STUDY OF CONCRETE PROPERTIES USING POLYETHYLENE TEREPHTHALATE (PET) AS AGGREGATE

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A Thesis Submitted to the

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Thesis Approved as to Style and Content for the

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DECLARATION

We hereby declare that this thesis is our original work and it has been written by us in its entirety. We have duly acknowledged all the sources of information which have been used in the thesis.

This thesis has also not been submitted for any degree in any university previously.

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October 2013

Dedicated

To

Our Beloved Parents

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ABSTRACT

In the ever demanding field of Civil Engineering, the materials used for structural applications have been considered a vital issue regarding the safety, durability and stability of the structures. Also the reduction of waste materials and substituting these with the regular materials in structural applications seem to be a viable option and a lot of researches are going on considering this issue. Keeping this in mind, the use and study of concrete properties using Polyethylene Terephthalate (PET) as aggregates has been adopted in this research. Since waste PET bottles are rising in an alarming rate and the reuse of these waste materials is highly demanding, a lot of researches have been taken into account considering the uses of PET in the structural and non-structural applications as aggregates. This research basically focuses on using melted PET as a partial replacement of coarse and fine aggregates. For this purpose 36 cylinders are prepared by replacing 20%, 30%, 40% and 50% by volume of the coarse aggregates and 50% by volume of the fine aggregates. Also three water-cement ratios (i.e. 0.42, 0.48 and 0.57) are taken under consideration for achieving optimum workability in using PET as aggregates. Afterwards, the test results obtained are compared with the cylinder specimens consisting regular aggregates. Firstly it has been observed that the cylinder specimens with melted PET as coarse and fine aggregates show a decline in compressive strength compared to the concrete samples with regular aggregates whereas the density of the former is reduced, making the concrete samples lightweight compared to the latter one. Secondly the workability increases with the increment of water-cement ratio of the samples. Thirdly the samples consisting PET as fine aggregates ensure better compressive strength compared to the samples having PET as coarse aggregates with the same water-cement ratio though the density of the latter reduces more than the former samples. Finally the compressive strength of the concrete samples reduces with the increment of the replacement percentage of the PET as coarse aggregates.

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CHAPTER 1

INTRODUCTION

1.1 General

Light Weight Concrete (LWC) has become a prominent issue in the modern concrete technology. Among various concepts the most accepted approach of light-weighting concrete relies upon replacing conventional coarse aggregate (i.e. stone chips, brick chips) relatively lighter aggregate. Using light weight concrete (LWC) has a significant advantage in structural application as it reduces the self weight along with the dimensions of the load-bearing members (i.e. beams, columns, foundations) of a structure.

Polyethylene Terephthalate (PET) bottle is replacing glass bottle nowadays, as it is convenient to use and handle. Furthermore, it is available everywhere. Because of that a large number of PET bottles are used and discarded daily which as a consequence has been affecting the environment adversely. So recycling and reusing plastics, especially PET, has been a growing concern for the environmentalists. Using recycled PET in concrete as a coarse aggregate can be highly demanding as well as environment friendly. Also the ever-growing waste management costs and systems regarding PET bottles can be declined significantly if it is used in large quantity in concrete.

Conventional use of brick chips as coarse aggregate for the construction works requires significant amount of bricks that gives rise to more brick-kilns which are hampering the environment by emitting high concentrated carbon monoxide (CO), carbon-dioxide (CO_2), different oxides of sulphur (SO_x) and particulate matters whereas melting PET emits gases, but in a lower scale. So using PET as coarse aggregate can significantly reduce these gas emissions.

In this study plastic bottles, conventionally known as PET bottles, are used as a partial replacement for both coarse and fine aggregates in concrete. Herein recycled PET bottles are melted and then cooled within molds to produce Plastic Coarse Aggregate

(PCA). The PETs can be melted and shredded simultaneously in order to have a rough surface for proper bonding between aggregates and binding materials which is essential for obtaining desired compressive strength.

1.2 Literature Review

1.2.1 Plastic

Selection of appropriate type of material for aggregate is an important part for concrete since the properties of a concrete vary according to the materials used in the mix design. There have been a lot of materials, especially plastic based recyclable materials, which were previously used by researchers as either coarse aggregate or fine aggregate or both in order to obtain a suitable behavior for concrete.

In recent years, replacing the natural coarse aggregates with natural and/or synthetic light weight aggregates is been considered a viable option as they reduce the self-weight of the concrete structures substantially. Several researches were conducted in order to obtain a suitable replacement ratio of plastic coarse aggregates with regular materials. Ghaly and Gill (2004) conducted a research using particles of post consumer plastic (PET) as a partial replacement of coarse aggregate, 5%, 10% and 15% by mass of coarse aggregate, in concrete mixture; and achieved compressive strengths of 52.12 MPa, 50.11 MPa and 43.63 MPa respectively for a water-cement ratio of 0.42. The strengths obtained are lower than the concrete without PET (61.14 MPa). They also observed that the change in water-cement ratio change the compressive strength of the concrete with the same replacement ratios. For water-cement ratio of 0.54 and 0.69, 47.94 MPa, 40.77 MPa, 36.21 MPa and 31.54 MPa, 30.25 MPa, 24.25 MPa compressive strengths were obtained respectively with the same replacement ratio used previously. The results indicate that the compressive strength of the concrete decreases with the increase of amount of plastic in concrete. Based on the digital imaging of the concrete cube section, Ghaly and Gill (2004) concluded that the reduction of compressive strength was proportional to the area of the plastic chips in the section. The compressive strength of concrete, with PET as aggregate, increases with the increase in age of the samples (Ghaly and Gill, 2004).

The fastest increase in stress is observed between 24 hours and 7 days after pouring. A gradual increase of stress takes place between 7 and 28 days. The observed behavior was true for all specimens tested with different plastic contents and the three water-cement ratios of 42%, 54%, and 69% Ghaly and Gill, 2004).

Replacing fine aggregates with plastic materials have been considered another possible alternative for lightweight aggregate concrete. In several works fine aggregates of concrete were fully or partially replaced in order to obtain variations in the test results. Choi et al. (2005) performed experiments on waste PET lightweight aggregate (WPLA) manufactured from waste PET bottles; Compressive strength of concrete, where WPLA were used by replacing 25%, 50% and 75% by volume of fine aggregate in concrete mixture, were 33.8 MPa, 31.8 MPa and 24.1 MPa respectively with a water-cement ratio of 0.45. Their experimentation was based on light weight aggregates which are cut to the range of 5 to 15 mm and mixed with granulated blast-furnace slag (GBFS) in a mixer where the temperature and rotation of the mixer was 250 ± 10 ˚C and 30-50 rpm for 20 sec. These aggregates were used as partial replacement of fine aggregates in making concrete samples. They also reported that slump values of waste PET lightweight aggregate concrete (WPLAC) increased as the water–cement ratio and the replacement ratio increased. The improvement ratios of workability represented 52%, 104%, and 123% in comparison with that of normal concrete at the water cement ratio 45%, 49%, and 53%, respectively. This may be attributed to not only the spherical and smooth shape but also to the absorption capacity of WPLA.

In a similar research Frigione (2010) substituted the fine aggregates of concrete by 5% of the weight of total fine aggregate (natural sand) used with an equal weight of PET aggregates manufactured from the waste un-washed PET bottles (WPET). He used waste PET bottles, un-washed and not separated PET on the basis of the color. The waste PET bottles were grinded to the size of 0.1–5 mm. In this research the compressive strength was determined to be 40.7 MPa with a water-cement ratio of 0.55 whereas the reference concrete (without plastic aggregates) has the compressive strength of 41.5 MPa.

Other researchers experimented on various plastic materials to be used as aggregates in concrete and stated some modifications that can be used in order to obtain better results. Ismail and Al-Hashmi (2010) used mixed iron filings and granulated plastic waste materials to substitute the fine aggregates in concrete composites. Type I Portland cement was mixed with the aggregates to produce the concrete composites. Three weight fractions (30, 40, and 50%) of iron filings waste aggregate were used with 5% of granulated plastic waste. They demonstrated the results of their research and concluded that as the waste iron content increases in mixes the tendency of the strength values increase by 6.4%, 9.6%, and 22.5% for 30%, 40% and 50% iron fillings, respectively. This tendency could be attributed to the pozzolanic activity of iron that overcomes the retardation of hydration caused by the hydrophobicity of waste plastic. For 10% plastic and 50% iron filler they obtained a flexural strength of 8.5 MPa.

Some researchers conducted their works based on the usage and properties of using different forms of plastic other than PET. Naik et al. (1996) determined the effect of post consumer waste High Density Polyethylene (HDPE) plastic in concrete as soft filler in the range of 0-5% of total mixture by weight. The HDPE plastics were shredded into irregular shaped flat particles of varying size from 4.7 to 9.5 mm. with the average thickness of 1 mm. The plastic particles were subjected to three chemical treatments, namely water, bleach and bleach with sodium hydroxide (NaOH), to improve their bonding with cementious matrix in concrete. From the experiment results from Naik et al. (1996), the compressive strength decreases with the increase of HDPE plastics in concrete particularly above 0.5% plastic addition. Among the three treatment used the highest compressive strength was obtained from alkaline bleach treatment contains bleach plus NaOH (5% HOCl and 4% NaOH). Among all concrete mixtures containing 4.5% post consumer plastics showed lower compressive strength than other mixtures. For 2% replacement of plastic aggregate treated in alkaline bleach at 28 days the compressive strength was around 15.2 MPa.

On different occasions the workability and the water-cement ratio are determined in order to have better judgments about the concrete properties. The water-cement ratio of the concrete has an influence on the workability. According to Frigione (2010) it was found that the WPET concretes display similar workability characteristics;

compressive strength and splitting tensile strength slightly lower that the reference concrete containing no plastic and a moderately higher ductility. Irrelevant differences in compressive strength was observed at 28 days and 1 year between reference concretes and mixes containing WPET at low water-cement ratio of 0.45; the differences become a little significant by increasing the water-cement ratio up to 0.55. It is likely that, due to the bleeding, by increasing the water-cement ratio, the interface between WPET and the hydrated cement Portland presents a higher porosity, also as a consequence of the flat shape of the WPET pieces. In a separate work, Choi et al. (2005) found that for a particular WLPA content the compressive strength increased with the decrease in water-cement ratio. For a water-cement ratio of 0.53 and 75% replacement of aggregate, the density of the sample was 2010kg/m³ with the slump value of 22.3 cm. They also observed the decrease in splitting tensile strength with the increase of water-cement ratio and replacement ratio. In the case of structural efficiency, i.e. compressive strength over density ratio, its value also decreases with the increased of water-cement and replacement ratios. The structural efficiency of WPLAC with the replacement ratio of 75% was about 21% lower than that of control concrete at the same water–cement ratios, and the structural efficiency of WPLAC with a water–cement ratio of 53% was about 15% lower than that of control concrete at the same replacement ratio. This may be attributed to the influence of WPLA weight and matrix strength.

1.2.2 Rubber

Like plastic materials, the selection of materials in case of waste rubber as aggregates is also an important factor to consider since the selection of right materials shows various properties of rubber-based concrete samples. A lot of researches have taken place in selecting the correct materials to be used in the concrete. Eldin and Senouci (1993) examined rubber-tire particles as concrete aggregate. They used two types of tire chips as coarse aggregate and replaced it with conventional aggregates in different proportions. The first type was named Edgar chips which were obtained by mechanical grinding. The other type was obtained by cryogenic grinding named Preston rubber. In a different research Al Bakri et al. (2007) conducted experiments on waste tire-rubber to be used as concrete. They used two types of waste rubber namely rubberized concrete and rubber filler in concrete. Also other experiments were conducted on concrete by using recyclable waste tire- rubber (El-Gammal et al., 2010).

Waste rubber using as aggregates in concrete having various replacement percentages by weight directly influences the compressive strength of the concrete specimens. Both the coarse and fine aggregates are replaced in different percentages and various researches have been conducted considering this issue. It has been observed that the increase in percentage of rubber used as coarse aggregate significantly decreases its compressive strength and also the splitting-tensile strength is decreased with the increase of rubber-tire used as aggregate (Eldin and Senouci, 1993). They used Edgar chips and these were sieved in three groups of 38, 25 and 19 mm maximum size and Preston chips were sieved by a maximum size of 6mm. Numerically the values of compressive strength were stated as (in MPa) 19.2, 11.6, 8.2 and 6.0 for using 25%, 50%, 75% and 100% of rubber aggregates (Edgar chips) respectively. These were used as a replacement of coarse aggregates. In a separate research El-Gammal et al. (2010) used chipped rubber to replace the coarse aggregates in concrete. They showed that the compressive strength of the controlled concrete gained 26.9 MPa whereas the chipped rubber (replacing coarse aggregates) gained the compressive strength of 2.68 MPa.

On the other hand, replacing the fine aggregates of concrete with waste rubber aggregates both partially and fully has been considered in various researches. It has also been observed that the various percentages of waste rubber aggregates used as the replacement of fine aggregate directly influences the obtained compressive strength of the specimens. Eldin and Senouci (1993) used sieved crumb rubber and a maximum size of 2mm was taken for experiments. It was used as a replacement of fine aggregate. It was also observed from the experiments that the compressive stress and the splitting tensile stress decreased with the increase amount of crumb rubber used as fine aggregates. However the failure pattern was more gradual rather than brittle of the specimens containing rubber aggregates. Furthermore these specimens containing rubber-tire has the ability to absorb a large amount of plastic energy and demonstrates plastic failure. In a separate research, El-Gammal et al. (2010) used crumb rubber to replace the fine aggregates. The waste tire rubber replaced the fine aggregate by 100% and 50% of fine aggregates by weight. It was observed from their research that the fine aggregates replaced with 100% crumb rubber and 50% crumb rubber specimens gained compressive strength of 4.94 MPa and 5.29 MPa respectively. So the more percentages of waste rubber used as fine aggregates give a decreasing compressive strength.

Consideration of the water-cement ratio related to compressive strength is also an important factor in the concrete using waste rubber as aggregates as a replacement of coarse and fine aggregate or both. Al Bakri et al. (2007) adopted two methods in this regard. In the first method (rubberized concrete) of their research, rubber was used in order to replace coarse aggregate in concrete. In the second method, shredded rubber was used as a filler material in the concrete. They have conducted the tests in 7 days and as a result only early age strength could be determined. They have experimented nine different samples having different water-cement ratio of 0.4, 0.5 and 0.7. 150 mm cubes were used as moulds in the experiments. While determining compressive strength it was observed that the rubber filler in concrete gained an average strength of 19.39 psi whereas rubberized concrete gained 6.598 psi. It was also observed from the experiments that the compressive strength of the samples decreased with the increase of water-cement ratio.

The workability and density of concrete is an important factor considering the slump values and unit weight of the samples. Al Bakri et al. (2007) experimented on the workability of rubberized concrete and it showed a decrease in slump with increase of volume waste tire-rubber content of total aggregate volume. It was also observed that mixtures made with conventional concrete were more workable than those having a combination of tire chips. They conducted experiments and showed that the average unit weight of the rubber filler in concrete was 2400kg/m^3 and the average unit weight of the rubberized concrete using tire rubber chips as replacement of aggregate addition in concrete was 1800kg/m^3. In a different research, El-Gammal et al. (2010) experimented and found that the density of the tire-rubber of the samples reduced significantly with respect to controlled concrete. The results showed 1.59 (t/m^3), 1.93 (t/m^3) and 2.02 (t/m^3) density for chipped rubber, 100% crumb rubber and 50% crumb rubber specimens respectively. However the controlled concrete was observed having density of 2.23 (t/m^3).

1.3 Comparative Analysis between Plastic and Rubber Aggregates

There are several benefits in using plastic materials in concrete. Firstly, plastic materials are extremely versatile and the ability to be tailored to meet specific technical needs is possible. Secondly, they are light-weight compared to conventional concrete. Thirdly, the durability and longevity is more as plastic aggregates can withstand more environmental impacts compared to brick chips and stone chips as they are resistant to chemicals, water and impacts. Fourthly, they have got excellent thermal and electrical insulation properties. Lastly, they have a unique ability to combine with other materials (i.e. binders, stone chips, brick chips, natural sand) and if used in proper proportion, plastic can make the concrete ductile. However, plastic materials are associated with some disadvantages over other materials. They have low bonding properties so that the strength of concrete gets reduced. Also their melting point is low, and thus, they cannot be used in situations with high temperatures.

There are several benefits of rubber among which the important property is the reduced density. The density of rubberized concrete is much less than the conventional concrete; as a result making it light than the conventional concrete. Most importantly the failure pattern of rubberized concrete is more gradual compared to brittle failure that provides a better warning in case of failure of the structural members. On the other hand, rubber cannot gain expected load bearing strength which is essential for structural purposes. Also waste tire-rubber absorbs water more; as a result pre-treatment is necessary for making it usable as aggregate in concrete. Adding to that waste-tire rubber consists of smooth surface which makes the bonding weaker with the binding materials.

After studying the previous studies it is detected that plastic aggregate have several advantages over rubber aggregate. In case of plastic materials used in concrete, higher compressive strength is achievable compared to rubberized concrete. Also water absorption is less in plastic aggregate; as a result higher strength is feasible. Adding to that the bondage between plastic aggregate and cement is more compare to the bondage between rubber and cement. Finally, thermal conductivity is less in plastic than rubber and as such plastic concrete can keep and ensure better temperature control. Considering the above facts, plastic aggregate has been used as it ensures the objectives and purposes of the project work.

1.4 Observation from the Literature Review

- The compressive strength obtained in various research works using plastic in concrete do not allow it to use for structural purpose.
- The use of shredded PET bottles and HDPE as a replacement aggregates restrict the proper bonding between the aggregates and cementious material as a result of the smooth surface of plastic aggregate.
- To make proper strong bonding chemical treatments or addition of polymer is required.
- The use of plastic as partial replacement of fine aggregate does not reduce the density of the concrete significantly.

1.5 Objectives

The objectives of this research are

- To study the suitability of plastic materials (PET) in concrete as a partial replacement of either coarse or fine aggregate.
- To study the properties of concrete, like compressive strength, density and workability of using plastic coarse aggregate (PCA) and plastic fine aggregate (PFA).
- To determine the possibility of using PCA and PFA concrete in load bearing structures.

1.6 Scope of Work

To achieve the above mentioned objectives the scope of this study involves,

- Performing experiments using different amounts of plastic coarse aggregate (PCA) replacement and water/cement ratios.
- Develop relationships among percentage of PCA replacements, water/cement ratios and compressive strengths.
- Furthermore, the density of the concrete made of PCA and concrete made of conventional aggregates are compared in order to recommend best possible usage of the concrete made from the specified plastic materials.

1.7 Organizing the Thesis

In the introductory chapter the overview of the research project is provided in order to have a clear vision of the entire thesis. Also relevant literature reviews are done so that the reviewers may have a clear concept of the previous works done related to the aforementioned thesis. Moreover, these reviews give a clear concept of the researches that have been undertaken over the world in the same field of material engineering and their structural or non-structural applications or both. Also a qualitative comparison is shown in the later parts of this chapter mentioning the advantages and disadvantages of using plastic materials and waste-rubber materials in concrete. At the end of this chapter, the objectives of the research work is prescribed for a clear perception of the overall agenda of the research project considering the gaps obtained in the reviews of the literatures provided and also the scopes of the work are mentioned.

In the second chapter the materials that are necessary for concrete samples are mentioned that includes binding material, coarse aggregates and fine aggregates. The properties of these materials are elaborately described as well as the gradations of the coarse aggregates and fine aggregates are shown in charts and tabular formats. In case of coarse aggregates and fine aggregates both the materials include Plastic Coarse Aggregates (PCA) and Plastic Fine Aggregates (PFA). The sieve analysis of the fine aggregates (sand) is shown in tabular formats along with the fineness modulus of the PCA and PFA combined with the regular coarse aggregates and fine aggregates in the chart format.

In the third chapter the methodologies obtained for the execution of the research project are described elaborately. The Specific Gravity Test and the Water Absorption Test are done to obtain the properties of the materials. The Slump Tests of the concrete samples of different combinations are done to find out the optimum workability. Furthermore, the Casting and Curing procedures of the specified concrete are described. Addition to that the Compressive Strength Tests of the concrete cylinders are performed after 28 days of casting. Lastly the mix design of the concrete samples mentioning the volume ratio of the materials used and the amount of materials needed (by weight) and the water-cement ratios are described and formulated in a tabular form for different combinations.

The fourth chapter entirely consists of the test results and the discussions related to the obtained results. The parameters of the PCA concrete and PFA concrete compared to the regular concrete samples are described in a tabulated format including density, workability, compressive strength and failure pattern for the convenience of understanding. Moreover, comparison among the properties and strength of the regular concrete, PCA concrete and PFA concrete are shown in graphs and bar charts. These charts and graphs are provided to compare the results obtained from different tests of the concrete samples which include workability with different water-cement ratio, density with different water-cement ratio and the compressive strength of the concrete with different water-cement ratio. This chapter also describes the possible reasons of the test results obtained.

Lastly the conclusions and recommendations related to the research project are mentioned in the final chapter of the thesis. The concluding section includes the final projections of the entire work done and the outcomes of the research related to the objectives prescribed in the first chapter. The recommendation section includes the recommended proposals of the research work based on the test results and discussions which include the possibility of the plastic materials to be used in real-life scenarios with promising results and the modifications required to achieve even better results.

CHAPTER 2

MATERIALS FOR CONCRETE

2.1 General

In the preparation of concrete mixture various materials are used. The materials used vary in properties and their function in the mixture. With the advancement of concrete technology along with conventional materials use of alternative materials and plasticizers are getting positive attention both in research and practical purposes. The materials are chosen based on the application and purpose of the concrete. Codes and various standards are available for the selection and collection of these materials to prepare the desired concrete mixture.

For the preparation of concrete mixture coarse aggregate, fine aggregate and binding material is the main ingredient. As coarse aggregate stone chips or brick chips is widely used while sand is used as fine aggregate. For binding the materials in concrete cement is the first choice as binding material.

To prepare special concrete such as Light weight concrete, high strength concrete, green concrete etc some alternative materials are used. For coarse aggregate (i.e. rubber, plastic, glass etc), fine aggregate (i.e. rice husk, saw dust, blast furnace slag etc), binding material (i.e. fly ash) are some commonly used alternatives. Sometimes polymers and plasticizers are used along with alternatives to achieve desired concrete properties.

2.2 Binding Material

As binding material we used Composite Cement. Its strength class was 42.5 N. It contained 65-79% clinker, 21-35% lime stone, fly ash, blast furnace slag and other minor additional constituents. Some tests have been performed to determine the properties of the used cement showed in Table2.1. Specific gravity, normal consistency, initial setting time and final setting of the cement was determined according to ASTM specifications, which are ASTM 188, ASTM C187, ASTM C191 and ASTM C150 respectively.

Table 2.1 Properties of Binding Material

Sl. No.	Characteristics	Value
01.	Normal consistency	28 mm
02.	Specific gravity	3.15
03.	Initial setting time	95mins
04.	Final setting time	10hrs

2.3 Coarse Aggregates

As coarse aggregate we used melted ‘PET’ (Polyethylene Terephthalate) along with brick chips. The melted pet is used to partially replace the brick chips as coarse aggregate in various proportions.

2.3.1 Brick Aggregates

The brick used in experimental purpose was obtained from local brick fields. The size of the aggregates generally depends on the nature of the work. Locally collected bricks were crushed and the maximum size of aggregates was 20mm. The aggregates were washed to remove dust and dart. The aggregates were dried until the surface dry condition was obtained.

The aggregates were tested according to ASTM C127 standard to obtain its physical properties. The results for various tests are given in Table 2.2 and Figure 2.1 shows the sieve shaker apparatus used for the sieve analysis aggregates.

Table 2.2 Properties of Coarse Aggregate (Brick)

Sl. No.	Characteristics	Value
01.	Type	Crushed
02.	Maximum size	25mm
03.	Specific gravity	2.33
04.	Water absorption	9.75%
05.	Fineness modulus	3.41

Figure: 2.1 Sieve Shaker Apparatus

2.3.2 Plastic Aggregates

Polyethylene Terephthalate (PET) is thermoplastic polyester with tensile and flexural modulus of elasticity of about 2.9 and 2.4 GPa respectively .Tensile strength up to 60 MPa and excellent chemical resistance. It is a semi-crystalline polymer, with a melting point of about 260℃ and a glass transition temperature ranging from 70 to 80℃, in relation to the amount of crystalline region enclosed in the amorphous phase. (Frigione, 2010)

The used lightweight coarse aggregate (LWCA) was collected from a local manufacturer. The aggregates were produced by melting waste pet bottles. The LWCA was crushed and sieved properly. The aggregates were gone through various tests according to ASTM C127 standard to obtain their physical properties. The properties are shown in Table 2.3 and Figure 2.2 shows the PET LWAC.

Table 2.3 Properties of Coarse LWCA (PET)

Sl. No.	Characteristics	Value
01.	Type	Crushed
02.	Maximum size	25mm
03.	Specific gravity	1.58
04.	Water absorption	0.43%
05.	Fineness modulus	3.15

Figure 2.2: Lightweight Aggregate (PET)

For the preparation of lightweight concrete the crushed and sieved coarse aggregates (Brick and PET LWCA both) were mixed together according to their Fineness modulus (FM) following the ASTM C33 standard. The graphical presentation of individual and combined FM for brick and PET LWCA is shown in Figure 2.3.

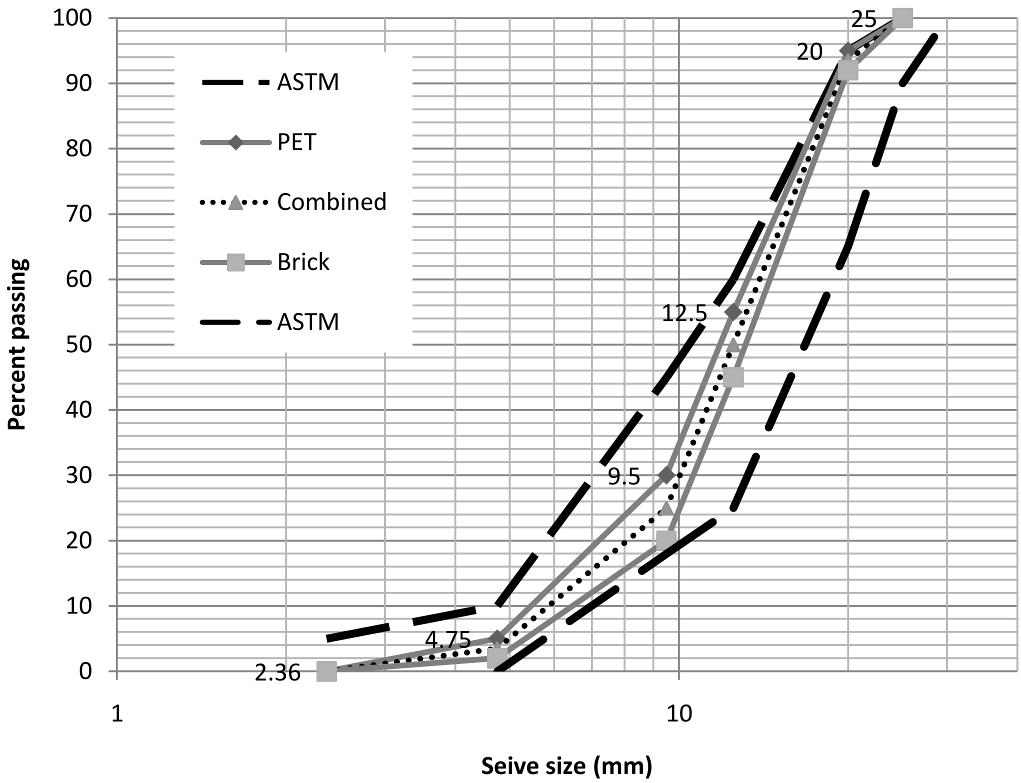

Figure 2.3: Fineness Modulus of Coarse Aggregate (ASTM C33)

2.4 Fine Aggregate

In the experiment local river sand is used. The sand was first sieved through 4.75mm sieve to eliminate particles greater than 4.75mm. Then it was washed to remove the dust. The sand was sieved through a standard set of sieve to determine the Fineness modulus and tests were performed according to ASTM C128 standard to get its various properties. The properties obtained are tabulated in Table 2.4 and Table 2.5 represents the sieve analysis of sand.

Table 2.4 Properties of Fine Aggregate (Sand)

Sl. No.	Characteristics	Value
01.	Type	Uncrushed (Natural)
02.	Specific gravity	2.43
03.	Water absorption	7%
04.	Fineness modulus	1.74

Table 2.5 Sieve Analysis of Fine Aggregate (Sand)

Sl. No.	Sieve No.	Mass Retained (gms)	Percent Retained	Percent Passing	Cumulative Percent Retained
01.	4.75mm	0	0	0	0
02.	2.36mm	0	0	0	0
03.	1.18mm	1.2	0.12	99.88	0.12
04.	600 µm	9.0	0.90	98.98	1.02
05.	300 µm	736.8	73.68	25.30	74.40
06.	150 µm	231.3	23.13	2.17	97.83
07.	Pan	21.7	2.17	-	
				Σ	173.67

Fineness Modulus of fine aggregate (sand) = Σ/100 = 173.67/100 = 1.74

In experiment as lightweight fine aggregate Polyethylene Terephthalate (PET) was also used as partial replacement of sand in some combination. The PET lightweight fine aggregate was manufactured in the same way as it was for lightweight coarse aggregates. The PET aggregates were shredded with a local-made cutter machine and sieved through a standard set of sieve and aggregates having size less than 4.75 mm were selected. The sieved aggregates were mixed together according to the Fineness modulus selected by following ASTM C33 standard. Tests were performed according to ASTM C128 standard to get the properties of PET aggregates which are tabulated in Table 2.6. Figure 2.5 shows the graphical presentation of fineness modulus of Lightweight Fine Aggregate.

Table 2.6 Properties of Lightweight Fine Aggregate (PET)

Sl. No.	Characteristics	Value
01.	Type	Crushed
02.	Specific gravity	1.27
03.	Water absorption	19.6%
04.	Fineness modulus	3.15

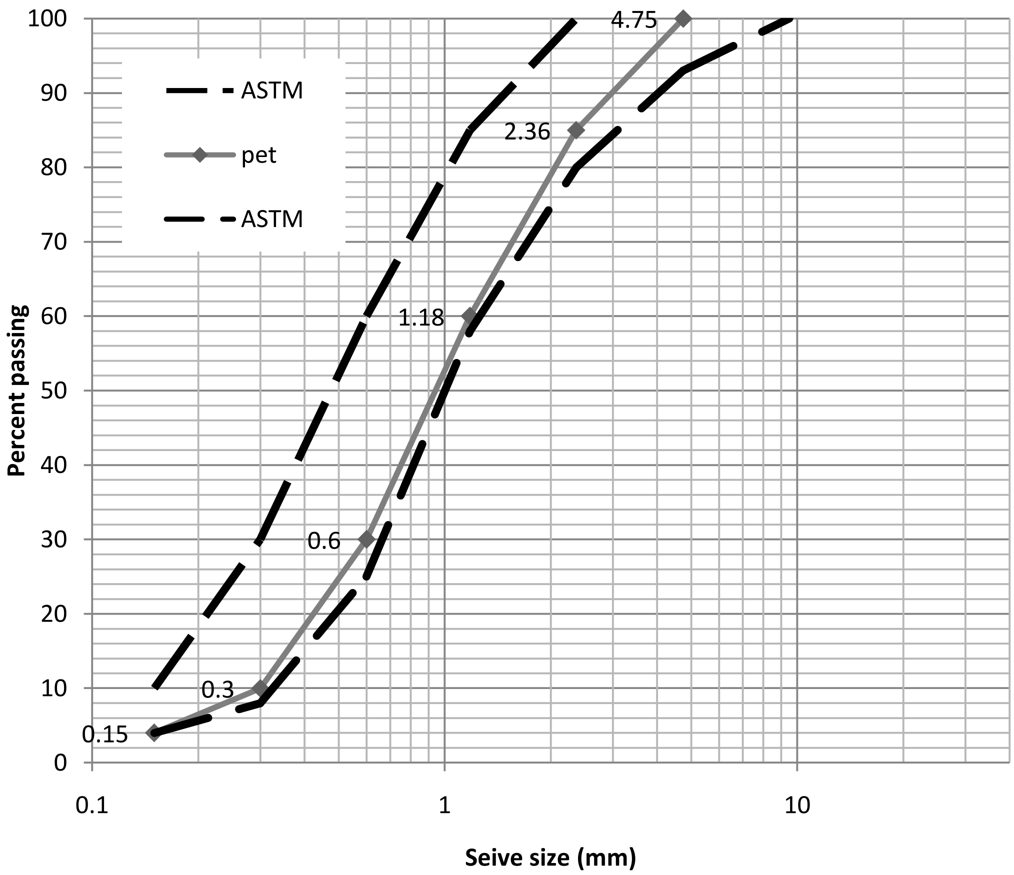

Figure: 2.4 Fineness Modulus of Lightweight Fine Aggregate (PET)

2.5 Conclusion

In this chapter the selected materials for thesis project are discussed elaborately along with their physical properties. Size and properties of coarse aggregate, Plastic Coarse Aggregate (PCA), fine aggregate, Plastic Fine Aggregate (PFA) are included in the aforementioned chapter. The selected binding material and its chemical properties are also mentioned along with other relevant data.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology chapter describes the procedures of obtaining the test results of the specimens defining their physical properties. Before casting, the materials had to go through some tests and after casting the cylinders are tested in order to measure the compressive strength and failure patterns. To achieve the experimental goals, the tests that are done are Specific Gravity Test, Water Absorption Test, Slump Test, Casting and Curing, Density Measurement and Compressive Strength Test.

3.2 Specific Gravity

This test is used to determine the specific gravity of aggregates by calculating the ratio of the weight of a given volume of aggregate to the weight of an equal volume of water. The specific gravity test measures aggregates' weight under three different sample conditions:

1. Oven-dry (no water in sample)
2. Saturated surface-dry (SSD, water fills the aggregate pores)
3. Submerged in water (underwater)

The standard coarse aggregate specific gravity and absorption test is ASTM C127 and ASTM C128 Specific Gravity and Absorption of Coarse Aggregate and Fine Aggregate respectively. Approximate test time is 3 days (from sample preparation to final dry weight determination).

Formula:

Bulk specific Gravity (Oven Dry), S_d:

$$\frac{A}{B-C} \quad (3.1)$$

Here, A=weight of oven dry test sample in air, g

B=weight of saturated surface dry test sample in air, g

C=weight of saturated test sample in water, g

Bulk specific Gravity (saturated surface dry), S_s:

$$\frac{B}{B-C} \tag{3.2}$$

Apparent specific gravity, S_a:

$$\frac{A}{A-C} \tag{3.3}$$

Water absorption:

$$\frac{B-A}{A} \text{x } 100\% \tag{3.4}$$

3.2.1 Basic Procedure for Coarse Aggregate

At first a constant weight of the sieved materials is taken and dried at a temperature of 110±5 in oven. After one hour of drying the weight of the sample is taken. A bucket containing the sample is drowned in water. The weight of drowned sample is taken. After that the sample is surface dried and the weight is taken. By using formulas mentioned above, the Bulk specific Gravity (Oven Dry) from Eqn. 3.1, Bulk specific Gravity (saturated surface dry) from Eqn. 3.2, apparent specific gravity from Eqn. 3.3 and water absorption capacity from Eqn. 3.4 are determined.

3.2.2 Basic Procedure for Fine Aggregate

The sieved sample of aggregates is thoroughly washed to remove finer particles and dust, drained and then placed in the wire basket and immersed in distilled water at a temperature between 22 and 32^{o}C. The weight of the sample is taken first before placing it under water. After that the basket and sample are immersed under water for a period of 24 + ½ hrs. Then the basket and aggregates are removed from the water, allowed to drain for a few minutes, after which the aggregates are gently emptied from the basket on to one of the dry clothes and gently surface-dried with the cloth. Afterwards the samples are transferred to a second dry cloth when the first would remove no further moisture. The aggregates are spread on the second cloth and exposed to the atmosphere away from direct sunlight till it appears to be completely surface-dry. The aggregates are then weighed. Lastly the aggregates are placed in an oven at a temperature of 100 to 110^{o}C for 24hrs. The samples are then removed from the oven, cooled and weighed. From the aforementioned formulas the desired properties for fine aggregates are determined.

3.3 Slump Test

The test is performed by using a mould known as a slump cone or Abrams cone. The cone is placed on a hard non-absorbent surface. Then the cone is filled with fresh concrete in three layers, each time it is tampered (a rod of standard dimensions) 25 times. At the end of the third stage, concrete is struck off flush to the top of the mould. The mould is carefully lifted vertically upwards, so as not to disturb the concrete cone. The slumped concrete takes various shapes, and according to the profile of slumped concrete, the slump is termed as true slump, shear slump or collapse slump.

3.4 Casting and Curing

6” x 12” cylinder moulds are used for casting fresh concrete. First grease is applied in the inner portion of the moulds. Then the moulds are filled up with concrete in three layers. In each layer 25 blows are given with a tampering rod. Then the moulds are placed for 24 hours for compaction. After 24 hours the cylinder are taken out from the moulds and the samples are made ready for curing. Ponding method of the samples is selected as curing method for the concrete specimens. After 24 hours of casting, all the cylinders are kept under water for 28 days at controlled temperature. Generally the compressive strength of concrete differs according to the age (i.e. 14, 21 & 28 days). For this project 28 days of curing are considered as standard. Curing is done for the increase in strength of the cylinders. This is done in a small pond and the temperature is controlled. Also fresh water is provided for better curing.

3.5 Compressive Strength Test

The compressive strength test is done after 28 days of casting concrete in cylinders. After finishing the Curing procedures, the cylinders are taken into the lab to determine the compressive strength of the samples. At first, the samples are grinded on the top and bottom surface with a grinding machine in order to have a smoother surface that would ensure uniformity in loading. Then the samples are entered into the compressive strength test machine known as Universal Testing Machine (UTM). Both the levers attached to the machine are kept in touch with the two surfaces of each cylinder. After placing the samples in the machine, the loads are applied unless the cylinder reaches its ultimate limit of taking the compression loads. The loads acted upon it are displayed in two units (psi and MPa) with the duration of the loads acted upon failure. Thus the compressive strength of the cylinders is obtained. The Structural lightweight concretes have densities ranging from 1360 to 1920 kg/m^3 (85 to 120 lb/ft^3) and minimum compressive strengths of 17.0 MPa (2500 psi). On the other hand, low-density concretes seldom exceed 800 kg/m^3 (50 lb /ft3) densities and are used chiefly as insulation. While their thermal insulation values are high, their compressive strengths are low, ranging from approximately 0.7 to 7.0 MPa (100 to 1000 psi) (ACI Education Bulletin E1-07).

3.6 Density Measurements of Aggregate

9” x 12” cylindrical moulds are used for measuring the density of the aggregates. First the materials are taken into the cylinder in three layers by giving 25 blows in each layer. The weights are taken afterwards. Then the weights are divided by the total volume of the cylinder to get the density of the materials.

3.7 Mix Design

The tests are carried out for three selected water-cement ratio. W/C ratio of 0.42, 0.48 and 0.57 has been selected to observe the performance of low to high water containing concrete mixture. The selected mix proportion is 1:1.5:3 (Cement: Fine aggregate: Coarse aggregate) by volume. The resultant mix proportions of all the mixes by weight are tabulated in the Table 3.1.

Table 3.1 Mix Design of the Concrete

Designation	w/c ratio	Water (kg)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Plastic Coarse Aggregate (kg)	Mix Proportion
W42P0	0.42	1.04	2.475	2.864	5.492	0	1:1.5:3
W42P2					4.393	0.745	1:1.5:3
W42P3					3.844	1.117	1:1.5:3
W42P4					3.295	1.490	1:1.5:3
W42P5					2.746	1.862	1:1.5:3
W48P0	0.48	1.19	2.475	2.864	5.492	0	1:1.5:3
W48P2					4.393	0.745	1:1.5:3
W48P3					3.844	1.117	1:1.5:3
W48P4					3.295	1.490	1:1.5:3
W48P5					2.746	1.862	1:1.5:3
W57P0	0.57	1.41	2.475	2.864	5.492	0	1:1.5:3
W57P2					4.393	0.745	1:1.5:3
W57P3					3.844	1.117	1:1.5:3
W57P4					3.295	1.490	1:1.5:3
W57P5					2.746	1.862	1:1.5:3

3.8 Failure Pattern of Concrete

According to ASTM C 39-03, "Standard Test Method for Compressive Strength of Cylinder Concrete Specimens," shows five different types of fractures.

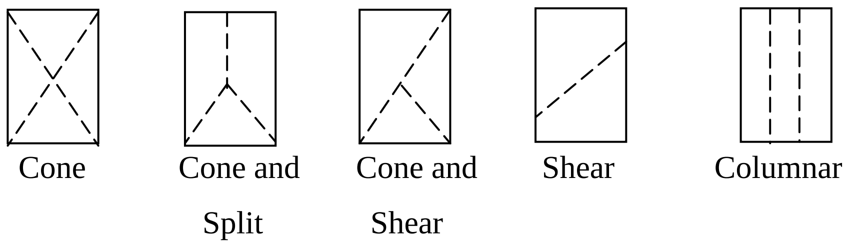

Figure 3.1: Various Failure Patterns of Concrete Cylinders

As shown in figure 3.1, the Cone Failure results when friction at the platens of the testing machine restrains lateral expansion of the concrete as the vertical compressive is applied. The Cone and Split Failure is the combination of coning and splitting of the concrete specimens. The Cone and Shear Failure occurs with the combination of both coning and shearing failure of concrete specimens. The Shear Failure occurs in the concrete specimen and failure occurs in the weak shearing zone diagonally. The Columnar Failure is the vertical failure occurring at the length of the specimens.

3.9 Conclusion

In this chapter the different methods obtained for determining the physical properties of the materials including specific gravity and water absorption are formulated and described elaborately. Also the properties of the concrete and the samples including slump value, compressive strength and density are discussed simultaneously.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

Considering the objectives of this experimental work and adopted methodologies certain experiments have been performed. The selected materials described in chapter three have been used for the experiments. Data obtained from the experiments have been analyzed to measure the suitability of Polyethylene Terephthalate (PET) as an alternative lightweight aggregate in load bearing structures. From the findings of the experiments, comparison between PET (both as coarse and fine aggregate) with regular concrete has been made and the deviations from our objectives also been determined.

This chapter contains several parameters of natural aggregate concrete (NAC), PET coarse aggregate (PCA) concrete and PET fine aggregate (PFA) concrete in various proportions. The parameters include density, workability, compressive strength and failure pattern which are shown in Table 4.1 and 4.2. Also further explanations are elaborately discussed.

4.2 Workability

Workability is an important property for concrete mixture. Workability is mainly affected by water content in the mixture along with mix proportion, and size, shape and grading of the aggregates. The selected w/c ratio for the experiment gives us the opportunity to compare the workability for low to high water content in concrete. From Tables 4.1 and 4.2 it was noted that for all type of concrete workability increases with the increment of water in the mixture. Though higher w/c ratio provides greater workability it also shows a tendency of “bleeding”, a particular form of segregation, during the casting of concrete. Due to bleeding certain amount of cement came to the surface along with water which is not desirable.

Table 4.1 Different Parameters for Regular Concrete and PCA Concrete

Percent of PCA	Water Cement Ratio	Density (Kg/m^3)	Slump (cm)	28 days Compressive Strength (MPa)	Average Compressive Strength (MPa)
0	0.42	2135.971	0.25	34.056	33.45
				32.844	
	0.48	2142.986	3.0	30.133	29.071
				28.009	
	0.57	2140.288	10.0	31.127	31.686
				32.245	
20	0.42	2059.353	1.80	30.633	30.314
				29.996	
	0.48	2048.112	3.50	25.143	24.827
				24.51	
	0.57	2004.946	9.0	23.667	24.221
				24.774	
30	0.42	2035.971	2.0	26.036	27.086
				28.135	
	0.48	2010.971	3.70	26.878	26.424
				25.97	
	0.57	1997.752	10.50	23.274	24.334
				25.394	
40	0.42	2034.173	2.0	26.193	25.956
				25.719	
	0.48	2001.349	4.0	25.792	26.455
				27.117	
	0.57	1985.162	13.0	24.453	22.897
				21.34	
50	0.42	1977.068	1.0	20.022	20.521
				21.019	
	0.48	1967.356	5.0	20.395	19.521
				18.647	
	0.57	1924.91	16.0	17.702	17.429
				17.155	

The shape of aggregate has great influence on good workability, where angular and flaky shaped aggregates make the concrete harsh in comparison to the rounded aggregates. The used brick aggregates were angular and flaky in shape while the used PCA were more round shaped. The round shape of PCA gives it less surface area and less voids along with the smooth surface of PCA than the brick aggregates together contributes to the less water absorption nature of PCA. These factors results in a good workability of PCA and improvement in workability with the increase of PCA amount is visible from the experiment results. The round shape of aggregate also greatly reduces the frictional resistance and improves workability. That's why the round shaped river sand contained concrete showed better workability than mechanically crushed flaky shaped PFA contained concrete.

Table 4.2 Different Parameters for Regular Concrete and PFA Concrete

Water Cement Ratio	Fine PET (%)	Density (Kg/m^3)	Slump (cm)	28 days Compressive Strength (MPa)	Average Compressive Strength (MPa)
0.42	0	2135.971	0.25	34.056	33.45
				32.844	
	50	2031.025	1.25	23.435	23.667
				23.898	
0.48	0	2142.986	3.0	30.133	29.071
				28.009	
	50	2028.417	1.50	23.602	23.093
				22.584	
0.57	0	2140.288	10.0	31.127	31.686
				32.245	
	50	1988.669	5.0	13.444	13.687
				13.929	

The relationship between workability and water cement ratio for regular concrete and lightweight concrete is tabulated in Table 4.3. The slump values increases with the rise in water cement ratio and PET aggregate replacement ratio. The values indicate better workability for PET coarse aggregate (PCA) concrete compared to regular concrete. However, workability shows an opposite trend while replacing fine aggregate (FA) with 50% PET fine aggregate (PFA) which is graphically shown in Figure 4.1. This is expected since PFA has a high water absorption capacity compare to conventional FA, like sand. It is also observed that for a similar water cement ratio and replacement ratio of coarse aggregate (CA) with PCA and PFA, the workability is much higher for PCA and lower for PFA compared to regular concrete.

Table 4.3 Slump Values for Regular Concrete and PET Replaced Concrete

Coarse PET (%)	Water Cement Ratio	Slump (cm)
0	0.42	0.25
	0.48	3.0
	0.57	10.0
20	0.42	1.80
	0.48	3.50
	0.57	9.0
30	0.42	2.0
	0.48	3.70
	0.57	10.50
40	0.42	2.0
	0.48	4.0
	0.57	13.0
50	0.42	1.0
	0.48	5.0
	0.57	16.0

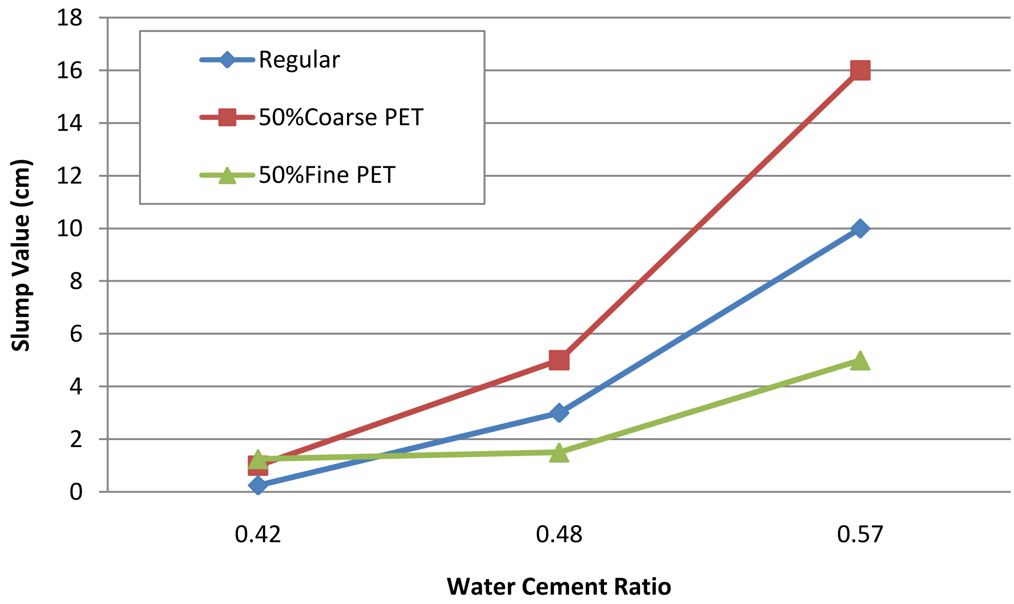

Figure 4.1 Water Cement Ratios vs. Slump Values for Regular Concrete and PET Replaced Concrete

4.3 Density

The density of the samples was measured at dry condition at 28 days just before the compressive strength test. The values obtained are shown in Figure 4.2. The figure indicates a gradual reduction in density of PET replaced concrete compared to regular concrete. As the water cement ratio increases, the density for PET replaced concrete decreases while the density of regular concrete remains almost same. It has also been observed that the density of the concrete decreases with the increase of PET as Coarse Aggregate. The reduction rate is the highest for 50% replacement of 0.57 water cement ratio. It is possible because the PCA has a low unit weight compared to regular CA (brick chips).

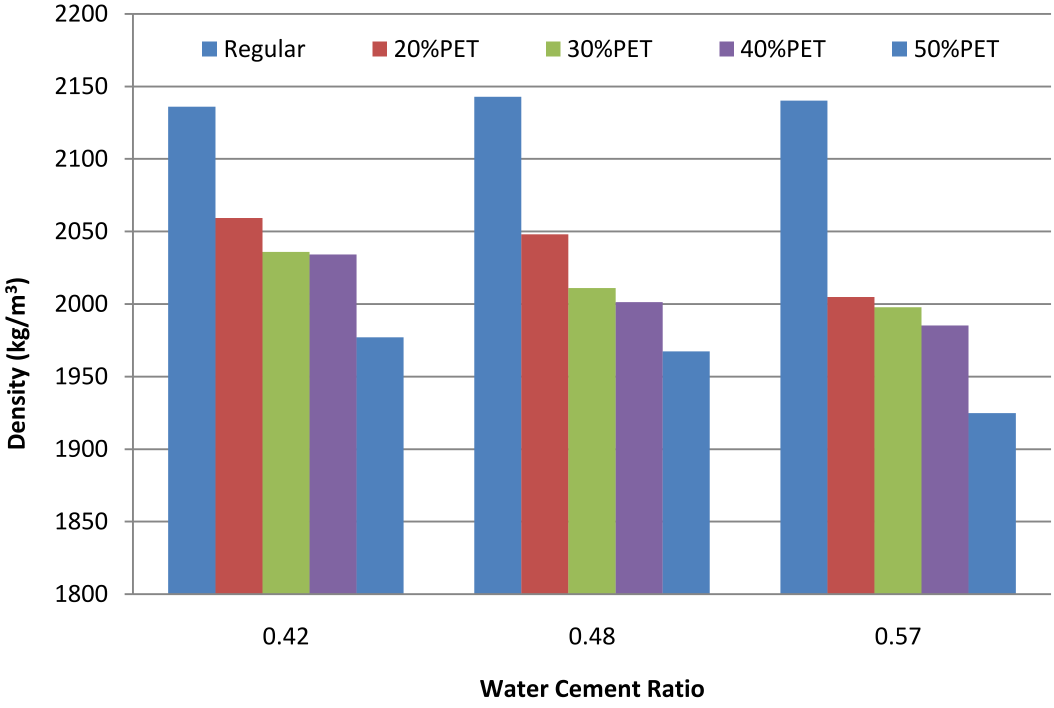

Figure 4.2 Density vs. Water Cement Ratio for Regular Concrete and Varying PCA Concrete

The density of PFA concrete has a lower density than the regular concrete as illustrated in Figure 4.3. However it has a higher density compared to the same amount of PCA concrete. Also with the increase of water cement ratio, the density of both PCA concrete and PFA concrete decreases but the density remains almost similar for regular concrete.

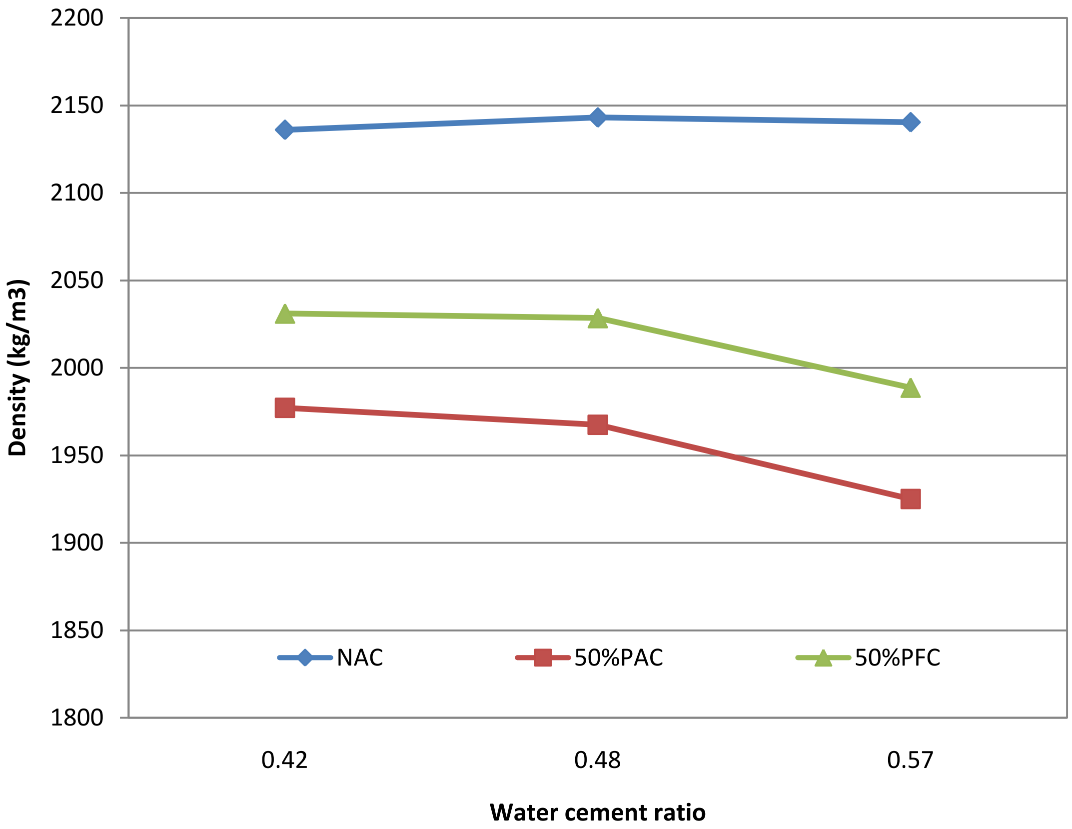

Figure 4.3 Variation in Density and Water Cement Ratio of NAC and PET Replaced Concrete

4.4 Compressive Strength

The compressive strength tests are carried out after 28 days of casting. The results show a trend of reduced compressive strength for PCA concrete compared to regular concrete (Figure 4.4). The strength decreases with the increment of PCA in concrete. Also the compressive strengths show a downward trend with the increase in water cement ratio for both regular concrete and PCA concrete. The probable reason for decreased compressive strength with the increment of PCA in concrete is the poor bondage between PCA and binding material. Figure 4.5 shows the weak bond in PCA concrete due to the smooth surface of PCA.

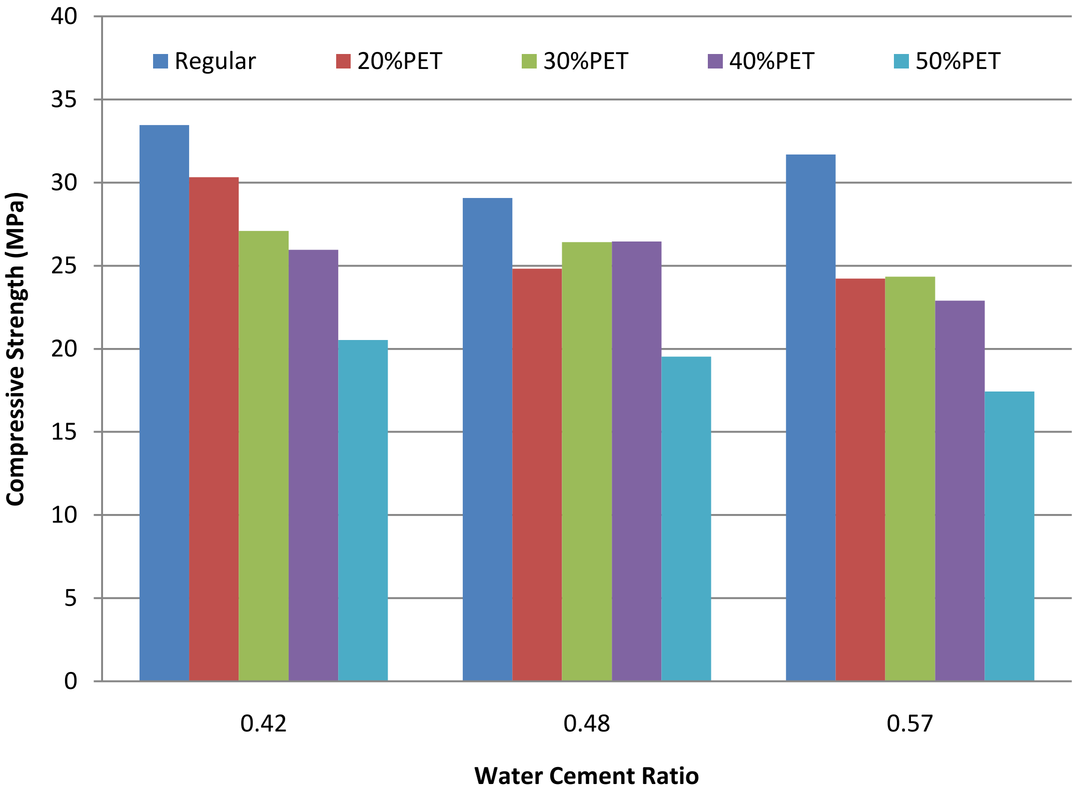

Figure 4.4 Compressive Strength (28 days) of Regular Concrete and PCA Concrete

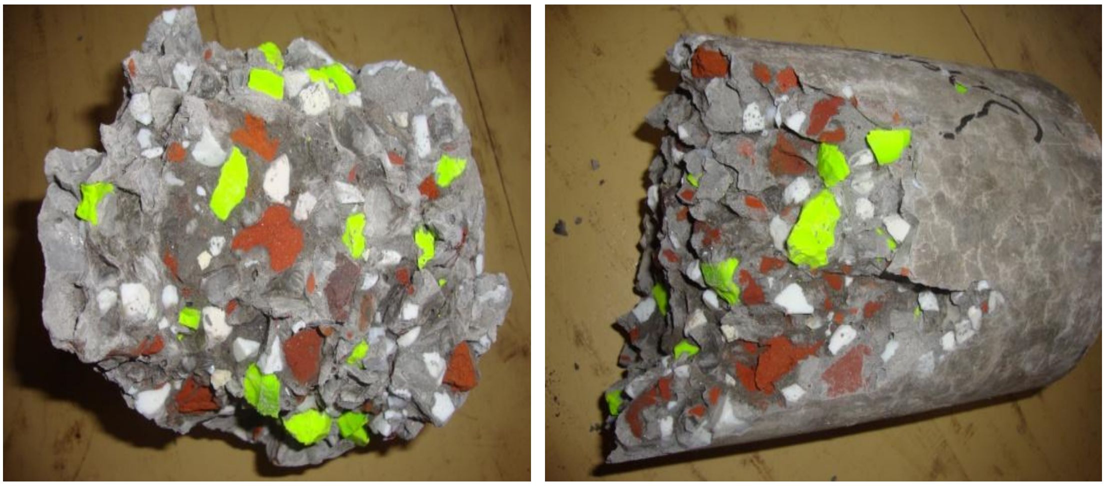

Figure 4.5 Bondage between PCA and Binding Material in Concrete

The decrease in compressive strength with increasing w/c ratio is as a fact of Abrams water-cement ratio law which states that 'The compressive strength of concrete is inversely proportional to the water-cement ratio of the mixture'.

The inter-face between the cement paste and aggregate known as 'Transition zone' which's integrity influences the compressive strength of concrete. Bleeding caused by higher w/c ratio in concrete promotes the accumulation of water in the transition zone of concrete resulting decrease in compressive strength of concrete. As from the properties of PCA we know that its water absorption capacity is almost zero in comparison to the absorption capacity of brick aggregates. This causes more accumulation of water in the transition zone. This extra water remaining in the transition zone results in poor paste structure and gel bond in the PCA concrete which greatly reduces its compressive strength.

Along with the bleeding water, the smooth surface of the PCA also contributes to the low compressive strength of PCA concrete. Rough aggregate surface of brick chips develop strong bondage between the aggregate and the cement paste but smooth surface of PCA is unable to develop strong bond results in a lower compressive strength than NAC. The failure pattern of the PCA concrete cylinders confirms the weak bondage between the PCA and cement paste (Figure 4.5). All the PCA contained cylinders in the experiment showed mortar failure cracks around the PCA.

For the same amount of PCA and PFA in concrete, the compressive strength of PFA concrete is higher than the PCA concrete for the lower water cement (0.42 & 0.48) ratio (Figure 4.6). However, the compressive strength decreases with the high water cement ratio of 0.57 for PFA concrete; whereas PCA concrete shows a consistency in reduction of the compressive strength relative to the water cement ratio. Table 4.4 shows the percent reduction of compressive strength of PFA concrete.

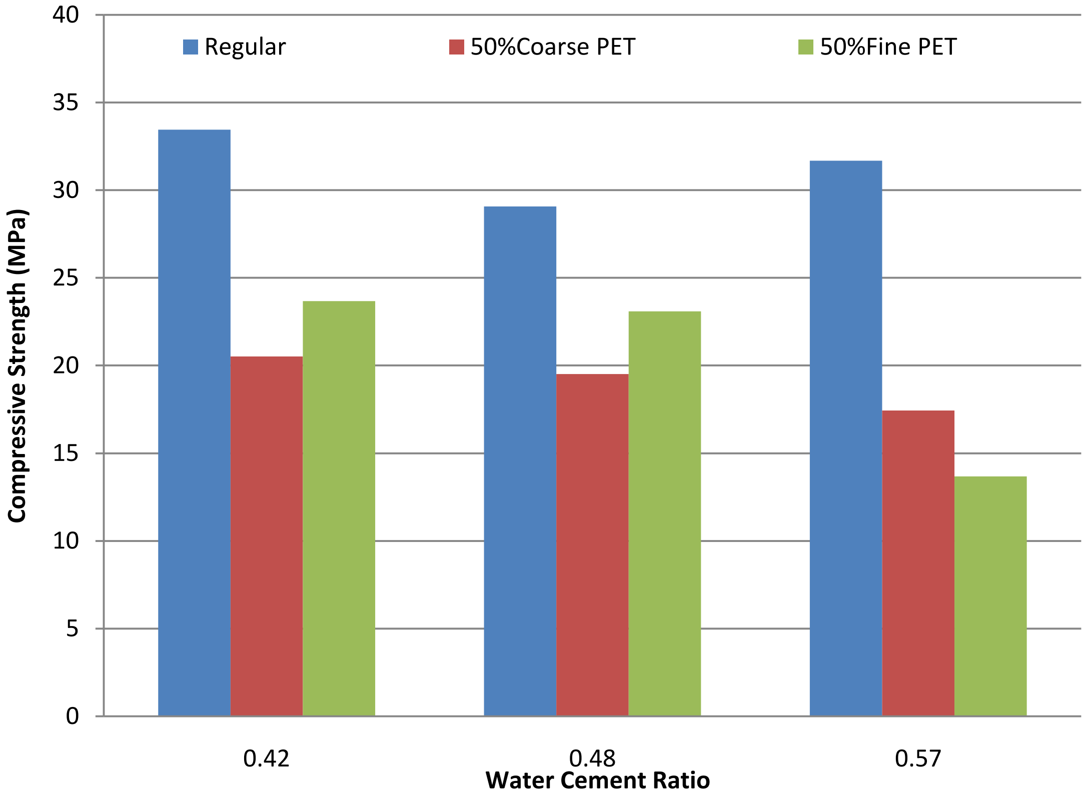

Figure 4.6 Compressive Strength for 50% PCA Concrete and 50% PFA Concrete Relative to Water Cement Ratio

Table 4.4 Percent Reduction of Compressive Strength for PFA Concrete

Water Cement Ratio	Compressive Strength of Regular Concrete (MPa)	Compressive Strength of 50 % Fine PET (MPa)	Percent (%) Reduction in Compressive Strength
0.42	33.45	23.67	29.3
0.48	29.07	23.09	20.6
0.57	31.67	13.69	56.8

4.5 Conclusion

From the experimental results it is seen that for all the combinations used the compressive strength satisfies the BNBC (Bangladesh National Building Code) specification of minimum load bearing strength (17 MPa) for concrete. In case of PCA and PFA for same replacement amount (50%) PFA contained concrete showed higher strength. In density reduction, the maximum reduction is seen for higher water-cement ratio with higher PCA replacement. For the same amount of PFA replacement the density reduction is less than PCA concrete. From the test results it is also clearly understandable that the workability is significantly increased with the increment of water-cement ratio for PET contained concrete. Again this rate is higher for PCA concrete.

The reduction in density of PCA concrete indicates that plastic can be used as an aggregate for lightweight concrete. Due to limitations only two sets of each sample concrete cylinders are made and average is being taken for comparison. The results indicates that PCA contained concrete is better suited over PFA contained concrete as a lightweight concrete aggregate.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1General

The present experimental work deals with the possibility of using the melted Polyethylene Terephthalate (PET) as a replacement of conventionally used coarse and fine aggregates to obtain a light weight concrete mixture which can be used in load bearing structures. Various experiments have been performed and results have been analyzed to justify the possibility. Based on the obtained results and analyzed data the findings of the experimental work and recommendations are described in this chapter.

5.2 Summary and Conclusion

The experimental results lead to the following conclusions:

1. The PCA and PFA can be used as an alternative for natural aggregates in concrete preparation. Along with the density reduction it also satisfies the criteria of minimum load bearing strength according to BNBC (Bangladesh National Building Code).
2. Although PCA and PFA concrete have lower unit weight they are not low enough to meet the ASTM specification of lightweight concrete. Only the 50% PCA contained concrete is close enough to meet the ASTM specification.
3. Despite having lower density the 50% PCA contained concrete fails to meet the BNBC specification to be used in load bearing structures.
4. Due to the shape and surface structure of the PCA the workability of concrete has been improved greatly which can provide the opportunity to work with reduced water content; and thus, increases compressive strength of concrete.

5.3 Recommendations

From the above experimental work and findings there are many areas for scope of work. To achieve the specified density for lightweight concrete the selection and production of PET aggregates can be modified. To achieve the desired strength and reduce the bleeding effect some water reducing agent can be used. To overcome the surface smoothness problem chemical treatment of PET aggregates can be recommended. Despite having some drawbacks the used PET aggregates can be used as lightweight aggregates in load bearing structures.

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