A STUDY OF
GREEN LIGHTWEIGHT CONCRETE USING POLYETHYLENE TEREPHTHALATE (PET) AS AGGREGATE

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DECLARATION

We hereby declare that this thesis is my/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.

November, 2014

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DEDICATED

TO

OUR BELOVED PARENTS

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ABSTRACT

It is the time for development and implementation of sustainable materials in construction and reduce the reliance on non-renewable sources. Uses of Polyethylene Terephthalate (PET), largely used for manufacturing plastic carry bottles, are rising in an alarming rate and the reuse of these plastic wastes is highly essential. Therefore, the main focus of this study is to use PET as a partial replacement for coarse aggregate in concrete. The safety, durability, and stability of the structure largely depend on the properties of concrete, and thus, it is imperative to prepare concrete with adequate compressive strength. In lieu with this objective, 18 cylinders are prepared with conventional concrete materials, and 54 more cylinders are prepared with PET as a partial replacement, 10%, 20%, and 30% by volume, of coarse aggregate to find out the best possible replacement ratio. Three water-cement ratio (i.e. 0.42, 0.48, and 0.57) are taken under consideration for achieving optimum workability in using PET as Plastic coarse aggregate.

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LIST OF SYMBOLS

S_d	Bulk specific gravity (oven dry condition)
S_s	Bulk specific gravity (SSD condition)
S_a	Apparent specific gravity
P	Maximum load
L	Length or height of concrete cylinder
d	Diameter of concrete cylinder
PP	Ploy Propylene
HDPE	High-density polyethylene
PCA	Plastic Coarse Aggregate
PET	Polyethylene terephthalate
FM	Fineness modulus

CHAPTER 1
INTRODUCTION

1.1 General

A sustainable industrial growth will influence the cement and concrete industry in many respects as the construction industry has environmental impact due to high consumption of energy and other resources. One important issue is the use of environmental-friendly concrete (“green”) concrete to enable world-wide infrastructure-growth without increase in CO_2- emission.

Polyethylene terephthalate (PET) is one of the most used materials in the packaging of several kinds of products. The packages made with PET are light, transparent, and with high resistance to impact, they do not interact chemically with binding materials, and they are not toxic. All these characteristics have made them gain presence in the polymer market and earn a major presence in the global industry.

Waste PET bottles have been reworked for drinking bottles by melting fusion, which turned out to be too costly. Alternative approach is to recycle waste PET bottles as eco-friendly aggregates to reduce the rework cost. However, results have been far from satisfactory. If waste PET bottles are reused as aggregates for green concrete, positive effects are expected on the recycling of waste resources and the protection of environmental control.

Use of green concrete requires less brick chips as coarse aggregate for the construction work which reduce environment pollution. In Bangladesh, conventionally bricks are adopted as main coarse aggregate which gives rise to more brick-kilns with significant environment degradation by emitting high concentrated carbon monoxide (CO), carbon-dioxide (CO_2), different oxides of sulphur (SO_x) and particulate matters. On the other hand, production of PET aggregates by melting emits gases, but in a lower scale. Therefore, using PET as coarse aggregate can significantly reduce these gas emissions.

In this study, brick chips as coarse aggregates in concrete are partially replaced with PET. This PET is obtained as byproduct while recycling of PET bottles in melted liquid condition. Then the melted PET is collected and cooled to obtain PET molds which are used as our coarse aggregates. Properties of concrete with partially replaced PET are studied and recommendations are made.

1.2 Literature Review

Properties of concrete largely depend on the type of material which is used as aggregate. Usually, civil engineers prefer to use stone chips, brick chips etc. but now a days by using modern technology researchers try use different types of waste reusable or recyclable materials instead of stone or brick chips. There have been a lot of materials, especially plastic based recyclable materials, which were previously used by researchers as either coarse or fine aggregate or both in order to obtain a suitable strength of concrete.

Gavela et al. (2004) used Ploy Propylene (PP) and Polyethylene Terephthalate (PET) as alternative replacement of a part of conventional aggregate. Two replacements were done by using 20% and 30% by volume of aggregates. Reference specimens without polymeric aggregates were also prepared. Two w/c ratios (.05 and 0.6) were used. For PP 20% and 30% with w/c ratio 0.5 the compressive strength was gained 25.6 MPa and 18.5MPa respectively for 7 days and 30.3 MPa and 23.5MPa respectively for 28 days. For 20% PET with w/c ratio 0.5 and 30% PET with w/c ratio 0.6 the compressive strength was 26.7 MPa and 19.0 MPa respectively for 7 days and 35.1 MPa and 24.0 MPa respectively for 28 days while without any plastic aggregate for w/c ratio 0.5 and 0.6 the conventional concrete compressive strength was 33.4 MPa and 31.5 MPa respectively for 7 days and 40.2 and 40.6 respectively for 28 days. The result shows that the 28-day compressive strength of concrete containing 20% and 30% by volume of aggregates ranged from 35.1 to 23.5 MPa while the flexural strength ranged from 5.03 to 2.89MPa. For same w/c ratio and same amount of PP and PET compressive strength of PET was higher than PP and also by increasing the amount of PET, the compressive strength was decreased.

Córdoba et al. (2013), studied PET of different sizes. They replaced 1%, 2.5% and 5% of coarse aggregate with 0.5mm, 1.5mm and 3mm PET particles. For 1% of PET and 0.5mm, 1.5mm and 3mm particles, Compressive strength 22.5 MPa, 20MPa and 14MPa respectively. For 2.5% of PET and 0.5mm, 1.5mm and 3mm particles, Compressive strength 23 MPa, 21 MPa and 12 MPa. For 5% of PET and 0.5mm, 1.5mm and 3mm particles, Compressive strength 21 MPa, 22.5 MPa and 13 MPa respectively. Values of concrete strength range from 10.0 to 21.3MPa, with a maximum improvement of 40% when 1.5mm PET particles are added. According to PET particle size, the values are higher for concrete with 1.5mm PET particles and lower for those with 3.0mm PET particles.

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.

Naik et al. (1996) determined the effects of inclusion of post-consumer plastic in concrete. The material, a high-density polyethylene (HDPE) with dimensions ranging from 4.7 to 9.5 mm, was used as fine aggregate in concrete. The particles of HDPE were subjected to three chemical treatments (water, bleach, bleach + NaOH) to improve their bonding with the cementations matrix. The plastic particles were added to the concrete in amounts ranging from 0% to 5% by weight of total mixture. Compressive strength decreased with increasing the amount of HDPE in concrete, particularly above 0.5% plastic addition. Of the three treatments used, the highest compressive strength was achieved when the plastic was treated with alkaline bleach. 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.

Albano et al. (2009) analyzed the mechanical behavior of concrete containing WPET, varying the water/cement ratio (0.50 and 0.60), the WPET content (10 and 20 vol. %) and the particle size (employing one small, i.e. 0.26 cm, and one big, i.e. 1.14 cm). The results indicated that, as the volume proportion and the particle size of WPET increased, WPET-filled concrete showed a decrease in compressive strength, splitting tensile strength, modulus of elasticity and ultrasonic pulse velocity; moreover, the water absorption increased. It was reported, however, that the concrete specimens were not fully compacted. Accordingly, they showed the formation of honeycombs which seriously affected the strength characteristics.

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.

1.3 Observations from Literature Review

The above literature review indicates that

- The compressive strength of concrete decreases with the increase amount of plastic coarse aggregate (PCA) in the concrete.
- The compressive strength of concrete decreases with the increase in water-cement (w/c) ratio.
- The workability improves with the increase in PCA percentage in concrete.
- The smooth surface of plastic aggregates restricts the proper bonding between the aggregates and binding materials as a result failure occurs through the interfacial transition zone.
- To achieve an efficient bonding between the plastic aggregates and cement mortar it is essential to have a rough outer surface for the aggregates which can be achieved through chemical and/or mechanical treatments.

1.4 Objectives

The objective of this work is to study the effect on concrete properties when natural coarse aggregates are partially replaced with PET.

1.5 Scope of Work

To achieve the aforementioned objective, the scope of this research includes:

- Determining the material properties of various components used in concrete.
- Preparing concrete with different PCA amounts and w/c ratio to achieve the objective.
- Studying the relationship among the amount of PCA, the w/c ratio and the compressive strength.

1.6 Organization of the Thesis

The overview of our project is provided in the introductory part showing comparison with the conventional concrete materials and our proposed light weight green concrete. After that, some relevant literature reviews are done so that the reviewers may have a clear concept of the preceding works which is related to the aforementioned proposition. Subsequently the observation from these reviews give a clear perception of the researchers that have been undertaken over the world in the same field of material engineering and their structural or nonstructural applications or both. Objective shows the purpose of the overall agenda of the research project considering the gaps found in the reviews of the literatures provided. At last scope of the work mentioned the results which are obtained for our thesis purpose.

In the second chapter the materials that are necessary for concrete mixtures are mentioned which includes binding material, coarse aggregates and fine aggregates. The properties of these materials are elaborately described as well as the gradations of the coarse aggregate and fine aggregate are shown in charts and tabular formats. In case of coarse aggregate (Plastic Coarse Aggregate) the fineness modulus of the PCA and the sieve analysis of the fine aggregate (sand) are shown in tabular and graph format.

After the second chapter third one comes with the elaborate description of the methodologies obtained for the execution of the research project. Various methods are used to get the result of both coarse and fine aggregate's different types of Specific Gravity, Water absorption capacity, Density. The slump tests are done of the concrete samples of different combinations to find out the workability. Furthermore, the casting and curing procedures of the specified concrete are described. Addition to that the compressive strength tests are done of the different combinations of the materials used in concrete samples after 28 days of casting. The mix design of the concrete samples point out the volume ratio of the materials used the amount of materials needed (by weight) and the water-cement ratios are described and formulated in a tabular form for different mixtures. Lastly the failure pattern shows the stability and the durability of the different concrete mixes which may relates with the safety purpose.

The test results and the discussions related to our obtained results is described in the fourth chapter. The parameters of the PCA 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 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, the compressive strength of the concrete with different water-cement ratio, the tensile strength of concrete with different water cement ratio.

Lastly the conclusion and the recommendation are given in the fifth chapter where there are list of references are given to make a link between our given data and the original sources. 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

2.1 General

Different materials are used for the preparation concrete mixture. These materials vary in properties and their function in the mixture. Different codes were followed for the specification of the materials. Both conventional and advanced alternatives were used. For the preparation of the concrete mixture, Bricks were used as traditional coarse aggregates and we replaced some percentage of them with Polyethylene Terepthalate (PET). Sylheti sand was used as fine aggregate. For binding materials we used cement.

2.2 Binding Materials

As binding materials we used Seven Rings cement (Portland cement). For the chemical composition, physical properties and compressive strength, we followed Quality test certificate of Seven Rings Cement. Specific Gravity of cement was recorded 3.15, Initial setting time 182 minutes and final setting time 374 minutes. These tests were done according ASTM specifications, which are ASTM C192, ASTM C187, ASTM C109 and ASTM C595.

Figure 2.1 Cement (binding material)

Table 2.1 Properties of seven rings cement

Chemical Composition	Unit	Specification	Test Result
Calcium Oxide (CaO)	(%)		55.17
Silicon dioxide (SiO_2)	(%)		22.14
Aluminum Oxide (Al_2O_3)	(%)		6.36
Ferric Oxide (Fe_2O_3)	(%)		3.44
Sulphur trioxide (SO_3)	(%)	Maximum 4.0	2.56
Magnesium Oxide (MgO)	(%)	Maximum 6.0	1.60
Loss On Ignition (LOI)	(%)	Maximum 5.0	2.31
Insoluble Residue (IR)	(%)		12.10
Moisture	(%)		0.11
Physical Property			
Fineness (Specific Surface)	(M^2/Kg)		365.40
Residue (By 45 Micron)	(%)		2.02
Setting Time, ASTM C191	Minutes		
Initial Setting Time	Minutes	45 minutes (min.)	182
Final Setting Time	Minutes	420 minutes (max.)	374
Water for normal consistency, ASTM C187	(%)		27.28
Soundness (By Autoclave method)	(%)	Maximum 0.80	0.011
Compressive Strength, ASTM C109	PSI		
3 days	PSI	1890	3240
7 days	PSI	2900	4316
28 days	PSI	3620	5690

2.3 Coarse Aggregates

Normal brick chips were used as conventional coarse aggregates. Then we replaced them with some percentage of PET.

2.3.1 Brick Aggregates

Bricks were collected from local brick fields. Then they were crushed according to the specifications, maximum size was 19mm whereas the minimum size was 2.36mm.

Brick chips were washed to make it clean from dust and dirt. Washed brick chips were kept until it attained the Surface Saturated Dry (SSD) condition. Then they were kept air-tight with the help of Polythene Cover so that it remains in SSD condition. All the bricks used in our experiment were in this condition.

Physical properties were obtained by testing the aggregates according to ASTM C136, ASTM C127 standard. The result of various result are given below:

Table 2.2 Properties of brick (coarse aggregate)

SL. No.	Characteristics	Value
01	Type	Crushed
02	Maximum size	19 mm
03	Minimum size	2.36 mm
04	Bulk specific gravity	1.96
05	Apparent specific gravity	2.29
06	Water absorption	14.87 %
07	Fineness modulus	6.38

Figure 2.2 Brick chips (coarse aggregate)

Table 2.3 Sieve analysis of brick chips (coarse aggregate)

Sl. No.	Sieve Size (mm)	Mass Retained (gm.)	% Retained	Cumulative % Retained	Cumulative % Passing
1.	75	-	-	-	-
2.	37.5	-	-	-	-
3.	19	27.2	5.44	5.44	94.56
4.	9.5	261.7	52.4	57.84	42.16
5.	4.75	149.8	29.99	87.33	12.17
6.	2.36	47.9	9.58	97.41	2.59
7.	1.18	-	-	97.41	2.59
8.	0.60	-	-	97.41	2.59
9.	0.30	-	-	97.41	2.59
10.	0.15	-	-	97.41	2.59
11.	Pan	12.9	2.58		0.1
				Total =	637.66

Fineness modulus (FM) of brick chips = 637.66/100 = 6.38

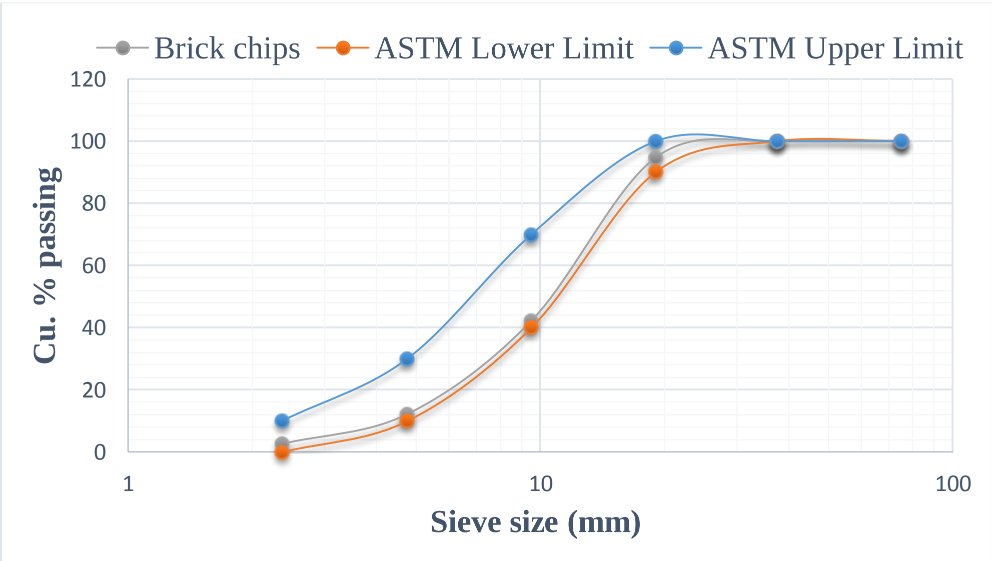


Figure 2.3 Fineness modulus of brick aggregate

2.3.2 Plastic Aggregates

Polyethylene terepthalete (PET) was used as a part of coarse aggregate where brick chips were partially replaced by it. PET is a thermoplastic polymer. PET in its natural state is a colorless, semi-crystalline resin. Based on how it is processed, it can be semi rigid to rigid. This PET is obtained as byproduct in melted condition while recycling of PET bottles. Then the melted PET is collected and cooled to obtain PET mold which then crushed, to use as coarse aggregate. Then this PET was sieved according to ASTM standard for coarse aggregate.

Figure 2.4 Production of PET

Some physical properties were obtained by testing according to ASTM C127, ASTM C136. The properties are shown in below:

Table 2.4 Properties of plastic coarse aggregate (PET)

Sl. No.	Characteristics	Value
01.	Type	Crushed
02.	Maximum size	19 mm
03.	Minimum size	2.36 mm
04.	Bulk specific gravity	1.31
05.	Apparent specific gravity	1.32
06.	Water absorption	0.35 %
07.	Fineness modulus	6.19

Figure 2.5 Plastic aggregate (PET)

Table 2.5 Sieve analysis of plastic coarse aggregate (PET)

Sl. No.	Sieve Size (mm)	Mass Retained (gm)	% Retained	Cumulative % Retained	Cumulative % Passing
1.	75	-	-	-	-
2.	37.5	-	-	-	-
3.	19	0	0	0	100
4.	9.5	159.8	32	32	68
5.	4.75	274.7	55	87	13
6.	2.36	64.9	13	100	0
7.	1.18	-	-	100	0
8.	0.60	-	-	100	0
9.	0.30	-	-	100	0
10.	0.15	-	-	100	0
11.	Pan	0	0		0
				Total =	619

Fineness modulus (FM) of PET = 619/100 = 6.19

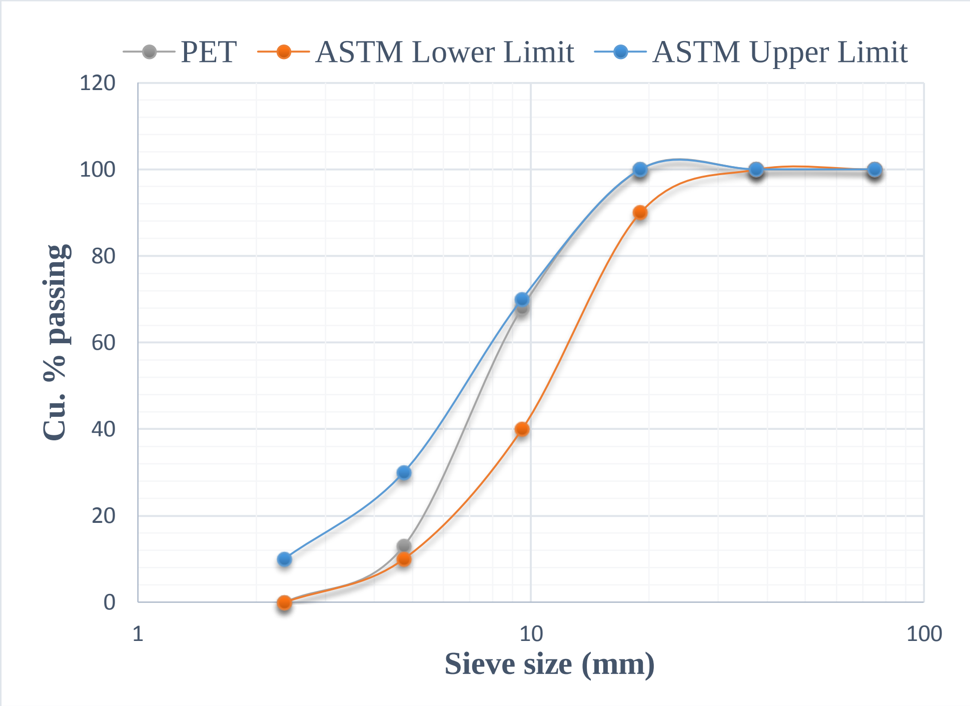


Figure 2.6 Fineness modulus of plastic coarse aggregate (PET)

2.4 Fine Aggregate

In our experiment we used shyleti sand as fine aggregate. It was collected from local shop in bags and mixed together preciously. Then the sand was sieved through 4.75 mm. Unwanted particles were removed from the sand. After measuring its moisture content sand was covered by plastic bag so that no moisture can inter or get-out from the sand. Different test are done, like sieve analysis, moisture content, bulk specific gravity, apparent specific gravity etc.

Then its physical properties were determined according to ASTM C128, ASTM C136 and ASTM C70-94 standards. Some properties like type of sand, maximum and minimum size, specific gravity, water absorption capacity- and sieve analysis are given below:

Table 2.6 Properties of fine aggregate (sand)

Sl. No.	Characteristics	Value
01.	Type	Uncrushed (Natural)
02.	Maximum size	4.75 mm
03.	Minimum size	0.15 mm
04.	Bulk specific gravity (oven dry)	2.146
05.	Bulk specific gravity (SSD)	2.33
05.	Apparent specific gravity	2.62
06.	Water absorption	8.40 %
07.	Fineness modulus	2.89

Figure 2.7 Sand (fine aggregate)

Table 2.7 Sieve analysis of fine aggregate (sand)

Sl. No.	Sieve Size (mm)	Mass Retained (gm)	% Retained	Cumulative % Retained	Cumulative % Passing
1.	75	-	-	-	-
2.	37.5	-	-	-	-
3.	19	-	-	-	-
4.	9.5	-	-	-	-
5.	4.75	0.1	0.02	0.02	99.98
6.	2.36	29.42	5.88	5.9	94.1
7.	1.18	91.91	18.37	24.27	75.73
8.	0.60	241.79	48.33	72.6	27.4
9.	0.30	80.25	16.04	88.64	11.36
10.	0.15	45.08	9.01	97.65	2.35
11.	Pan	11.75	2.35		
				Total =	289.08

Fineness modulus (FM) of sand = 289.08/100 = 2.89

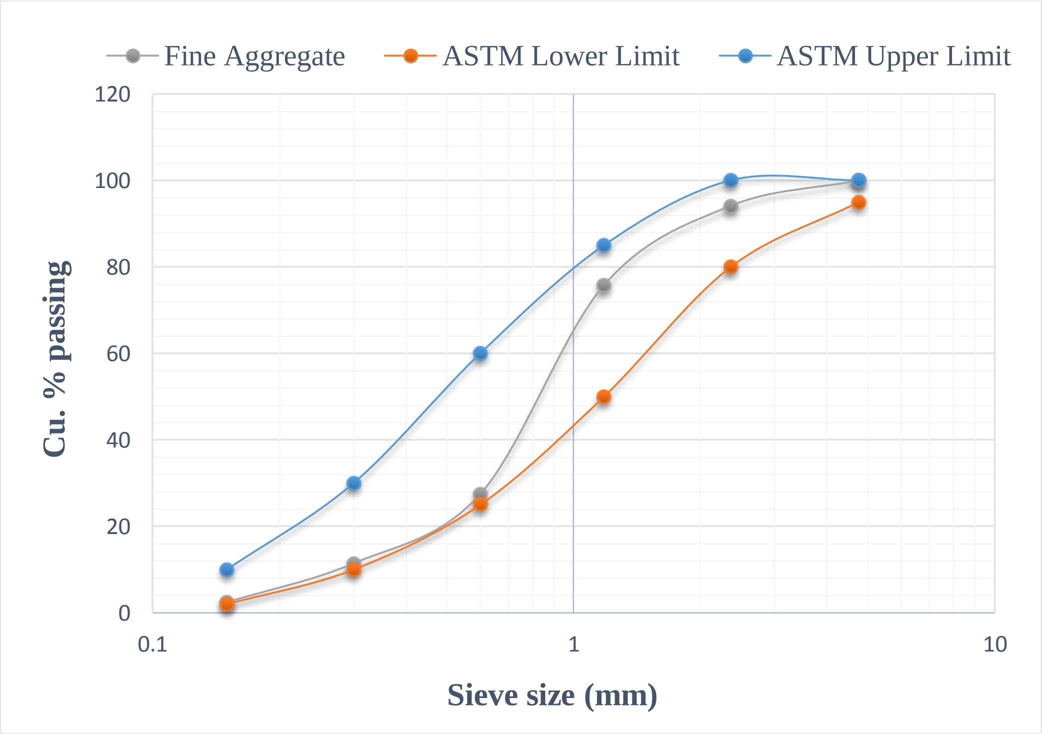


Figure 2.8 Fineness modulus of sand (fine aggregate)

2.5 Conclusion

Different properties of different materials which are used in this project are elaborately discussed in this chapter. How the materials are collected, there transportation, size, specific gravity, water absorption capacity, chemical properties of binding material etc. are mentioned along with other relevant data.

CHAPTER 3
METHODOLOGY

3.1 Introduction

Two steps of testing is used to attain their characteristics as before casting and after casting. Before casting the materials had to go through some tests in order to find their physical characteristics and after casting the cylinders were tested in order to measure the compressive strength and their corresponding failure patterns. The tests those were 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),

$$S_d = \frac{A}{B-C} \tag{3.1}$$

Here,

A = weight of oven dry test sample in air, gm

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

C = weight of saturated test sample in water, gm

Bulk specific gravity (SSD):

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

Apparent specific gravity:

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

Water absorption:

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

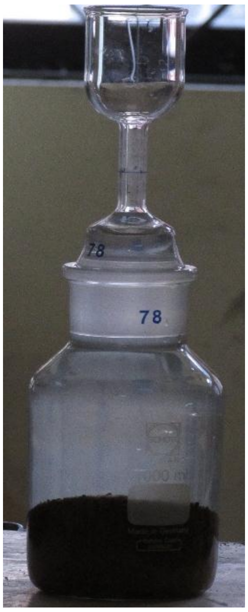


Figure 3.1 Specific gravity of sand

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.

Figure 3.2 Measurement of brick chips

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 22o and 32o 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 100o to 110o 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.

Figure 3.3 Sand and PET in airtight bag

3.3 Mix Design

For three selected water-cement ratio the tests are carried out. Water cement ratio of 0.42, 0.48 and 0.57 are used. The selected mix proportion is 1: 1.5: 3 (Cement: fine aggregate: coarse aggregate) by volume. The coarse aggregate is partially replaced by PET by volume 10%, 20% and 30%. There is also sample concrete cylinder which contain only brick chips as coarse aggregate. For compressive strength test three cylinders and for tensile strength test three cylinders, total six cylinders are casted for each designation or mixing criteria. Four percentage of coarse aggregate are used for one water-cement ratio, and for three W/C ratio total twelve percentage of coarse aggregate are used. That means total 72 (12 x 6) cylinder are casted in the project to determine both compressive and tensile strength test. The coarse aggregate is partially replaced by volume. But the aggregates amount is determined in weight (kg) by the help of specific gravity of the aggregate. So the mix proportion 1: 1.5: 3 is maintain by the volume.

Table 3.1 Mix design for 1cft concrete (by weight)

Designation	w/c ratio	Water (kg)	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Plastic coarse aggregate (kg)
W42P00	0.42	12.10	28.81	31.96	53.78	0
W42P10					48.40	3.59
W42P20					43.02	7.19
W42P30					37.64	10.78
W48P00	0.48	13.46	28.03	31.10	52.33	0
W48P10					47.09	3.50
W48P20					41.86	6.99
W48P30					36.63	10.49
W57P00	0.57	15.36	26.94	29.89	50.29	0
W57P10					45.26	3.36
W57P20					40.23	6.72
W57P30					35.21	10.08

Table 3.2 Mix design for 1cft concrete (by volume)

Designation	w/c ratio	Water (ft^3)	Cement (ft^3)	Brick (ft^3)	PET (ft^3)	Sand (ft^3)	Total (ft^3)
W42P00	0.42	0.19	0.15	0.44	0.00	0.22	1.00
W42P10	0.42	0.22	0.14	0.43	0.00	0.21	1.00
W42P20	0.42	0.25	0.14	0.41	0.00	0.21	1.00
W42P30	0.42	0.19	0.15	0.40	0.04	0.22	1.00
W48P00	0.48	0.22	0.14	0.39	0.04	0.21	1.00
W48P10	0.48	0.25	0.14	0.37	0.04	0.21	1.00
W48P20	0.48	0.19	0.15	0.35	0.09	0.22	1.00
W48P30	0.48	0.22	0.14	0.34	0.09	0.21	1.00
W57P00	0.57	0.25	0.14	0.33	0.08	0.21	1.00
W57P10	0.57	0.19	0.15	0.31	0.13	0.22	1.00
W57P20	0.57	0.22	0.14	0.30	0.13	0.21	1.00
W57P30	0.57	0.25	0.14	0.29	0.12	0.21	1.00

3.4 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 smooth surfaced 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.

Figure 3.4 Slump test

3.5 Casting and Curing

4” x 8” cylinder mould are used for casting fresh concrete. First all moulds are cleaned and oiled properly and grease is applied in the inner portion of the moulds. Care is taken that there is no gaps in the mould so no possibility of leakage of slurry. The cement, water, coarse aggregate and fine aggregate are weighted first according to mix design. The concrete mixture are prepared by automatic mixture machine. Then the moulds are filled up with concrete in two layers. In each layer 25 blows are given with the tampering rod. Then the moulds are placed for 24 hours for compaction. After 24 hours the cylinder are taken out from the moulds by loosening the screws of the steel 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 designated by marker at the top of the cylinder and 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.

Figure 3.5 Casting and opening of concrete cylinder

Figure 3.6 Curing of concrete cylinder

3.6 Density measurement

The density of concrete are measured from 4” x 8” concrete cylinder. The cylinder are taken from curing pond and outside water is cleaned by a piece of towel. The weights are taken afterwards. Then the weight are divided by the total volume of the cylinder to get the density of concrete.

Figure 3.7 Density measurement

3.7 Compressive strength test

After 28 days of curing compressive strength test is done. The cylinder are taken to the lab after finishing the curing and density measurement. The samples are entered into the Universal Testing Machine (UTM) to determine compressive strength after measuring its diameter to determine its contact surface area. In this project, for capping of concrete we use rubber capping. Its thickness is 2.5 in with a larger diameter of concrete cylinder and it is placed between the top lever and top surface of cylinder. Both the levers of UTM machine are kept in touch with the two surface of cylinder. After placing the samples in the machine, the loads are applied unless the cylinder reaches its ultimate limit of taking the compression loads. When ultimate load is obtained, there is a drop of load value in graph in the computer screen and ultimate load is obtained in KN unit. Which is then divided by the contact surface area to measure compressive strength. For each designation or mixing properties, average of three cylinder's compressive strengths are taken.

Figure 3.8 Compressive strength test by Universal Testing Machine

3.8 Split tensile strength test

The tensile strength of the resultant mix is judged in terms of split tensile strength. For this, concrete cylinder size are 4” diameter x 8” height. The test are conducted after 28 days of curing. For tensile strength test no capping is necessary. The samples are lay down in the UTM (Universal Testing Machine) machine in such a way that between the two levers, curve surface of concrete is placed. Then the loads are applied until the concrete cylinder fails. From the machine ultimate load value is obtained in KN (Kilo Newton) unit. By the measurement value of cylinder diameter and height in meter unit, from the equation tensile strength value is determined. Three cylinders tensile strength value are taken for each mixing properties or designation.

Tensile strength (KN/m2) = $=2P/(\pi Ld)$

Where, P = Maximum load

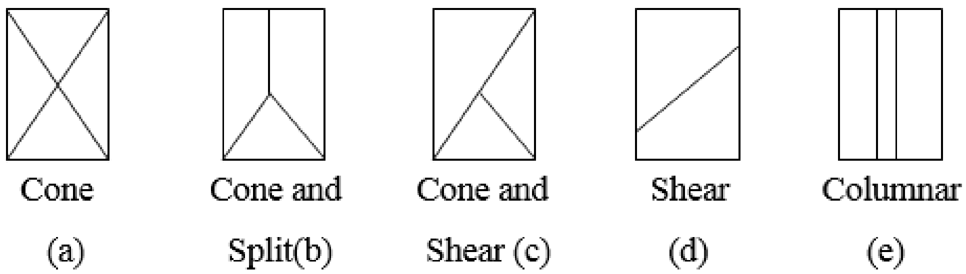
L = Height of concrete cylinder

d = Diameter of concrete cylinder

Figure 3.9 Split tensile strength test by Universal Testing Machine

3.9 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:



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 (a). The cone and split is the combination of cone and splitting of the concrete specimen (b). The cone and shear results according to the combination of both cone and shear failure of a concrete specimen (c). The shear failure occurs in the concrete specimen and failure occurs in the weak shearing zone (d). The columnar failure occurs vertical to the length of the specimens (e).

3.10 Conclusions

In this chapter the physical properties of the materials including specific gravity and water absorption are determined, formulated and described elaborately. Also the properties of the concrete and the samples including slump value, compressive strength, tensile strength, density, mix design, possible failure pattern are discussed simultaneously.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 General

Based on the objective of this study materials are collected and tested. The selected materials and their physical properties, are obtained through experiments according to ASTM standards, described in Chapter 2. Polyethylene Terephthalate (PET) is used as an alternative lightweight coarse aggregate in load bearing structures. From the findings of the experiments, comparisons are made about concrete with various combinations. The Table 4.1 contains summary of the various tests performed, such as density, workability, compressive strength and tensile strength.

Table 4.1 Summary of the test results for regular and PET concrete

% of PCA	W/C ratio	Density (kg/m^3)	Slump (cm)	compressive strength (MPa)	Tensile strength (MPa)
0	0.42	2146.5	0.635	23.72	2.78
	0.48	2120.5	5.715	15.81	2.69
	0.57	2110.1	6.35	12.09	2.94
10	0.42	2118.9	1.49	19.87	2.90
	0.48	2071.7	7.62	11.2	2.36
	0.57	2028.0	16.34	9.36	2.65
20	0.42	2018.2	2.14	10.88	2.17
	0.48	2003.5	7.89	11.54	1.94
	0.57	1992.6	17.78	10.34	1.94
30	0.42	1986.3	6.16	10.63	2.02
	0.48	1967.9	15.24	8.19	1.91
	0.57	1963.9	20.32	10.52	1.85

4.2 Workability

Workability is one of the physical parameters of concrete which affects the strength and durability as well as the cost of labor and appearance of the finished product. Concrete is said to be workable when it is easily placed and compacted homogeneously i.e. without bleeding or segregation. Unworkable concrete needs more work or effort to be compacted in place. Workability is the property of fresh concrete which is indicated by the amount of useful internal work required to fully compact the concrete without bleeding or segregation in the finished product. An onsite simple test for determining workability is the slump test.

Table 4.2 Slump value for regular and PET concrete

Coarse PET (%)	Water-cement ratio	Slump value (cm)
0	0.42	0.635
	0.48	5.715
	0.57	6.35
10	0.42	1.49
	0.48	7.62
	0.57	16.34
20	0.42	2.14
	0.48	7.89
	0.57	17.78
30	0.42	6.16
	0.48	15.24
	0.57	20.32

The relation between workability with water-cement ratio and % of PET are tabulated in Table 4.2. The changes of slump value with water-cement ratio, for different percentage of PET are also shown in Figure 4.1. The slum value increases with the increase of water-cement ratio and PET replacement ratio. Workability increases for concrete with PET coarse aggregate because of its shape and smooth surface.

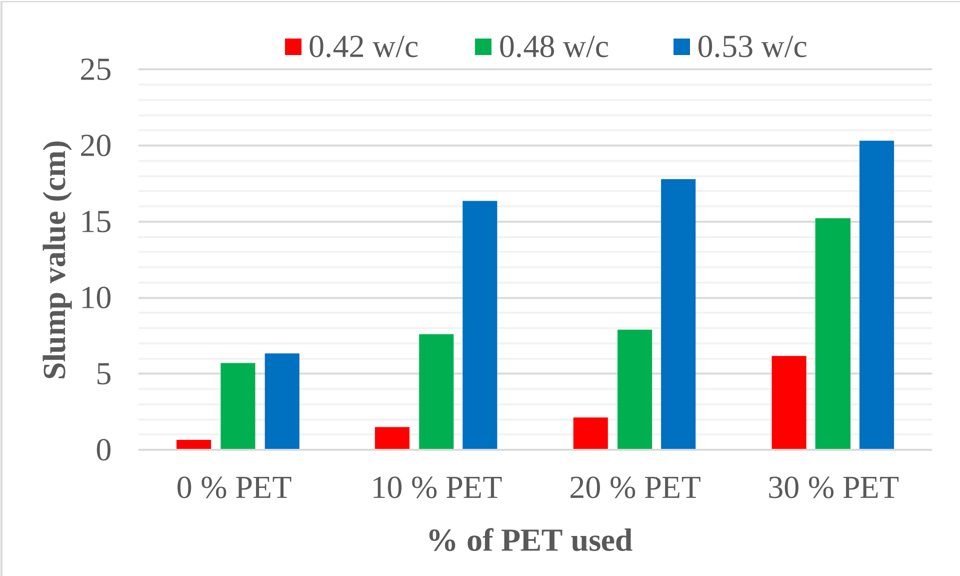


Figure 4.1 Slump value vs. percentage of PET used for different w/c ratio

The increase in slump value from w/c ratio of 0.42 to 0.48 is much higher (411% for 10% PET) than w/c ratio 0.48 to 0.57 (114% for 10% PET). For change of w/c ratio from 0.42 to 0.48, the increase of slump value is much higher for normal concrete (800%) than plastic aggregate concrete (147% for 30% PET). The increase of slump value, for 10% to 20% replacement of coarse aggregate, is much lesser (44% for w/c ratio 0.42) than 10% replacement (135% for w/c ratio 0.42) and 20% to 30 % replacement (188% for w/c ratio 0.42). For wet concrete optimum value of slump test is varied from 15 cm to 17 cm. So for 30% replacement of coarse aggregate with 0.48 w/c ratio and for 20% replacement with 0.57 w/c ratio can be used to get desired results.

4.3 Density

The density of concrete is a measure of its unit weight. Concrete is a mixture of cement, fine and coarse aggregates, water and various admixtures. The unit weight of concrete (density) varies mostly depending on the amount and density of the aggregate, the amount of entrained air (and entrapped air), and the water and cement content. The density of the samples was measured at dry condition at 28 days just before the compressive strength test. Density values of all the cylinders for various conditions are given in Table 4.1. The changes of density with different percentage of PET with water-cement ratio are shown in Figure 4.2. With increasing percentage of

PET in concrete the density is gradually decreasing which is mostly due to the low unit weight of PET. The maximum reduction was observed for the replacement of coarse aggregate with 30% of PET and the reduction of density was about 7.5%. For 10% of replacement of coarse aggregate the density reduction is very less (2.3% for water-cement ratio 0.48). Density reduction is almost 6% for any 20% replacement (0% to 20% or 10% to 30% PET used).

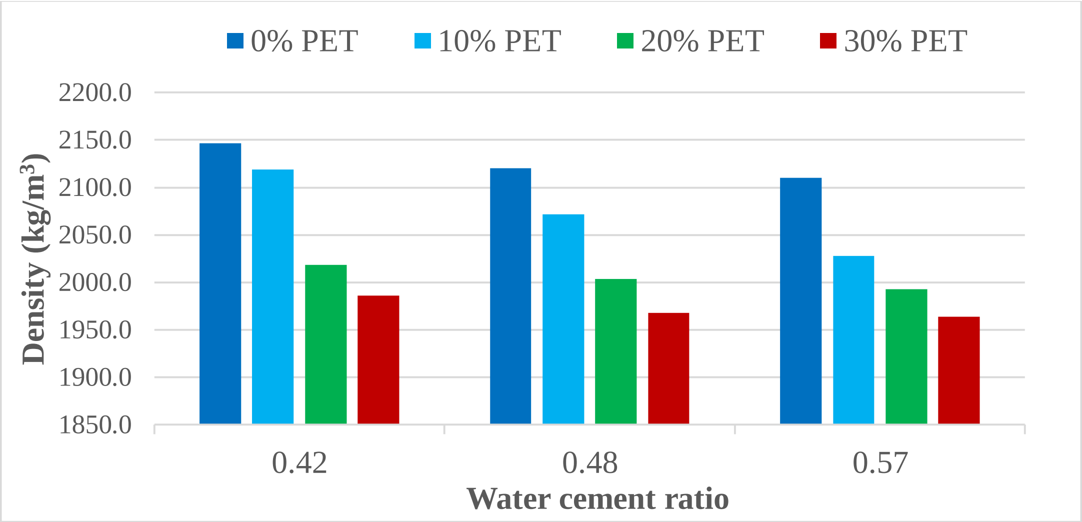


Figure 4.2 Density vs. w/c ratio for Regular and PET replaced concrete

The change of density with water-cement ratio are given in Figure 4.3. From the graph, the density is reduced with the increase in water cement ratio. The maximum reduction for water-cement ratio is occurred for concrete with 10% PET. Density is reduced 2.23% for changing w/c ratio from 0.42 to 0.48 and 4.3% for changing w/c ratio from 0.42 to 0.57. However, reduction of density for water-cement ratio is insignificant comparing to percentage of different PET used. Lowest density as well as unit weight can be gained by using 30% of PET and 0.57 w/c ratio.

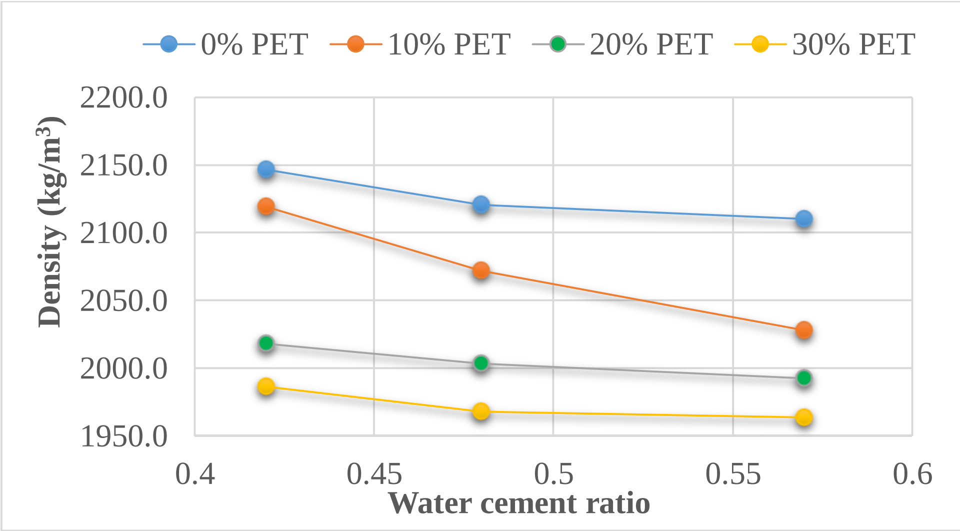


Figure 4.3 Density with respect to w/c ratio

4.4 Compressive strength

Strength of hardened concrete measured by the compression test. The compressive strength is measured by crushing cylindrical concrete specimens in compression testing machine (ASTM Standard). The compressive strength of concrete is calculated by the failure load divided with the cross sectional area resisting the load; and are reported in Table 4.1 in pounds per square inch in US customary units and mega Pascal's (MPa) in SI units.

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. 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.

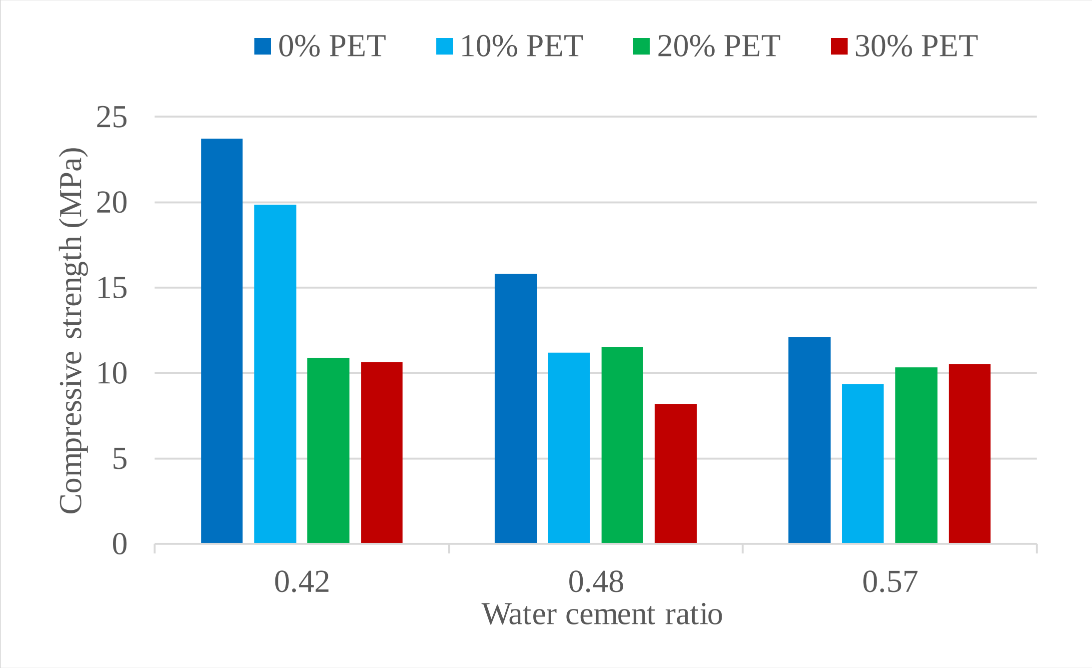


Figure 4.4 Compressive strength vs. w/c ratio for Regular and PET concrete

The decreasing strengths with different percentage of PET used for different water cement ratio are shown in Figure 4.4. For 20% and 30% PET compressive strength remains almost same. However, about 55% reduction of strength is observed for 30% PET replaced concrete for water-cement ratio of 0.42. The percentage of reduction of strengths for various PET replaced concrete with regular concrete are shown in Table 4.3. For changing PET 10% to 20% strength reduction is much more (10.5% reduction for w/c ratio 0.57) than 20% to 30% PET (1.7% reduction for 0.57 w/c ratio).

Table 4.3 Percentage reduction of compressive strength

Water cement ratio	Compressive strength of regular concrete (MPa)	Compressive strength of 30% coarse PET (MPa)	Percentage reduction in compressive strength (%)
0.42	23.72	10.63	55.2
0.48	15.81	8.19	48.2
0.57	12.09	10.52	13.0

The compressive strength is also reduced for increasing water-cement ratio which is shown in Figure 4.5. The reduction is much more for changing w/c ratio 0.42 to 0.48 than 0.48 to 0.57 w/c ratio. For regular concrete 33% strength reduction for 0.42 to 0.48 w/c ratio and 23.5% reduction for 0.48 to 0.57 w/c ratio. Compressive strength reduction is 23% and 28.4% respectively for concrete of 30% PET used. For 20% and 30% PET concrete compressive strength change is very little.

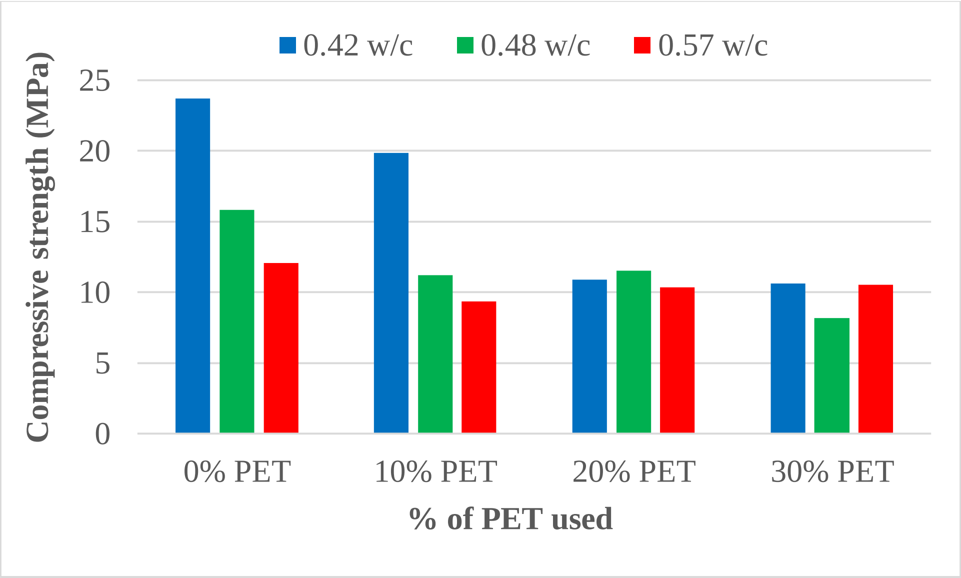


Figure 4.5 Compressive strength vs. percentage of PET used for different w/c ratio

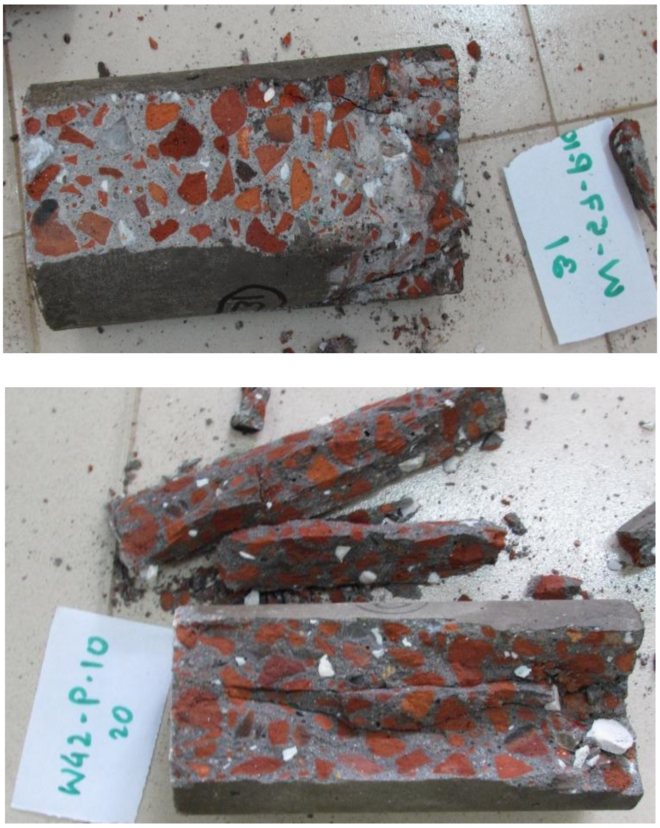


Figure 4.6 Failure by compressive strength

4.5 Tensile strength

Tensile strength of a material is the tension stress at which a material breaks or permanently deforms (changes shape). Tensile strength is an important property of concrete because concrete structures are highly vulnerable to tensile cracking due to various kinds of effects and applied loading itself. However, tensile strength of concrete is very low in compared to its compressive strength. Due to difficulty in applying uniaxial tension to a concrete specimen, the tensile strength of concrete is determined by indirect test methods: 1) Split Cylinder Test and 2) Flexure Test. Split tensile test is used in our project.

The value of tensile strength is give in Table 4.1 in MPa and the value change with respect to percentage of PET value used is shown in Figure 4.7. Tensile strength is reduced with the increase of % of PET used. Though due to some error, tensile strength is increase a very little for 10% PET used in 0.42 water-cement ratio, but in all other cases tensile strength reduced due to increase of PET. For 20% and 30% PET concrete the tensile strength is almost same. The percentage of reduction in tensile strength is shown in Table 4.4. Tensile strength is reduced 37% for 30% replacement of coarse aggregate with PET for 0.57 w/c ratio.

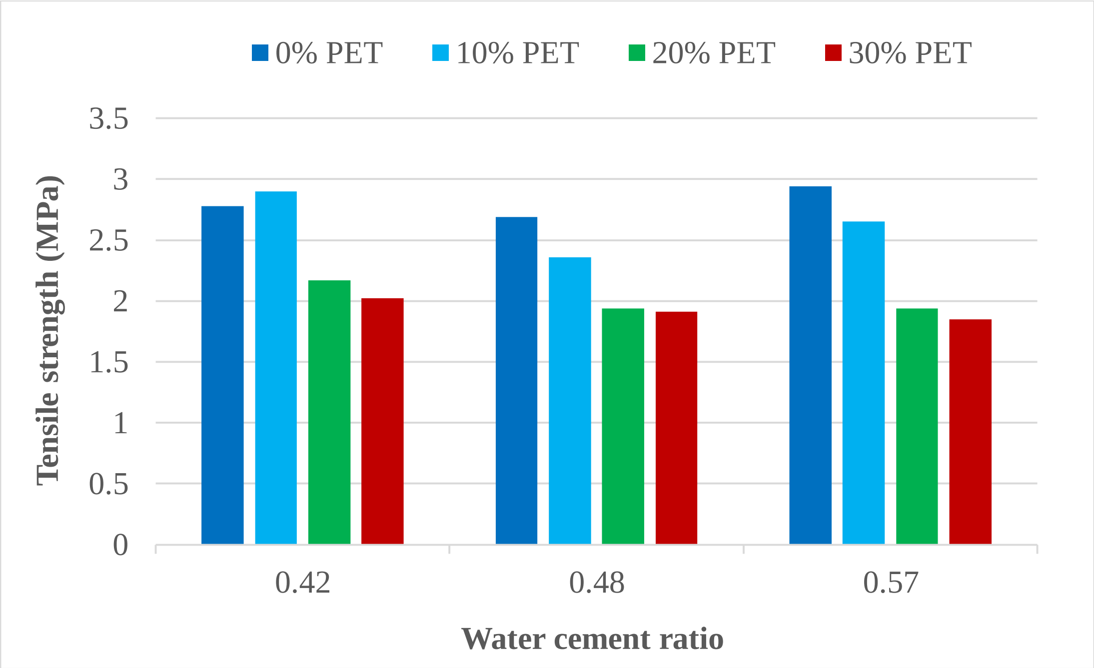


Figure 4.7 Tensile strength vs. w/c ratio for Regular and PET replaced concrete

Table 4.4 Percentage reduction of tensile strength

Water cement ratio	Tensile strength of regular concrete (MPa)	Tensile strength of 30% coarse PET (MPa)	Percentage reduction in tensile strength (%)
0.42	2.78	2.02	27.3
0.48	2.69	1.91	29
0.57	2.94	1.84	37.1

The reduction of tensile strength due to the change of water-cement ratio is shown in Figure 4.8, where, the change is very less than the change for percentage of PET used. The tensile strength is almost same for different w/c ratio (0.42, 0.48, and 0.57) for 0%, 20% and 30% PET used. The change is much more for 10% PET concrete.

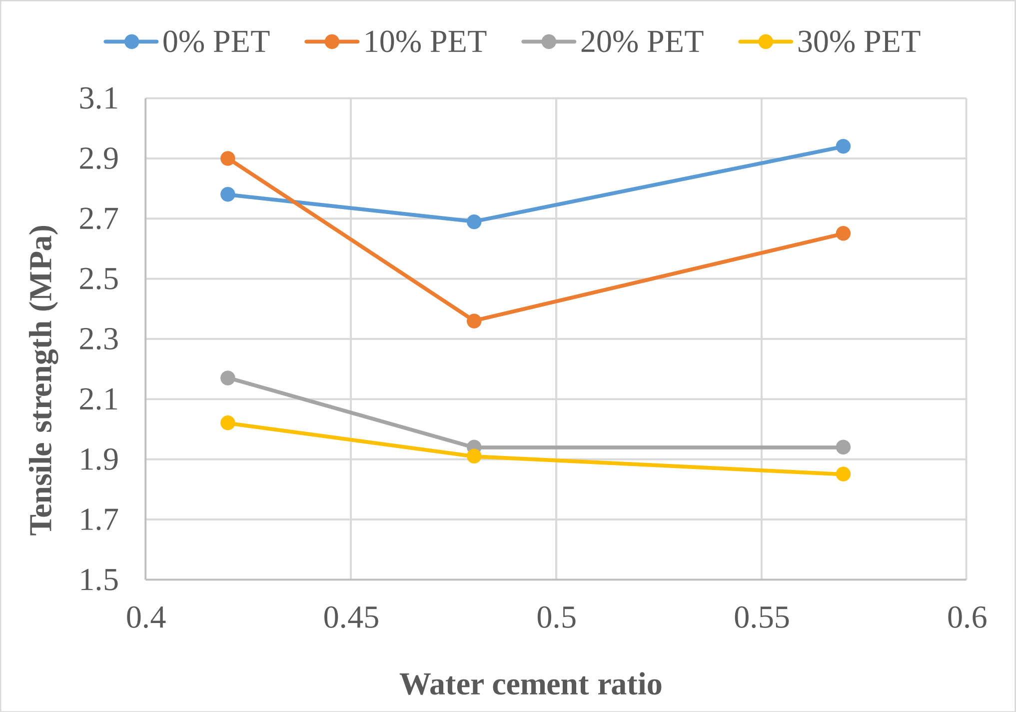


Figure 4.8 Tensile strength vs. w/c ratio

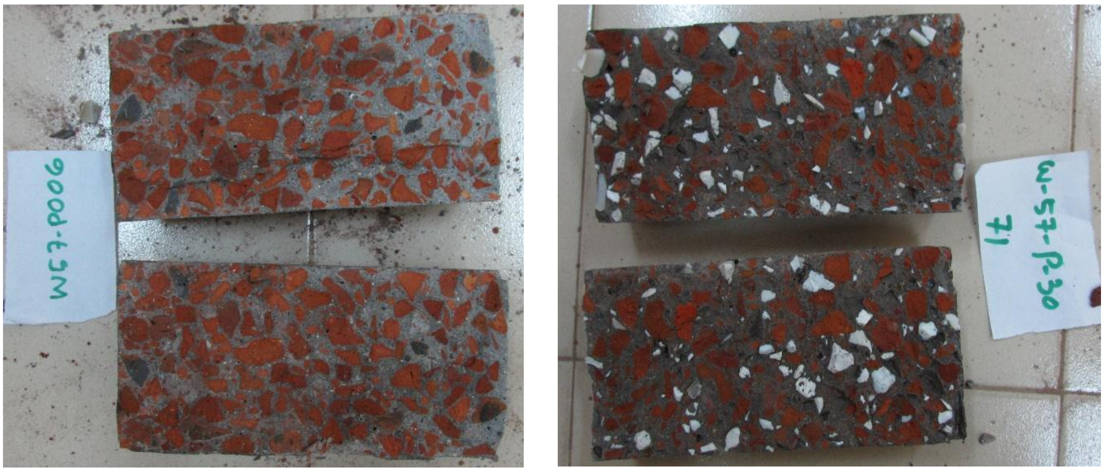


Figure 4.9 Concrete failure by tensile strength

4.6 Conclusion

From the above result it is seen that coarse aggregate can be partially replaced by plastic coarse aggregate (PET). The density is reduced by it but the compressive and tensile strength is also reduced by using plastic coarse aggregate. The strength is also less for higher water-cement ratio. However, high workability is achievable with lower water-cement ratio. Therefore, the plastic coarse aggregate can be used as an aggregate for light weight concrete but not suitable for high load structural building.

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 General

Conventional coarse aggregate is partially replaced by plastic coarse aggregate (PET) in this study. Three different percentage of plastic coarse aggregate (PET) is used in order to find an optimum replacement solution. Three water-cement ratios (0.42, 0.48 and 0.57) are adopted for comparing the results with respect to the change of water-cement ratio. From the various experimental results and their interpretation conclusions are drawn and recommendations are made.

5.2 Summary and Conclusion

The conclusions that can be made from this experiment are given below:

1. Polyethylene Terephthalate (PET) as a plastic coarse aggregate (PCA) can be used to partially replace conventional coarse aggregate in concrete.

2. Because of its lower specific gravity, PCA has helped reducing the unit weight of concrete which can be advantageous for creating light weight concrete structures.

3. Due to the use of PCA in the concrete mixture the density, compressive strength and tensile strength are reduced with change in water-cement ratio.

4. The reduction of compressive and tensile strength for increasing water-cement ratio is less than for increasing percentage of PCA. The main reason of decreasing strength is the lowest bonding capacity of PCA.

5. The workability of concrete is improved by increasing percentage of PET used because of the shape and surface condition of Polyethylene Terephthalate (PET). Therefore, a reduced water cement ratio could be used in the mix design of concrete while using PET as coarse aggregate and achieve higher strength and workability.

5.3 Recommendations

The plastic coarse aggregate can be used to get light weight concrete. For a certain density for lightweight concrete for a given water-cement ratio, the amount of percentage of plastic coarse aggregate can be achieved. For a desired strength and workability water-cement ratio can be modified. The strength reduction problem can be overcome or reduced by chemical treatment of Polyethylene Terephthalate (PET). Therefore, for further research can be done to increase strength of lightweight concrete by chemical or mechanical treatment of Polyethylene Terephthalate (PET).

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