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A STUDY ON GREEN CONCRETE USING RECYCLED POLY-ETHYLENE TEREPHTHALATE (PET) AS PARTIAL REPLACEMENT OF COARSE AGGREGATE

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Abstract: The enormous number of plastic bottles made from Poly-Ethylene Terephthalate (PET) deposited in domestic wastes and landfill is one of the environmental concerns in the world. It is now time for the development and implementation of sustainable recycled materials in construction to reduce the generated wastages. Furthermore, the assimilation of PET as aggregate can significantly improve certain properties of concrete, like reduced density and increased workability. PET is significantly lighter than natural aggregate (NA), and therefore, its incorporation lowers the density of the resulting concrete. The purpose of this study is to investigate the possibility of using recycled PET waste in concrete mixes as aggregate replacement to find a way to make low-cost lightweight concrete of effective compressive strength and also reduce the environmental effects of PET disposal. For this work numbers of cylinders are prepared with conventional concrete materials, and also a good number of cylinders are prepared by replacing 10%, 20% and 30%, by volume, of coarse aggregate (brick chips) with PET. Three different w/c ratios (i.e. 0.42, 0.48, and 0.57) are taken under consideration for achieving optimum workability in using PET as plastic coarse aggregate. The combination of 10% coarse aggregate replacement and 0.42 w/c showed improved result both in compressive and tensile strength test. This study also assures that reusing waste plastic as a coarse-substitution aggregate in concrete gives a good approach to produce structural concrete and solve the solid waste disposal problems posed by plastics.

1 Introduction

A sustainable industrial growth will influence the cement and concrete industry in many respects as the construction industry has an 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 worldwide infrastructure-growth without increase in CO_2 emission. Use of green concrete requires fewer brick chips, as coarse aggregate, for the construction work which reduce environment pollution. In Bangladesh, conventionally bricks are adopted as a 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 (Daraina et al. 2013). Objective of this study is to eliminate the excessive use of brick chips by replacing with a recycled lighter particle than brick which can create a healthy environment as well as light weight structure.

Lightweight aggregate (LWA) is an important material in reducing the unit weight of concrete conforming with special concrete structures of large high-rise buildings (Neville 1996). LWA has a higher seismic resistance as concrete can absorb shock better in lower density. It has a significantly low thermal conductivity and improved sound absorption capacity. Besides, it has low water absorption capacity which helps to protect the concrete from any sorts of chemical attack and reduce water consumption in curing. To make the structure light-weight, researchers try to find out any type of particle which should be lighter than conventional aggregate. In the recent years of research, waste plastic has been chosen as an option for its various positive properties with concrete mix.

Nowadays the consumption of plastic has grown substantially all over the world and this has created huge quantities of plastic-based waste. Plastic waste is now a serious environmental threat to the modern way of living. The fraction of plastic wastes in household wastes is large and increases with time. In each country, the waste composition is different, since it is affected by socioeconomic characteristics, consumption patterns and waste management programs, but generally, the level of plastics in waste composition is high. The major users of plastic are the packaging industries. The largest component of the plastic waste is polyethylene, followed by polypropylene, polyethylene terephthalate and polystyrene. In Dhaka City, solid waste typically contains 3 to 5% plastics consisting mainly poly ethylene terephthalate (PET) bottles, polyvinyl chloride (PVC), high density polyethylene (HDPE), low density polyethylene (LDPE) and polypropylene (PP). Following the great demand in recent years, a large number of industries have been set up for producing food grade PET bottles in Bangladesh (Hossain and Zakaria 2010). The production of PET bottles was introduced in the country for marketing drinking water in the early 90's. 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 a presence in the polymer market and earn a major presence in the global industry. In spite of great utility, PET bottles can create an environmental problem for their indestructible nature taking up a growing percentage of municipal solid waste streams and pose environmental challenges. Tania (2014) mentioned the huge amount of PET bottles were dumped on the roadside, bank of river and sewerage in the city, which block the flow of water in the drains and sewerage system of Dhaka city. Waste PET bottles had been reworked for drinking bottles by melting fusion, which turned out to be too costly. However, if waste PET bottles were reused as coarse aggregates for concrete, positive effects are expected on the recycling of waste resources and the protection of environmental containment.

Incorporation of plastic aggregate (PA), such as PET aggregate can significantly improve some of the properties of concrete due to its high toughness and good abrasion behavior. PET is significantly lighter than natural aggregate (NA) and therefore its inclusion lowers the densities of the resulting concrete (Saikia and de Brito 2012; Islam, Meherier, and Islam 2016). Rebeiz and Fowler (1996) found that very good flexural strength can be obtained with reinforced polymer concrete (PC) using unsaturated polyester resins based on recycled polyethylene terephthalate (PET). This property can be used to develop lightweight concrete. The use of shredded waste PET in concrete can reduce the dead weight of concrete, thus lowering the earthquake risk of a building, and it could be helpful in the design of an earthquake-resistant building (Akçaözoğlu, Atiş, and Akçaözoğlu 2010). On the other hand, the strength properties and modulus of elasticity of concrete containing various types of PA are always lower than those of the corresponding reference concrete containing NA only. The decrease in bond strength between PA and cement paste as well as the inhibition of cement hydration due to the hydrophobic nature of plastic are the reasons for the poor mechanical properties of concrete containing plastic. Treating plastic chemically and coating plastics with slag and sand powders can improve the mechanical performance of concrete by improving the interaction between cement paste and PA (Naik et al. 1996; Choi et al. 2009; Choi et al. 2005).

A few studies have been performed in the past to determine the effectiveness of using plastic as aggregate. The majority of those studies were related to reusing of crushed waste PET bottles as a partial replacement of fine aggregates in concrete. Marzouk et al. (2007) used shredded PET particles as partial sand-substitute aggregates (2% to 100% volume replacement) within cement concrete composites for building purposes. Córdoba et al. (2013), studied PET of different sizes with the replacement of 1%, 2.5% and 5% of coarse aggregate with 0.5 mm, 1.5 mm and 3 mm PET particles respectively. 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 which were subjected to three chemical treatments (water, bleach, bleach + NaOH) to improve their bonding with the cementations matrix. Choi et al. (2009; 2005) used waste PET coated with slag and sand, respectively. They replaced fine aggregates, 25%, 50% and 75% by volume, with modified PET and obtained the compressive strength of 33.8 MPa, 31.8 MPa and 24.1 MPa, respectively for 0.45 w/c ratio. They also experienced improved workability of 52%, 104% and 123% in comparison with normal concrete for w/c ratios of 0.45, 0.49 and 0.53 respectively.

Based on the former studies, PET shows it's potential to be used in concrete as a partial replacement for aggregates. Therefore, in this study both the fresh and hardened properties of concrete with melted waste PET used as coarse aggregate with different percentage of replacement as well as w/c ratio and tries to find out the applicability of waste PET bottles as aggregate in concrete with satisfactory workability and load bearing capacity.

2 Materials

2.1 Cement

As a binding material, Type I Portland cement conforming to ASTM C150 specification was used in this study. Chemical composition tests for cement were performed following ASTM C 114 and results are shown in Table 1. Physical properties were tested according to ASTM C204 for fineness, ASTM C191 for initial and final setting time, ASTM C187 for normal consistency and ASTM C109 for compressive strengths. The specific gravity was recorded as 3.15. Physical properties of the cement are presented in Table 2.

Table 1 Chemical composition of cementitious material

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

2.2 Coarse and Fine Aggregate

2.2.1 Brick Chips

Locally crushed brick aggregate (in SSD condition) were used as a coarse aggregate of which the maximum size was 19 mm whereas the minimum size was 2.36 mm. Physical properties were obtained by testing the aggregates according to ASTM standards (ASTM C127 and ASTM C136).

2.2.2 Polyethylene terephthalate (PET)

Polyethylene terephthalate (PET) was used as a part of coarse aggregate where brick chips were partially replaced by it. PET is a thermoplastic polymer and in its natural state it is a colorless, semi-crystalline resin. It consists of polymerized units of the monomer ethylene terephthalate, with repeating ($C_{10}H_8O_4$) units. Based on how it is processed, it can be semi-rigid to rigid. In the present study, PET is obtained as a byproduct in melted condition while recycling of PET bottles. The melted PET is then collected and cooled to obtain PET mold which then crushed, to use as coarse aggregate (Figure 1). According to the ASTM standards PET coarse aggregate were sieved and tested for physical properties.

Table 2 Physical properties of cement

Physical Properties	Unit	Specification	Test Results
Fineness (Specific Surface)	(m^2/Kg)	260 (min.)	365.40
Residue (By 45 Micron)	(%)		2.02
Setting Time			
Initial Setting Time	Minutes	45 minutes (min.)	182
Final Setting Time	Minutes	375 minutes (max.)	374
Normal consistency	(%)		27.28
Soundness (By Autoclave method)	(%)	Maximum 0.80	0.011
Compressive Strength			
3 days	MPa (psi)	12 (1740)	22.4 (3240)
7 days	MPa (psi)	19 (2760)	29.8 (4320)
28 days	MPa (psi)	28 (4060)	39.2 (5690)

Figure 1: Production of Polyethylene terephthalate (PET)

2.2.3 Sand

Local Sylheti sand (Red Sand) was used as fine aggregate. It's then cleaned from different debris and other organic materials. Its physical properties were determined according to ASTM standards (ASTM C128 and ASTM C136).

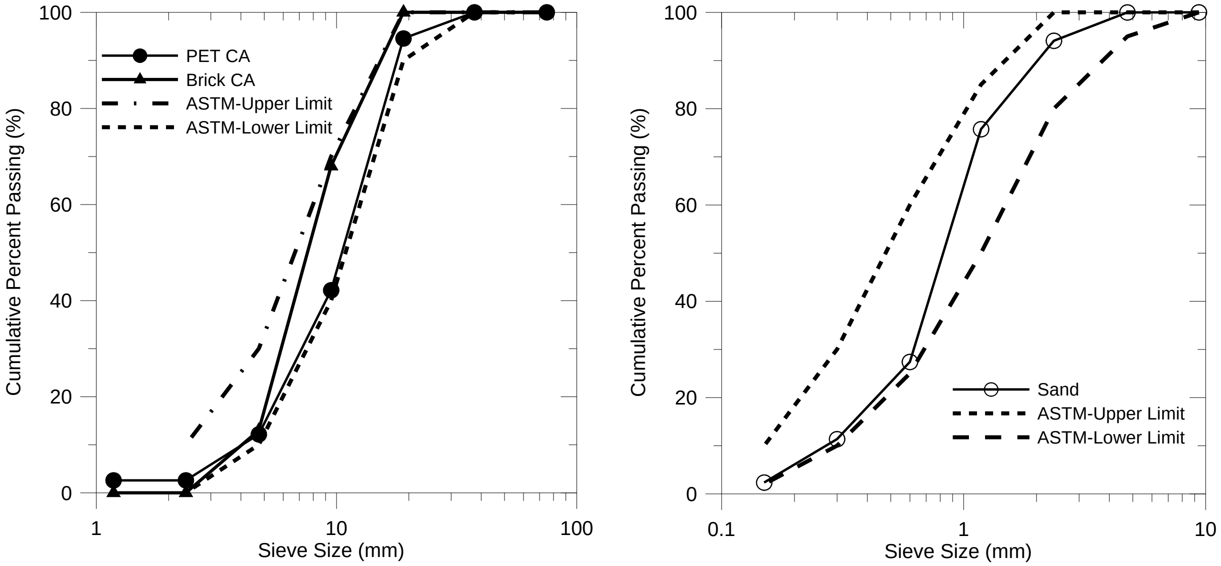
3 Experimental Procedure

3.1 Sieve Analysis of Aggregates

Particle size distributions of all the aggregates were performed according to the ASTM C136. ASTM standard sieves ranging from sieve 76.2 mm to sieve No 200 (0.075 mm) were used to obtain the grading of coarse (Brick and PET) and fine (sand). Two sieve analysis tests for each material were carried out and their average results were considered. Particle size distributions of both coarse and fine aggregates are shown in Figure 2(a) and 2(b). As observed from the figures, in both cases gradation of aggregates are within the ASTM standard limits.

3.2 Physical Properties of Aggregates

Necessary physical properties of brick chips, PET and sand are obtained by following the previously mentioned standards in materials section. It is observed that PET has low specific gravity which makes it lighter than the other aggregates. Furthermore, low water absorption capacity of PET helps to prevent any types of chemical attack from water or environment.



(a) Coarse aggregate (b) Fine aggregate

Figure 2: Particle size distribution of aggregates.

Table 3 Physical properties of aggregates

Components Name	Coarse Aggregate		Fine Aggregate
	Brick Chips	PET	Sand
Maximum size	19 mm	19 mm	4.75 mm
Minimum size	2.36 mm	2.36 mm	0.15 mm
Bulk specific gravity	1.96	1.31	2.33
Apparent specific gravity	2.29	1.32	2.62
Water absorption Capacity	14.87 %	0.35 %	8.40 %
Fineness modulus	6.38	6.19	2.89

3.3 Concrete Preparation

Twelve concrete mixes were made to investigate the engineering properties of concrete with and without containing plastic aggregates. By volume replacement of conventional coarse aggregates were 0%, 10%, 20% and 30% with PET. The concrete mixes were made with three water-to-cement ratios: 0.42, 0.48 and 0.57 with selected mix proportion of 1: 1.5: 3 (Cement: fine aggregate: coarse aggregate) by volume. Details of the mix proportioning are given below in Table 4 for weight base calculation. The combination of % of PET and w/c ratio shows 12 types of concrete mixtures. A total number of (12 x 12) 144 cylindrical (4'' x 8'') concrete specimens, twelve from each mix, were cast. The specimens were left to initial curing for 24 hours with the mold in a moist room; then demolded and kept in a constant condition under fresh water for 28 days at a controlled temperature. On the 28 th day after casting, various tests of samples were performed according to ASTM standard.

Table 4 Mix Design for 1 cum concrete (by weight)

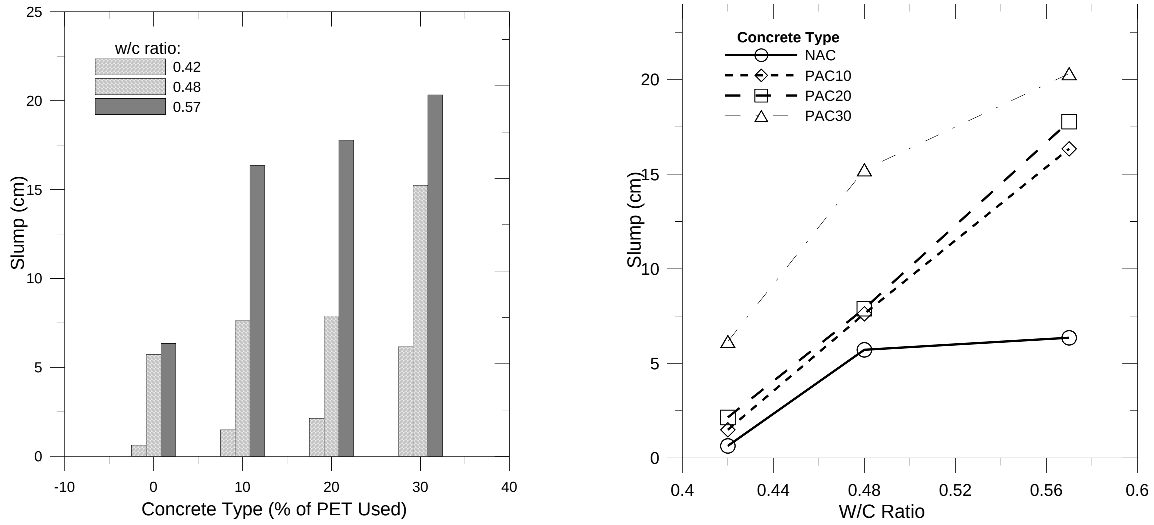
Designation	w/c ratio	Water (kg)	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Plastic coarse aggregate (kg)
NAC-W42	0.42	187	446	516	989	0
PAC10-W42					890	50
PAC20-W42					791	100
PAC30-W42					692	150
NAC-W48	0.48	187	390	451	865	0
PAC10-W48					779	44
PAC20-W48					692	88
PAC30-W48					606	131
NAC-W57	0.57	187	328	380	729	0
PAC10-W57					656	37
PAC20-W57					583	74
PAC30-W57					510	111

4 Result and Discussion

Fresh and hardened properties of concrete were obtained through a number of tests according to ASTM standards and the summary test results are given below:

4.1 Workability

Workability of concrete is measured in terms of slump value. Therefore, higher slump value indicates higher workability. For normal design, the standard value for slum test is (8 ± 2) cm. As described in Figure 3, result shows the high percentage of PET with high water cement ratio gives high slump value. Especially, for lower w/c ratio of 0.42, workability of 30% PET aggregate concrete (PAC30) has 870% increase in workability compare to normal aggregate concrete (NAC). On the other hand, increases in workability for PAC30 with w/c ratios of 0.48 and 0.57 are 167% and 220%, respectively. Moreover, increase in workability is linear with PET aggregate concrete compare to NAC.



(a) Slump value variation with percentage of PET variation for different w/c ratio

(b) Slump value for different w/c ratio

Figure 3: Slump value of concrete.

4.2 Density

The unit weight of concrete (density) varies mostly depending on the amount and density of the aggregate, the amount of entrained air, and the water and cement content. The density of the samples was measured at the saturated surface dry (SSD) condition of 28 days samples just before the compressive strength test. The density of PET containing concrete PAC gave gradual decreasing value with increasing PET content, as displayed in Figure 4, due to the low unit weight of PET. The maximum density reduction of 7.2% was observed for the PAC30 (replacement of coarse aggregate with 30% of PET). For PAC10 and PAC20 concretes the density reduction is 2.5% and 5.7%, respectively.

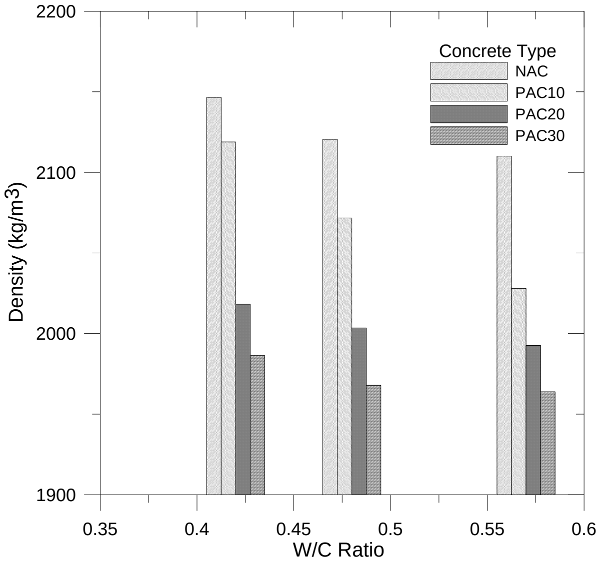
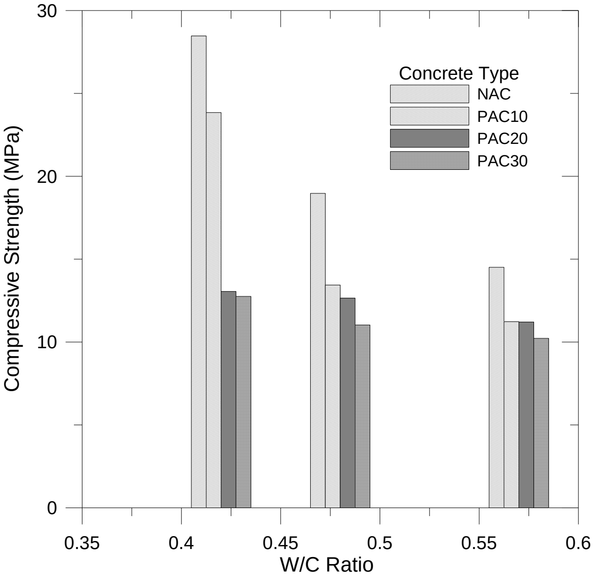


Figure 4: Density vs. w/c ratio for normal and PET aggregate replaced concrete.

4.3 Compressive Strength

The compressive strength tests are carried out after 28 days of casting. The results in Figure 5 show a trend of reduced compressive strength for PET aggregate concrete (PAC) with the increment of PET in concrete compared to the normal aggregate concrete (NAC). Moreover, the compressive strengths show a downward trend with the increase in w/c ratio for both NAC and PAC. The probable reason for decreased compressive strength with the increment of PET in concrete is the poor bondage between PET and binding material. For PAC20 and PAC30, compressive strength remains almost similar. However, about 55%, 42% and 30% reduction of strength is observed for PAC for the water-cement ratio of 0.42, 0.48 and 0.57, respectively. Similar trend is observed for PAC20. The compressive strength is also reduced for increasing water-cement ratio which is shown in Figure 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 44% and 16% respectively for w/c ratio 0.42 to 0.48 and 0.48 to 0.57 for PAC10. Figure 6 shows typical failure mode of combined aggregate-mortar; and columnar fracture type for the samples.



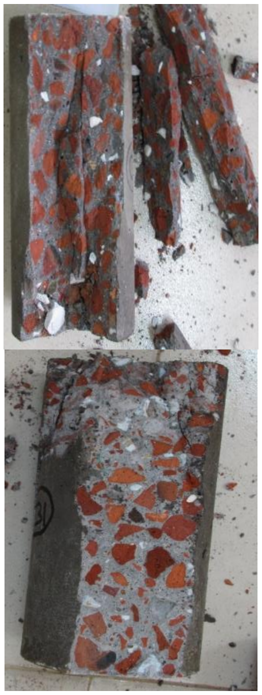
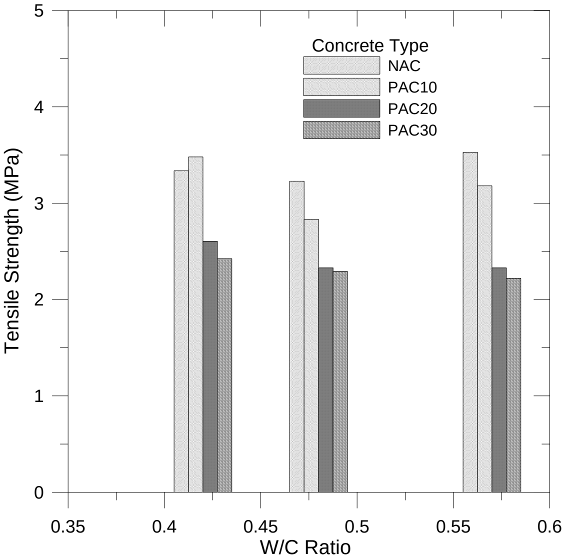


Figure 5 Variation of compressive strength with w/c ratio for different concrete type.

Figure 6 Concrete failure by compression (PAC10-W42 & PAC10-W57).

4.4 Tensile Strength

Tensile strength is reduced with the increase of % of PET used. Tensile strength increased a very little for PAC10 in 0.42 w/c ratio, but in all other cases, tensile strength reduced due to increase of PET. PAC10 with w/c ratio of 0.48 and 0.57 showed tensile strength variation in the range of 10%. However, for PAC20 and PAC30 the tensile strength is almost same. For these, tensile strength reduction is in the range of 22% to 37% for 0.57 w/c ratio.



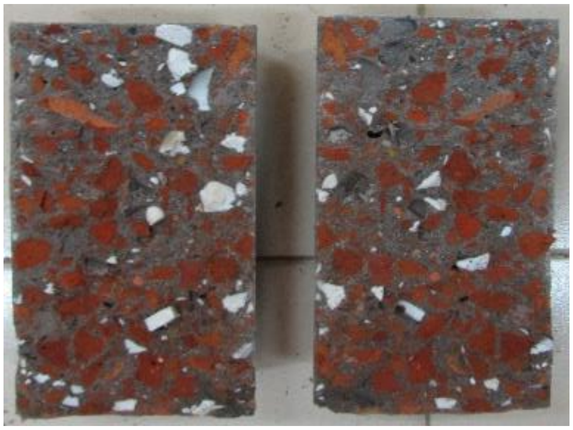


Figure 7 Variation of tensile strength with w/c ratio for different concrete type.

Figure 8 Failure by split tension test (Specimen PAC20-W42)

5 Conclusion

The results of this study have led us to the following conclusions.

- Polyethylene Terephthalate (PET) as a plastic coarse aggregate (PCA) can be used to partially replace conventional coarse aggregate in concrete. Because of its lower specific gravity, PCA has helped reducing the unit weight of concrete which can be advantageous for creating lightweight concrete structures.
- The slump values of waste plastic (PET) concrete mixtures showed a tendency to increase above the slump of the reference concrete mixture. Lowest value is observed in NAC mixture with 0.42 w/c ratio; whereas, PAC30 with 0.57 w/c ratio gives the highest value.
- The compressive strength values of all waste plastic (PET) concrete mixtures tend to decrease below the values for the reference concrete mixtures with increasing the waste plastic (PET) ratio at all curing ages. Of them, PAC10 with 0.42 w/c ratio gives a desirable strength than the other mixtures. Loss of strength may be attributed to the decrease in the adhesive strength between the surface of the waste plastic (PET) and cement paste. In addition, waste plastic (PET) is hydrophobic material which may restrict the hydration of cement. This disadvantage can be resolved by roughing up the PCA surface.
- The splitting tensile strength of concrete containing any type of PCA are proportional to its compressive strength. The tensile strength values of waste plastic (PET) concrete mixtures tend to decrease below the values for the reference concrete mixtures with increasing the waste plastic (PET) content. However, PAC10 with 0.42 w/c ratio gives the desirable strength.
- This preliminary study shows that 10% PCA replaced concrete with 0.42 w/c could be recommended for structural work for its accepted and assumed relationships between engineering properties, compressive strength and tensile strength.

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