatile but also significant contributors to plastic waste accounting for around 26.8% of total plastic waste(Bernat 2023). To address PET waste, various recycling methods exist, including mechanical, chemical, and bio recycling, as well as upcycling. One innovative approach being explored involves incorporating waste PET into concrete mixtures as a partial replacement for fine aggregate, offering a cost-effective solution that could mitigate environmental impact and conserve natural resources.

The construction industry is one of the major consumers of the world resources. This industry alone consumes almost 32% of the total world resources, this includes 12% of the total fresh water supply and approximately 40% of the energy. Nearly 40% of the raw material extracted from earth is consumed by this industry along with approximately 25% of the virgin wood(Yeheyis et al. 2013).

An important component of the construction industry is concrete which comprises of cement, water, coarse aggregate, and fine aggregate. Globally the demand of the aggregates has reached an enormous 40 billion tons annually(Tam et al. 2018).

Overall, the research aims to proves the possibility of using PET waste in concrete mix, a low-cost alternate material with good properties. This method not only tackles solid waste problems especially plastics but also contributes to protection of the natural aggregates and provides a sustainable option.

Objectives and Aims:

The main aim of the work is to evaluate the performance of concrete mix with partial replacement of the natural fine aggregate with recycled PET plastic.

Specific Objectives:

- Successful incorporation of recycle PET plastic aggregates to develop a sustainable concrete mix.
- Investigate the fresh and hardened properties of the concrete mix to understand the performance and durability.
- Compare the findings with conventional concrete mix.

Expected Outcomes:

- Development of the sustainable concrete mix design.
- Reduction of the PET plastic waste.
- Motivation to collect the waste PET plastics.
- Reduction in the extraction of the natural resources and preservation of the ecosystem.

Work Plan

- **Months 1-4: Project Initiation and Proposal, Literature Review and Methodology**
  - Develop a project plan and submit the proposal.
  - Gain the approval from the supervisor.
  - Conduct an in-depth literature review on replacement of the PET plastic as fine aggregate in concrete mix.
  - Finalize the research design and methodology.
- **Months 5-6: Prepare Samples and conduct the tests.**
  - Prepare the materials.
  - Prepare the concrete mix using recycled PET.
  - Conduct the tests to analyse the fresh concrete properties.
  - Prepare the specimens.
  - Conduct the tests on the specimens to analyse the mechanical properties of the concrete.
  - Begin data collection and analysis.
- **Months 7-9: Report Writing**
  - Compile findings into a comprehensive report.
  - Submit the draft for check.
- **Month 10: Finalizing and Presenting Results**
  - Review and finalize the report.
  - Prepare a presentation summarizing key findings and recommendations.

Resources Required:

- **Equipment:**
  - Grinder for grinding the recycled PET plastics.
  - Sieve to analyse the grading of natural and plastic aggregates.
  - Concrete mixer to manufacture the concrete.
  - Fresh concrete testing equipment's like cone and board.
  - Moulds for specimen.
  - Machines to test mechanical properties.
- **Software:**
  - Word
  - Excel.
  - Adobe acrobat reader.
  - Endnote.
- **Access:**
  - Access university library resources and online databases for literature review.
  - Google Scholar

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Appendix B

Project Risk Assessment

B.1 Risk Assessment for Concrete Mixer

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Risk Assessment for Concrete Mixer

1. General Information
   - **Assessment Date:** 15th August 2024
   - **Assessor Name:** Muhammad Obaid
   - **Location:** Soilmat Engineers, Karachi
   - **Reviewed By:** Ejaz Shah
2. Equipment Details
   - **Equipment Name:** Concrete Mixer
   - **Manufacturer:** S.G corporation
   - **Model Number:** SG-212-22
   - **Serial Number:** FC-QC-10

3. Hazard Identification and Risk Assessment Table

Hazard	Risk	Likelihood	Severity	Risk Level	Control Measures
Mechanical Hazards	Injury from moving parts	Possible	Major	High	Install guards, use emergency stop buttons.
Electrical Hazards	Electric shock	Unlikely	Major	Medium	Regular inspections, ensure proper grounding.
Overloading	Equipment failure	Possible	Major	High	Set maximum load limits, provide training on loads.
Slipping Hazards	Falls due to wet surfaces	Likely	Moderate	Medium	Maintain clean work area, use anti-slip mats.
Noise Hazards	Hearing damage	Likely	Minor	Medium	Provide hearing protection and conduct noise assessments.

4. Control Measures
   - **Engineering Controls:** Ensure proper maintenance and functionality of safety features; use machines with built-in safety mechanisms.
   - **Administrative Controls:** Develop and implement safe operating procedures, conduct regular training sessions, and maintain an incident reporting system.
   - **Personal Protective Equipment (PPE):** Provide hard hats, gloves, safety boots, and hearing protection.

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5. Emergency Procedures

- **Emergency Stop:** Clearly mark and train personnel on the use of emergency stop controls.
- **First Aid:** Ensure first aid kits are available, and personnel are trained in basic first aid.
- **Evacuation Plan:** Make sure all workers are familiar with the evacuation routes and procedures in case of an emergency.

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6. Review and Monitoring

- **Inspection Frequency:** Weekly inspections and after any incidents or maintenance work.
- **Review Period:** Annually or whenever changes in operations occur.
- **Incident Reporting:** Document all incidents and near misses to improve safety measures.

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7. Signatures [redacted]

- **Assessor Signature:** ____________________
- **Date:** ____________________ [redacted]
- **Reviewed By Signature:** __
- **Date:** ____________________

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B.2. Risk Assessment for the Compressive Strength Testing Machine

SOILMAT ENGINEERS

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SME

Risk Assessment for Compressive Strength Testing Machine (CTM)

1. General Information

- **Assessment Date:** 12th September 2024
- **Assessor Name:** Muhammad Obaid
- **Location:** Soilmat Engineers Laboratory Karachi
- **Reviewed By:** Ejaz Shah

2. Equipment Details

- **Equipment Name:** Compressive Strength Testing Machine
- **Manufacturer:** China
- **Model Number:** AXIS
- **Serial Number:** AX-70i

3. Hazard Identification and Risk Assessment Table

Hazard	Risk	Likelihood	Severity	Risk Level	Control Measures
Mechanical Hazards	Injury from moving parts	Possible	Major	High	Install guards, use safety interlocks.
Electrical Hazards	Electric shock	Unlikely	Major	Medium	Regular maintenance, ensure proper grounding.
Overloading	Equipment failure	Possible	Major	High	Implement overload protection, training on max loads.
Material Hazards (sharp edges)	Cuts and lacerations	Possible	Moderate	Medium	Use proper PPE, inspect materials before testing.
Environmental Hazards	Noise exposure	Likely	Minor	Medium	Provide hearing protection, ensure proper ventilation.

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4. Control Measures

- **Engineering Controls:** Install safety guards, emergency stop buttons and ensure proper machine design.
- **Administrative Controls:** Create SOPs for safe operation, establish training programs, and maintain an incident reporting system.
- **Personal Protective Equipment (PPE):** Provide safety glasses, gloves, and ear protection.

5. Emergency Procedures

- **Emergency Stop:** Clearly label and train on the use of emergency stop controls.
- **First Aid:** Ensure first aid kits are available, and personnel are trained in basic first aid.
- **Evacuation Plan:** Familiarize all personnel with evacuation routes and procedures.

6. Review and Monitoring

- **Inspection Frequency:** Monthly inspections and after any incidents.
- **Review Period:** Annually or when changes occur in equipment or procedures.
- **Incident Reporting:** Document all incidents and review for future prevention strategies.

7. Signatures [redacted]

- **Assessor Signature:** ____________________
- **Date:** ____________________
- **Reviewed By Signature:** [redacted]
- **Date:** ____________________

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B.3. Risk Assessment for Furnace

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Geotechnical, Material, Structural Engineers and Testing Laboratories

SME

Risk Assessment for Furnace

1. General Information

- **Assessment Date:** 12th September
- **Assessor Name:** Muhammad Obaid
- **Location:** Soilmat Engineers
- **Reviewed By:** Ejaz Shah

2. Equipment Details

- **Equipment Name:** Furnace
- **Manufacturer:** SAF Therm
- **Model Number:** 0-3000 C
- **Serial Number:** FC-QC-06

3. Hazard Identification and Risk Assessment Table

Hazard	Risk	Likelihood	Severity	Risk Level	Control Measures
High Temperatures	Burns or heat-related injuries	Likely	Major	High	Use thermal insulation, provide PPE (heat-resistant gloves, aprons).
Fire Hazards	Fire outbreak	Possible	Major	High	Implement fire safety measures, keep fire extinguishers accessible.
Gas Leaks	Explosion or poisoning	Unlikely	Major	Medium	Regular maintenance, install gas detection systems.
Electrical Hazards	Electric shock	Possible	Major	Medium	Ensure proper grounding, inspect wiring regularly.
Inhalation of Fumes	Respiratory issues	Likely	Moderate	Medium	Ensure proper ventilation, provide respirators if necessary.

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Page **1** of **2**

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Appendix C

C.1. Cement Setting Time

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SME

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Karachi. Ph: 34623161-2, 35458647, Fax: 34632483
E-mail: soilmatengineers@yahoo.com

CLIENT : Mr. Majid

Date: 20/08/2024

PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate

LAB. No.: 1349

CEMENT SETTING TIME BY VICAT NEEDLE

ASTM C 191

S. NO.	SAMPLE MARK	INITIAL SETTING TIME	FINAL SETTING TIME
1	Lucky Cement (OPC)	120 Minutes	290 Minutes
		Specification Limits as per ASTM C-150	
		Not less than 45 min	Not more than 375 min

SOILMAT ENGINEERS

C.2. Cement Chemical Test

SOILMAT ENGINEERS

B-136, Block-1, Opp. N.E.D. University, Main University Road, Gulistan-e-Jauhar,
Karachi. Ph: 34623161-2, 35458647, Fax: 34632483
E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid

DATE: 28/08/2024

PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate

LAB. No.: 1349

CHEMICAL TEST RESULT

ASTM C-150

S. NO.	TEST			Lucky Cement (OPC) Sample
1	Silica	as	SiO_2	19.39%
2	Alumina	as	Al_2O_3	5.25%
3	Alkali Content (Na_2O + 0.658 K_2O)			0.69%
4	Iron Oxide	as	Fe_2O_3	4.22%
5	Calcium Oxide	as	CaO	62.99%
6	Magnesium Oxide	as	MgO	2.02%
7	Sulphuric Anhydride	as	SO_3	2.89%
8	Insoluble Residue			0.85%
9	Loss on Ignition			2.42%
10	Tricalcium Aluminate	as	(C_3A)	6.78%
11	Lime Saturation Factor		(LSF)	0.96

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C.3. Fineness Test of Micro Silica

SOILMAT ENGINEERS

SME

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E-mail: soilmatengineers@yahoo.com

CLIENT : Mr. Majid

PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate

LAB. No.: 1349

DATE: 30/08/2024

LABORATORY TEST RESULTS OF FINENESS

S.NO.	SAMPLE MARK	SILICA FUME (RETAINED AT 45 µm SIEVE)
1	Silica Fume (Fospak)	8.8%

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C.4. Chemical Test of Micro Silica

SOILMAT ENGINEERS

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid

DATE: 05/09/2024

PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate

SAMPLE MARK: Silica Fume (Fospak)

LAB. NO: 1349

CHEMICAL TEST RESULT OF SILICA FUME

S. NO.	TEST	RESULTS
1	Silica as SiO_2	91.48%
2	Loss on Ignition	3.39%
3	Sulphur Trioxide as SO_3	Nil
4	Magnesium Oxide as MgO	0.43%
5	Alkali Content ($Na_2O + 0.658\ K_2O$)	0.39%
6	Chloride Content	0.086%
7	Free Calcium Oxide as CaO	0.89%
8	Free Silicon as Si	0.52%

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C.5. Concrete Mix Design Control Mix

SOILMAT ENGINEERS
Geotechnical, Material, Structural Engineers and Testing Laboratories

LAB NO : CM 1349 — *Date: 15/08/2024*

Mr. Majid
Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
CLASS 7250 PSI WITH LUCKY CEMENT OPC CYLINDRICAL STRENGTH
(Control Mix)

TYPE OF CEMENT		LUCKY CEMENT OPC	
NOMINAL MAX.SIZE OF AGGREGATE		19.0	mm
28 DAYS WORKING COMPRESSIVE STRENGTH		7,250	PSI

(FOR TRIAL TAKE)

CEMENT (95.0)		513	Kg
EXPANSILICA FOSPAK (5.0%)		27	Kg
W/C RATIO		0.27	
AIR VOIDS		2.0	%
SPECIFIC GRAVITY OF FINE AGG.		2.663	
LOOSE DENSITY OF FINE AGG.		1.680	gm/cc
SPECIFIC GRAVITY OF COARSE AGG.	COMBINED	2.640	
DRY RODED DENSITY OF COARSE AGGREGATE	COMBINED	1.534	gm/cc
LOOSE DENSITY OF COARSE AGG.	COMBINED	1.425	gm/cc
ABSORPTION OF FINE AGG.		1.282	%
ABSORPTION OF COARSE AGG.	COMBINED	0.842	%

ABSOLUTE VOLUME METHOD QUANTITIES FOR 1 cu.m OF CONCRETE			
CEMENT(a)	0.16286	m^3	
EXPANSILICA FOSPAK (b)	0.01227	m^3	
FREE WATER (c)	0.14580	m^3	
AIR VOIDS(AS PER TABLE A1 5.3.3) (d)	0.02000	m^3	
TOTAL ABSOLUTE VOLUME OTHER THAN AGGREGATES (Vt=a+b+c+d)	0.34093	m^3	
TOTAL ABSOLUTE VOLUME FOR COARSE + FINE AGG. (e=1-vt)	0.65907	m^3	
As per table A1.5.3.6 ACI-211, the volume of coarse aggregate of Nominal maximum size of 19.0 mm & sand of FM 2.937			0.62
WEIGHT OF COARSE AGGREGATE	951	kg	
ABSOLUTE VOLUME OF COARSE AGGREGATE (f)	0.36031	m^3	
ABSOLUTE VOLUME OF FINE AGGREGATE (g=e-f)	0.29876	m^3	
WEIGHT OF FINE AGGREGATE	796	kg	
ABSORBED WATER	18.21	lit	

QUANTITIES FOR 1 cu.m OF CONCRETE		
CEMENT (95.0)	513	kg
EXPANSILICA FOSPAK (5.0%)	27	kg
WATER	164	lit
COARSE AGGREGATE 19.0mm (70%)	666	kg
COARSE AGGREGATE 10.0mm (30%)	285	kg
FINE AGGREGATE(SCRENED BY 3/8" SIEVE)	796	kg
ADMIXTURE FOSPAK SUPER-40 (1.0%)	5.40	lit

INITIAL SLUMP ACHIEVED WAS 100mm

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Page 5 of 40

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C.6. Concrete Mix Design 5% PET Mix

SOILMAT ENGINEERS

Geotechnical, Material, Structural Engineers and Testing Laboratories

SME

LAB NO : CM 1349

Date: 16/08/2024

Mr. Majid

Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate

CLASS 7250 PSI WITH LUCKY CEMENT OPC CYLINDRICAL STRENGTH

(5% Plastic)

TYPE OF CEMENT		LUCKY CEMENT OPC	
NOMINAL MAX.SIZE OF AGGREGATE		19.0	mm
28 DAYS WORKING COMPRESSIVE STRENGTH		7,250	PSI

(FOR TRIAL TAKE)

CEMENT (95.0)		513	Kg
EXPANSILICA FOSPAK (5.0%)		27	Kg
W/C RATIO		0.27	
AIR VOIDS		2.0	%
SPECIFIC GRAVITY OF FINE AGG.		2.663	
LOOSE DENSITY OF FINE AGG.		1.680	gm/cc
SPECIFIC GRAVITY OF COARSE AGG.	COMBINED	2.640	
DRY RODED DENSITY OF COARSE AGGREGATE	COMBINED	1.534	gm/cc
LOOSE DENSITY OF COARSE AGG.	COMBINED	1.425	gm/cc
ABSORPTION OF FINE AGG.		1.282	%
ABSORPTION OF COARSE AGG.	COMBINED	0.842	%

ABSOLUTE VOLUME METHOD

QUANTITIES FOR 1 cu.m OF CONCRETE

CEMENT(a)		0.16286	m^3
EXPANSILICA FOSPAK (b)		0.01227	m^3
FREE WATER (c)		0.14580	m^3
AIR VOIDS(AS PER TABLE A1 5.3.3) (d)		0.02000	m^3
TOTAL ABSOLUTE VOLUME OTHER THAN AGGREGATES	(Vt=a+b+c+d)	0.34093	m^3
TOTAL ABSOLUTE VOLUME FOR COARSE + FINE AGG. (e=1-vt)		0.65907	m^3
As per table A1.5.3.6 ACI-211, the volume of coarse aggregate of Nominal maximum size of 19.0 mm & sand of FM 2.937		0.62	
WEIGHT OF COARSE AGGREGATE		951	kg
ABSOLUTE VOLUME OF COARSE AGGREGATE (f)		0.36031	m^3
ABSOLUTE VOLUME OF FINE AGGREGATE (g=e-f)		0.29876	m^3
WEIGHT OF FINE AGGREGATE		796	kg
WEIGHT OF FINE AGGREGATE 95%		756	Kg
WEIGHT OF PLASTIC 5% OF FINE AGGREGATE		40	Kg
ABSORBED WATER		18.21	lit
ABSORBED WATER AFTER 5% PLASTIC		17.7	lit

QUANTITIES FOR 1 cu.m OF CONCRETE

CEMENT (95.0)	513	kg
EXPANSILICA FOSPAK (5.0%)	27	kg
WATER	163	lit
COARSE AGGREGATE 19.0mm (70%)	666	kg
COARSE AGGREGATE 10.0mm (30%)	285	kg
FINE AGGREGATE (SCRENED BY 3/8" SIEVE) 95%	756	kg
WEIGHT OF PLASTIC 5% OF FINE AGGREGATE	40	kg
ADMIXTURE FOSPAK SUPER-40 (1.0%)	5.40	lit

INITIAL SLUMP ACHIEVED WAS 150mm

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C.7. Concrete Mix Design 10% PET Mix

SOILMAT ENGINEERS

Geotechnical, Material, Structural Engineers and Testing Laboratories

SME

LAB NO : CM 1349

Date: 16/08/2024

Mr. Majid

Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate

CLASS 7250 PSI WITH LUCKY CEMENT OPC CYLINDRICAL STRENGTH

(10% Plastic)

TYPE OF CEMENT		*LUCKY CEMENT OPC*	
NOMINAL MAX.SIZE OF AGGREGATE		*19.0*	*mm*
28 DAYS WORKING COMPRESSIVE STRENGTH		*7,250*	*PSI*

(FOR TRIAL TAKE)

CEMENT (95.0)		*513*	*Kg*
EXPANSILICA FOSPAK (5.0%)		*27*	*Kg*
W/C RATIO		*0.27*	
AIR VOIDS		*2.0*	*%*
SPECIFIC GRAVITY OF FINE AGG.		*2.663*	
LOOSE DENSITY OF FINE AGG.		*1.680*	*gm/cc*
SPECIFIC GRAVITY OF COARSE AGG.	*COMBINED*	*2.640*	
DRY RODED DENSITY OF COARSE AGGREGATE	*COMBINED*	*1.534*	*gm/cc*
LOOSE DENSITY OF COARSE AGG.	*COMBINED*	*1.425*	*gm/cc*
ABSORPTION OF FINE AGG.		*1.282*	*%*
ABSORPTION OF COARSE AGG.	*COMBINED*	*0.842*	*%*

ABSOLUTE VOLUME METHOD

QUANTITIES FOR 1 cu.m OF CONCRETE

CEMENT(a)		0.16286	m^3	
EXPANSILICA FOSPAK (b)		*0.01227*	m^3	
FREE WATER (c)		0.14580	m^3	
AIR VOIDS(AS PER TABLE A1 5.3.3) (d)		0.02000	m^3	
TOTAL ABSOLUTE VOLUME OTHER THAN AGGREGATES	(Vt=a+b+c+d)	0.34093	m^3	
TOTAL ABSOLUTE VOLUME FOR COARSE + FINE AGG. (e=1-vt)		0.65907	m^3	
As per table A1.5.3.6 ACI-211, the volume of coarse aggregate of Nominal maximum size of 19.0 mm & sand of FM 2.937				0.62
WEIGHT OF COARSE AGGREGATE		951	kg	
ABSOLUTE VOLUME OF COARSE AGGREGATE (f)		0.36031	m^3	
ABSOLUTE VOLUME OF FINE AGGREGATE (g=e-f)		0.29876	m^3	
WEIGHT OF FINE AGGREGATE		796	kg	
WEIGHT OF FINE AGGREGATE 90%		716	Kg	
WEIGHT OF PLASTIC 10% OF FINE AGGREGATE		80	Kg	
ABSORBED WATER		18.21	lit	
ABSORBED WATER AFTER 10% PLASTIC		17.2	lit	

QUANTITIES FOR 1 cu.m OF CONCRETE

CEMENT (95.0)	513	kg
EXPANSILICA FOSPAK (5.0%)	27	kg
WATER	163	lit
COARSE AGGREGATE 19.0mm (70%)	666	kg
COARSE AGGREGATE 10.0mm (30%)	285	kg
FINE AGGREGATE (SCRENED BY 3/8" SIEVE) 90%	716	kg
WEIGHT OF PLASTIC 10% OF FINE AGGREGATE	80	kg
ADMIXTURE FOSPAK SUPER-40 (1.0%)	5.40	lit

INITIAL SLUMP ACHIEVED WAS 180mm

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Appendix D

D.1. Compressive Strength Test Results

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE: August 30, 2024
Area: 28.28 Sq. Inch

COMPRESSIVE STRENGTH RESULT OF CYLINDER ASTM C-39

S. NO.	SAMPLE MARK	CLASS	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	COMPRESSIVE STRENGTH PSI.	COMPRESSIVE STRENGTH N/mm^2.
1	Control Mix	7250 PSI	23-Aug-24	30-Aug-24	7	101550	7914	54.6

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SOILMAT ENGINEERS

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT :	Mr. Majid
PROJECT:	Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.:	1349

DATE:	August 31, 2024
Area:	28.28 Sq. Inch

COMPRESSIVE STRENGTH RESULT OF CYLINDER ASTM C-39

S. NO.	SAMPLE MARK	CLASS	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	COMPRESSIVE STRENGTH PSI.	COMPRESSIVE STRENGTH N/mm².
1	5% Plastic	7250 PSI	24-Aug-24	31-Aug-24	7	64200	5003	34.5

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SOILMAT ENGINEERS

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E-mail: soilmatengineers@yahoo.com

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 1, 2024
Area:	28.28 Sq. Inch

COMPRESSIVE STRENGTH RESULT OF CYLINDER ASTM C-39

S. NO.	SAMPLE MARK	CLASS	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	COMPRESSIVE STRENGTH PSI.	COMPRESSIVE STRENGTH N/mm².
1	10% Plastic	7250 PSI	25-Aug-24	1-Sep-24	7	58000	4520	31.2

SOILMAT ENGINEERS
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E-mail: soilmatengineers@yahoo.com

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 2, 2024
Area:	28.28 Sq. Inch

COMPRESSIVE STRENGTH RESULT OF CYLINDER ASTM C-39

S. NO.	SAMPLE MARK	CLASS	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	COMPRESSIVE STRENGTH PSI.	COMPRESSIVE STRENGTH N/mm².
1	Control Mix	7250 PSI	19-Aug-24	2-Sep-24	14	113250	8826	60.9

SOILMAT ENGINEERS

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 4, 2024
Area:	28.28 Sq. Inch

COMPRESSIVE STRENGTH RESULT OF CYLINDER ASTM C-39

S. NO.	SAMPLE MARK	CLASS	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	COMPRESSIVE STRENGTH PSI.	COMPRESSIVE STRENGTH N/mm².
1	5% Plastic	7250 PSI	21-Aug-24	4-Sep-24	14	76700	5978	41.2

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SOILMAT ENGINEERS
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Karachi. Ph: 34623161-2, 35458647, Fax: 34632483
E-mail: soilmatengineers@yahoo.com

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 5, 2024
Area:	28.28 Sq. Inch

COMPRESSIVE STRENGTH RESULT OF CYLINDER ASTM C-39

S. NO.	SAMPLE MARK	CLASS	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	COMPRESSIVE STRENGTH PSI.	COMPRESSIVE STRENGTH N/mm².
1	10% Plastic	7250 PSI	22-Aug-24	5-Sep-24	14	56150	4376	30.2

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 12, 2024
Area:	28.28 Sq. Inch

COMPRESSIVE STRENGTH RESULT OF CYLINDER ASTM C-39

S. NO.	SAMPLE MARK	CLASS	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	COMPRESSIVE STRENGTH PSI.	COMPRESSIVE STRENGTH N/mm².
1	Control Mix	7250 PSI	15-Aug-24	12-Sep-24	28	150800	11753	81.0

SOILMAT ENGINEERS SME

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SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 13, 2024
Area:	28.28 Sq. Inch

COMPRESSIVE STRENGTH RESULT OF CYLINDER ASTM C-39

S. NO.	SAMPLE MARK	CLASS	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	COMPRESSIVE STRENGTH PSI.	COMPRESSIVE STRENGTH N/mm².
1	5% Plastic	7250 PSI	16-Aug-24	13-Sep-24	28	79100	6165	42.5

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SOILMAT ENGINEERS

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 13, 2024
Area:	28.28 Sq. Inch

COMPRESSIVE STRENGTH RESULT OF CYLINDER ASTM C-39

S. NO.	SAMPLE MARK	CLASS	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	COMPRESSIVE STRENGTH PSI.	COMPRESSIVE STRENGTH N/mm².
1	10% Plastic	7250 PSI	16-Aug-24	13-Sep-24	28	74700	5822	40.1

SOILMAT ENGINEERS SME

D.2. Split Tensile Strength Test Results

SOILMAT ENGINEERS

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SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	August 30, 2024
HEIGHT:	12.0"
DIA:	6.0"

SPLITTING TENSILE STRENGTH RESULT OF CONCRETE CYLINDERS
ASTM C496

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	SPLITTING TENSILE STRENGTH PSI.	SPLITTING TENSILE STRENGTH N/mm².
1	Control Mix	23-Aug-24	30-Aug-24	7	37200	725	5.0

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	August 31, 2024
HEIGHT:	12.0"
DIA:	6.0"

SPLITTING TENSILE STRENGTH RESULT OF CONCRETE CYLINDERS
ASTM C496

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	SPLITTING TENSILE STRENGTH	
						PSI.	N/mm².
1	5% Plastic	24-Aug-24	31-Aug-24	7	28600	557	3.8

SOILMAT ENGINEERS SME

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 1, 2024
HEIGHT:	12.0"
DIA:	6.0"

SPLITTING TENSILE STRENGTH RESULT OF CONCRETE CYLINDERS
ASTM C496

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	SPLITTING TENSILE STRENGTH	
						PSI.	N/mm^2.
1	10% Plastic	25-Aug-24	1-Sep-24	7	28250	550	3.8

SOILMAT ENGINEERS SME

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 2, 2024
HEIGHT:	12.0"
DIA:	6.0"

SPLITTING TENSILE STRENGTH RESULT OF CONCRETE CYLINDERS
ASTM C496

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	SPLITTING TENSILE STRENGTH PSI.	N/mm².
1	Control Mix	19-Aug-24	2-Sep-24	14	46250	901	6.2

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B-136, Block-1, Opp. N.E.D. University, Main University Road, Gulistan-e-Jauhar,
Karachi. Ph: 34623161-2, 35458647, Fax: 34632483
E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 4, 2024
HEIGHT:	12.0"
DIA:	6.0"

SPLITTING TENSILE STRENGTH RESULT OF CONCRETE CYLINDERS
ASTM C496

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	SPLITTING TENSILE STRENGTH	
						PSI.	N/mm².
1	5% Plastic	21-Aug-24	4-Sep-24	14	28700	559	3.9

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 5, 2024
HEIGHT:	12.0"
DIA:	6.0"

SPLITTING TENSILE STRENGTH RESULT OF CONCRETE CYLINDERS
ASTM C496

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	SPLITTING TENSILE STRENGTH	
						PSI.	N/mm².
1	10% Plastic	22-Aug-24	5-Sep-24	14	26500	516	3.6

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Karachi. Ph: 34623161-2, 35458647, Fax: 34632483
E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 12, 2024
HEIGHT:	12.0"
DIA:	6.0"

SPLITTING TENSILE STRENGTH RESULT OF CONCRETE CYLINDERS
ASTM C496

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	SPLITTING TENSILE STRENGTH	
						PSI.	N/mm².
1	Control Mix	15-Aug-24	12-Sep-24	28	54850	1068	7.4

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 13, 2024
HEIGHT:	12.0"
DIA:	6.0"

SPLITTING TENSILE STRENGTH RESULT OF CONCRETE CYLINDERS
ASTM C496

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	SPLITTING TENSILE STRENGTH	
						PSI.	N/mm².
1	5% Plastic	16-Aug-24	13-Sep-24	28	32450	632	4.4

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE:	September 13, 2024
HEIGHT:	12.0"
DIA:	6.0"

SPLITTING TENSILE STRENGTH RESULT OF CONCRETE CYLINDERS
ASTM C496

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	AXIAL LOAD Kg	SPLITTING TENSILE STRENGTH	
						PSI.	N/mm².
1	10% Plastic	16-Aug-24	13-Sep-24	28	30500	594	4.1

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D.3. Flexural Strength Test Results

SOILMAT ENGINEERS

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE: August 30, 2024

Length of Span: 18"
Width: 6.0"
Height: 6.0"

Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
ASTM C-78-02

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	APPLIED LOAD Kg	MAXIMUM APPLIED LOAD lbs	MODULUS OF RUPTURE (R) PSI	MODULUS OF RUPTURE (R) Mpa
1	Control Mix	23-Aug-24	30-Aug-24	7	5150	11351	946	6.5

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE: August 31, 2024

Length of Span: 18"
Width: 6.0"
Height: 6.0"

Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
ASTM C-78-02

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	APPLIED LOAD Kg	MAXIMUM APPLIED LOAD lbs	MODULUS OF RUPTURE (R) PSI	MODULUS OF RUPTURE (R) Mpa
1	5% Plastic	24-Aug-24	31-Aug-24	7	3650	8045	670	4.6

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Karachi. Ph: 34623161-2, 35458647, Fax: 34632483
E-mail: soilmatengineers@yahoo.com

CLIENT : Mr. Majid

PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate

LAB. No.: 1349

DATE: September 1, 2024

Length of Span: 18"
Width: 6.0"
Height: 6.0"

Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

ASTM C-78-02

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	APPLIED LOAD Kg	MAXIMUM APPLIED LOAD lbs	MODULUS OF RUPTURE (R) PSI	MODULUS OF RUPTURE (R) Mpa
1	10% Plastic	25-Aug-24	1-Sep-24	7	2550	5620	468	3.2

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E-mail: soilmatengineers@yahoo.com

SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE: September 2, 2024

Length of Span: 18"
Width: 6.0"
Height: 6.0"

Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
ASTM C-78-02

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	APPLIED LOAD Kg	MAXIMUM APPLIED LOAD lbs	MODULUS OF RUPTURE (R) PSI	MODULUS OF RUPTURE (R) Mpa
1	Control Mix	19-Aug-24	2-Sep-24	14	5900	13004	1084	7.5

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E-mail: soilmatengineers@yahoo.com

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE: September 4, 2024

Length of Span: 18"
Width: 6.0"
Height: 6.0"

Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
ASTM C-78-02

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	APPLIED LOAD Kg	MAXIMUM APPLIED LOAD lbs	MODULUS OF RUPTURE (R) PSI	MODULUS OF RUPTURE (R) Mpa
1	5% Plastic	21-Aug-24	4-Sep-24	14	4050	8926	744	5.1

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SME

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE: September 5, 2024

Length of Span: 18"
Width: 6.0"
Height: 6.0"

Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)

ASTM C-78-02

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	APPLIED LOAD Kg	MAXIMUM APPLIED LOAD lbs	MODULUS OF RUPTURE (R) PSI	MODULUS OF RUPTURE (R) Mpa
1	10% Plastic	22-Aug-24	5-Sep-24	14	3200	7053	588	4.1

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E-mail: soilmatengineers@yahoo.com

CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE: September 12, 2024

Length of Span: 18"
Width: 6.0"
Height: 6.0"

Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
ASTM C-78-02

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	APPLIED LOAD Kg	MAXIMUM APPLIED LOAD lbs	MODULUS OF RUPTURE (R) PSI	MODULUS OF RUPTURE (R) Mpa
1	Control Mix	15-Aug-24	12-Sep-24	28	7200	15869	1322	9.1

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CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE: September 13, 2024

Length of Span: 18"
Width: 6.0"
Height: 6.0"

Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
ASTM C-78-02

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	APPLIED LOAD Kg	MAXIMUM APPLIED LOAD lbs	MODULUS OF RUPTURE (R) PSI	MODULUS OF RUPTURE (R) Mpa
1	5% Plastic	16-Aug-24	13-Sep-24	28	4250	9367	781	5.4

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CLIENT : Mr. Majid
PROJECT: Concrete Mix Design Using Recycled PET Plastic as Partial Replacement of the Natural Fine Aggregate
LAB. No.: 1349

DATE: September 13, 2024

Length of Span: 18"
Width: 6.0"
Height: 6.0"

Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)
ASTM C-78-02

S. NO.	SAMPLE MARK	DATE OF CASTING	DATE OF TESTING	AGE IN DAYS.	APPLIED LOAD Kg	MAXIMUM APPLIED LOAD lbs	MODULUS OF RUPTURE (R) PSI	MODULUS OF RUPTURE (R) Mpa
1	10% Plastic	16-Aug-24	13-Sep-24	28	3900	8596	716	4.9