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Study of Concrete Properties Using Polyethylene Terephthalate as Coarse Aggregate

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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, 24 cylinders are prepared by replacing 10%, 20% and 30% by volume of the coarse aggregates. Standard Water-cement ratios (i.e. 0.45) are taken under consideration for achieving optimum workability in using PET as coarse 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 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 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.

Keywords*- Lightweight Concrete, Polyethylene Terephthalate, PET, Conpressive Strength, Density*

I. INTRODUCTION

The consumption of plastic has grown substantially all over the world in recent years and this has created huge quantities of plastic-based waste. These wastes are almost non-degradable in the natural environment even after a long period of exposure. It is not feasible to use waste polymers for land filling, which require huge land space area and hence the land loses its fertility. It also causes serious problems such as clogging in drainage system, wastage of resources and environmental pollution. In this consequence, greater attention is being focused worldwide on the environment and safeguarding the natural resources through recycling of waste plastic materials in the recent years. A lot of researches concerning use of several kinds of plastic wastes in building materials have been published in last few years. Thus, utilization of waste plastic materials in concrete as aggregates is considered as the most feasible utilization to overcome the problems regarding safe disposal of increasingly huge amount of waste plastic materials.

According to the report on composition of plastic waste and market assessment of the plastic recycling sector in Dhaka city, about 6493 tons/day of solid waste had been generated during 1991, 13330 tons/day during 2005 and 27,000 tons/day during 2014 in Bangladesh. In the Dhaka city corporation area, about 33,156 Tons/day of solid waste had been generated, of which 4.15% was composed of plastic materials during 2005 and 5.46% during 2014. The report indicates that plastic waste generation increases at the rate of 10.43% per year. The annual plastic consumption in the United States is more than 11 million tons and 80% of the post-consumer plastics are sent to landfills, 8 % is incinerated and only 7% is recycled while, in UK the amount of plastic waste generated was about 3 million tons in 2001 of which only 7 % was recycled. The addition of polymer aggregate increase impermeability, impact resistance and workability of concrete and can used in a variety of recast applications such as utility components e.g., drains for acid wastes, underground vaults and junction boxes, sewer pipes, and power line transmission poles (R. Siddique et al. 2008). Polymer aggregate is significantly lighter than natural aggregate and therefore its incorporation lowers the densities of the resulting concrete. This property can be used to develop lightweight concrete (Rai et al. 2012). The use of shredded waste polymer aggregate in concrete can reduce the dead weight of concrete, thus lowering the earthquake risk of a building.

II. DETERMINATION OF CONCRETE INGREDIENTS PROPERTIES

A. Cement

Cement is a fine, grey powder. It is mixed with water and materials such as sand, gravel and crushed stone to make concrete. The cement and water form a paste that binds the other materials together as the concrete hardens. The specific gravity of Portland cements ranges from 3.12 to 3.16. Its measured fineness by particles size ranges from 10 micron to 50 microns. The Portland Composite cement namely HOLCIM CEMENT, type CEM II/B-M (S-V-L), strength class 42.5 N, manufactured by Lafarge Holcim Ltd was used in this study. The different properties of cement are presented in Table I.

TABLE I. PROPERTIES OF CEMENT

Physical Properties	Test Results
Standard Consistency	27.5%
Specific Gravity	2.60
Initial Setting Time	105 min
Final Setting Time	10hrs
Compressive Strength	
after 7 days of curing	41.75 KN
after 14 days of curing	54.173 KN

B. Fine Aggregate

Fine aggregate is the aggregate most of which passes through a 4.75mm IS sieve 15 and contain only that much coarser material as is permitted by the specifications. It should be clean, free from organic substances and alkalinity. The grain size should be uniformly distributed. In this study, Sylhet sand was used as fine aggregate. The following tests were employed to determine the properties of fine aggregate and coarse aggregate:

1) Sieve analysis of fine aggregate:

500g sample of fine aggregate was taken for sieve analysis. The sieves that were used for the determination of fineness modulus are No. 100, No. 50, No. 30, No. 16. Aggregate with at least 85% passing No. 4 sieve and more than 5 % retained on a No. 8 sieve. The value of Fineness Modulus was 2.6.

2) Specific gravity test & water absorption capacity test:

With this specific gravity of each constituent known, its weight can be converted into solid volume and this is also required in calculating the compacting factor in connection with the workability measurements. This test conforms to the ASTM standard requirements of specification C128. Bulk specific gravity is defined as the ratio of the weight of the aggregate (SSD or Oven dry) to the weight of water occupying a volume equal to that of the solid excluding the impermeable pores. Apparent specific gravity is the ratio of the weight of the aggregate dried in an oven at 100 to 110^{0}C for 24 hours to the weight of water occupied a volume equal to that of the solid including the impermeable pores. Total internal moisture content of an aggregate in the saturated surface dry condition may be termed as absorption capacity, although it is sometimes referred to simply absorption. Absorption values are used to calculate the change in the weight of an aggregate due to water absorbed in the pore spaces within the constituent particles, compared to the dry condition.

TABLE II. PROPERTIES OF FINE AGGREGATE

Properties	Test Results
Specific Gravity	
Oven Dry Basis	2.35
Saturated Surface Dry Basis	2.45
Water Absorption Capacity (%)	4.06%

C. Coarse Aggregate

The aggregate most of which are retained on the 4.75 mm IS sieve is termed as coarse aggregate. In this study, locally available stone aggregate and recycled plastic aggregate having the maximum size of 19 mm were used as coarse Aggregate. The aggregates were washed to remove dust as well as dirt and were dried to surface dry condition. The stone aggregates were tested according to ASTM. In this study, recycled Polyethylene Terephthalate (PET) type plastic was used to replace coarse aggregates for making concrete specimens. In this study, plastic aggregate having the maximum size of 19 mm was used.

Tests for coarse aggregate:

1) Sieve analysis of coarse aggregate:

A series of sieves were taken in order like fineness modulus test. No. 100, No. 50, No. 30, No. 16, No. 8, No. 4, 3/8 in., 3/4 in. and 1.5 in. which are the ASTM sieves. The test method conforms to the ASTM standard requirements of specification C136. 2000 g of sample was taken for sieve analysis. The observed FM value is 9.6 for coarse aggregate and 8.5 for recycled plastic aggregate.

2) Specific Gravity and Absorption Capacity of Coarse Aggregate:

The test method for specific gravity and water absorption capacity covers the determination of bulk specific gravity, apparent specific gravity and water absorption of fine aggregate. In this study, saturated surface dry aggregate had been used to determine the specific gravity of coarse aggregate. The test method for specific gravity and water absorption capacity conforms to the ASTM standard requirements of specification C127. Here are the properties of coarse aggregate on Table III.

TABLE III. PROPERTIES OF COARSE AGGREGATE

Properties	Test Results	
	Stone Aggregate	Recycled Plastic Aggregate
Bulk Specific Gravity		
Oven Dry Basis (OD)	7.85	1.8
Saturated Surface Dry Basis (S.S.D.)	8.22	1.8
Water Absorption Capacity (%)	0.56%	0.7%

3) *Bulk Density of Coarse Aggregate:*

Bulk density is the traditional terminology used to describe the property of concrete which is weight per unit volume. The test method for bulk density conforms to the ASTM standard requirements of specification C29. The density of stone aggregate is 8.922 and plastic aggregate is 6.722.

D. Water

Water is essential in the production of concrete in order to precipitate chemical with the cement, to wet the aggregate and to lubricate the mixture for easy workability. Since the quality of water affect the strength, it is necessary to work with pure water. In this study drinking water had been used in mixing of concrete.

E. Recycling of Waste Plastic

There are various methods of recycling. In this study, mechanical recycling was applied to prepare recycled plastic aggregate. The post-consumer waste plastic materials such as broken plastic bottle, bucket, basket and thin container made by Polyethylene Terephthalate (PET) had been collected, shredded and washed. Secondly, dried shredded materials were melted. Then these molten plastics were again shredded into small pieces within the size-range of 4-19 mm.

III. CONCRETE MIXING AND TESTING

Most of the available mix design methods are based on empirical relationships, charts and graphs developed from extensive experimental investigations. In this study, ACI mix design method has been used. This method is based on the fact that for a given maximum size of coarse aggregate, the water content determines the workability of mix. Using the steps of ACI method of mix proportioning for M30 grade concrete and then for convenience of working the mix proportion was considered as 1:1.5:3.

A. Test Specimens Preparation

Production of quality of concrete requires meticulous care exercised at every stage of manufacture of concrete. The quality of concrete can be controlled by following casting process properly. The various stages of casting of test specimens are:

- Batching
- Mixing
- Compacting
- Curing
- Finishing

B. Tests of Concrete

1) *COMPRESSIVE STRENGTH TEST*:

The compressive strength test was determined according to ASTM C39/C39M using 100mm x 200mm cylinder specimens. The specimens were tested at the ages of 28 days of curing. A Universal Testing Machine (UTM) with a load capacity of 2000 kN was used in the compression test and the loading rate was 2.0kN/s. The maximum or crushing load of the specimen was obtained from the compression machine. The compressive strength fc was calculated by dividing the crushing load by the contact surface area of the test specimen, as shown in the following equation.

$$f_c' = \frac{P}{A_c}$$

Where, P = Crushing load (N), A_c = Contact area of specimen (mm^2).

2) *DRY DENSITY TEST*:

Dry density is the traditional terminology used to describe the property of concrete which is weight per unit volume. Density of the concretes modified with recycled polymer aggregate also decreases significantly with the recycled plastic aggregate content. In this study, dry density of concrete was determined for each partial replacement of stone aggregate by 0%, 10%, 20% and 30% of recycled plastic aggregate.

IV. RESULT AND ANALYSIS

Testing of hardened concrete plays an important role in controlling and confirming the quality of cement concrete work. To perform this study, total 24 standard cylinder specimens were tested. Among these, 24 cylinders were tested to determine the compressive strength. Dry density of concrete was determined by using all of the tested cylinder specimens. Curing period for the cylinder specimens were 28 days.

A. COMPRESSIVE STRENGTH

The test results of compressive strength at 28 days of curing period are presented in Table IV and variation of compressive strength of concrete with various percentages of plastic is presented graphically in Figure 01. The compressive strength of unmodified and modified concrete specimens with various contents of plastic aggregates showed that the compressive strength of concrete goes on decreasing with increase in percentage of plastic aggregate. But the rate of reducing compressive strength was low which may be due to the decrease in adhesive strength between the surface of the waste plastic aggregate and the cement paste. In addition, waste plastic is hydrophobic material which may restrict the hydration of cement. Also, the compressive strength of stone aggregate is very nearly to the compressive strength of plastic aggregate.

TABLE IV. COMPRESSIVE STRENGTH OF CONCRETE WITH VARIOUS % OF PLASTIC

% of plastic	Compressive Strength			
	28 days (1:1.5:3)		28 days (1:2:4)	
	(MPa)	(Psi)	(MPa)	(Psi)
0	21.17	3070.94	20.14	2921.87
10	19.36	2808.57	18.70	2713.16
20	17.47	2534.27	15.54	2254.01
30	16.98	2462.72	13.773	1997.60

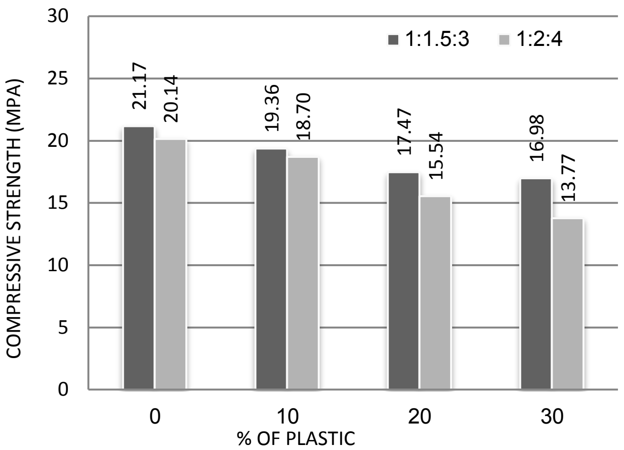

Figure 1. Compressive Strength of Concrete with Varying Percentage of Plastic Content

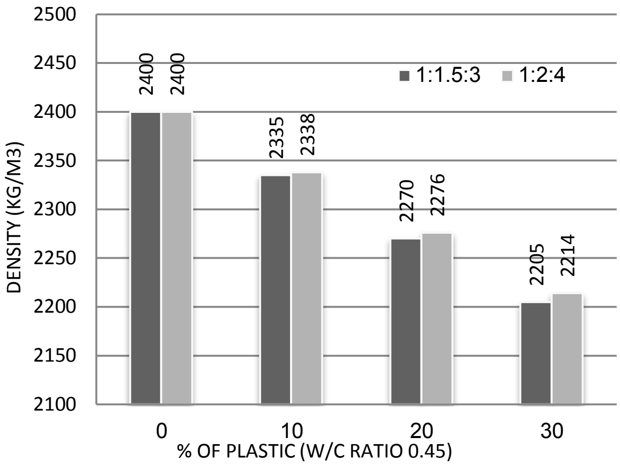

Figure 2. Density Comparison for Regular Concrete and Varying PCA Concrete at Different Mix Ratio

B. *Density*

The density of the samples was measured at dry condition at 28 days just before the compressive strength test and also the volumetric method. The values obtained are shown in Table V and Table VI. The obtained values indicate 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 was the highest for 30% replacement of 0.45 water cement ratio. It is possible because the PCA has a low unit weight compared to regular CA.

TABLE V. DENSITY OF REGULAR CONCRETE AND VARYING PCA CONCRETE (1:1.5:3)

For 1 cubic meter of concrete (1:1.5:3)							
%	*Volume (cft)*			*Weight (kg)*			
Plastic	Cement	F. A.	C. A.	Stone	Plastic	Sand+ Cement	Total
0	9.62	14.44	28.87	1290	-	1110	2400
10	9.62	14.44	28.87	1161	64.10	1110	2335
20	9.62	14.44	28.87	1032	128.19	1110	2270
30	9.62	14.44	28.87	903	192.29	1110	2205

TABLE VI. DENSITY OF REGULAR CONCRETE AND VARYING PCA CONCRETE (1:2:4))

For 1 cubic meter of concrete (1:2:4)							
%	*Volume (cft)*			*Weight (kg)*			
Plastic	Cement	F. A.	C. A.	Stone	Plastic	Sand+ Cement	Total
0	7.56	15.12	30.25	1290	-	1110	2400
10	7.56	15.12	30.25	1161	67.15	1110	2338
20	7.56	15.12	30.25	1032	134.29	1110	2276
30	7.56	15.12	30.25	903	201.44	1110	2214

The density of PCA concrete has a lower density than the regular concrete as illustrated in Figure 02. However, it had a higher density compared to the same amount of PCA concrete. Also, with the increase of water cement ratio, the density of PCA concrete decreases but the density remained almost similar for regular concrete.

V. CONCLUSIONS

From the test results and analysis, the following conclusion has been drawn for recycled plastic aggregate concrete:

- Compressive strengths were decreased with the increase in recycled plastic content. These amounts of decreasing were between 8.54% to 19.80% for concrete containing 10% to 30% recycled plastic. The minimum value of compressive strength after 28 days curing was 13.773 MPa (1997.60 psi) for 30% replacement of stone aggregate which was less than the minimum value of 17.0 MPa (2500 psi) for structural application. But compressive strength value of 17.47MPa (2534.27 psi) for 20% replacement of aggregate was higher than this recommended value. So, up to 15% replacement of stone aggregate by recycled plastic is applicable for structural application.
- The dry density of concrete made with 10%, 20%, and 30% replacement of stone aggregate by recycled plastic aggregate were about 2.7%, 5.4%, and 8.11% lower than that of normal concrete respectively. The lowest density was found as 2.05kN/m^3 for 30% replacement of stone, which was 8.11% lower than that of normal concrete. These results indicate that incorporation of recycled plastic significantly reduce the weight of concrete.
- Finally, recycled plastic aggregate may be used up to 10% replacement of stone aggregate in concrete.

VI. Recommendations

Further testing and studies on the recycled plastic aggregate concrete is highly recommended to indicate the strength characteristics of recycled plastic aggregates for application in high strength concrete. There are some recommendations given below for further studies:

a. Since, the water/cement ratio has a great effect on the strength of concrete, hence different water/cement ratio can be used to investigate the properties of concrete.

b. Admixtures can be used to improve bonding between plastic aggregate and other materials.

c. More investigations and laboratory tests such as modulus of elasticity, water absorption capacity, creep of concrete etc. are also recommended to know the characteristics of recycled aggregate.

d. More trials with different particle sizes and percentages of recycled aggregate are recommended to get different outcomes.

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