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Research Paper

Experimental investigation on the properties of concrete containing post-consumer plastic waste as coarse aggregate replacement

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ABSTRACT

The consumption of various forms of plastic has been increased in recent days due to the boost in industrialization and other human activities. Most of the plastic wastes are abandoned and require large landfill area for storage. More importantly, the low biodegradability of plastic poses a serious threat to environment protection issue. Various methods have been followed for the disposal of plastic in an attempt to reduce the negative impact of the plastic on the environment. Recently, various types of plastic have been incorporated in concrete to minimize the exposure of plastic to the environment. The aim of this study is to investigate the properties of concrete containing polyethylene terephthalate (PET), and high density polyethylene (HDPE) plastic that were used as partial replacement of coarse aggregate (CA). In this study, four compositions of stone aggregate(S): plastic waste ratios have been used by volume basis: 100% S: 0% Plastic (control concrete), 90% S: 10% PET, 90% S: 10% HDPE, and 90% S: 5% PET+5% HDPE. The effects of waste plastic addition on the mechanical properties of concrete are presented in this paper. Test results reveal that minimum reduction in compressive strength has been found 35% in case of 10% PET plastic replaced concrete whereas splitting tensile strength for 10% PET replaced concrete has been increased by 21% while compared to control concrete. In addition, fresh unit weight of concrete containing plastic waste has been decreased by 4% in comparison to control concrete.

1 Introduction

The production and consumption of plastic are observed all over the world at the recent time. The plastic waste is a serious environmental threat. The waste generally hinders the ground water flow and also blocks the movement of roots. Plastic waste contains various toxic elements such as cadmium and lead [1]. It pollutes our natural environmental systems such as soil, and water due to its non-biodegradable property. If it is stored in the landfill or any other places, it may block the drainage system of the soil. The blocked drains can be responsible for the breeding grounds of mosquitoes and other water

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borne diseases [2]. Plastic waste reduces the percolation rate of water and also deteriorates the fertility of soil. In addition, plastic waste dumped into rivers, streams, seas and other waterbodies contaminates the water and marine life. The health of the aquatic animals consuming plastic waste can be deteriorated greatly due to its toxicity [3]. Recycling of plastic waste is a viable solution to get rid of the solid waste problems. Reusing plastic waste in the production of cement concrete may be a good solution for disposing of plastic waste due to its economic and environmental benefits [4]. However, loads of study have been done on the use of plastic waste such as polyethylene terephthalate (PET) bottle [5-7], high density polyethylene (HDPE) [8] used as aggregate in the concrete. A study demonstrated that plastic waste usage in concrete would help to resolve some of the solid waste problems created by plastic waste [9]. An experimental study reveals that PET-aggregate incorporation improves the toughness behaviour of the resulting concrete [10]. The effects of plastic waste addition on the fresh, mechanical and thermal properties of concrete have been investigated in a study [10]. A study has been performed to observe the compressive strength, unit weight and workability of PET aggregate concrete in comparison with the natural aggregate concrete [11]. A study reveals that compressive strength, tensile splitting strength, modulus of elasticity and flexural strength of concrete deteriorate due to the incorporation of PET-aggregate and the reduction of these properties increase with the addition of plastic aggregate [12]. But apparently no study has been done yet which can compare the effects of PET plastic and HDPE plastic on the mechanical properties of concrete. In this study, it has been tried to investigate the properties of concrete incorporated with PET plastic, HDPE plastic individually and also with the mixture of PET and HDPE plastic [13].

In the present study, PET and HDPE plastic were collected from the left-out water bottles and plastic containers, and then cut them down into flakes to be used as a partial replacement of coarse aggregates in the concrete mix. In this study, four compositions of stone aggregate (S): plastic waste ratios have been used by volumetric method that are 100%S: 0% Plastic (control concrete); 90% S: 10% PET plastic, 90% S: 10% HDPE plastic, and 90% S: 5% PET+5% HDPE plastic. Before making concrete, the aggregates were investigated for absorption capacity, bulk specific gravity and size determination. Cylindrical concrete specimens were prepared and tested for obtaining compressive strength and splitting tensile strength. Finally, a comparative study has been carried out between the test results of concrete containing plastic waste and control specimen.

2 Experimental Program

2.1 Materials

General purpose Portland composite cement CEM-II was used in this study. The normal consistency of the cement was measured 31.7% as per ASTM C187. The initial and final setting time was determined 178min and 300min respectively according to ASTM C191 and 28days compressive strength of cement mortar was evaluated 23.54 MPa following ASTM C109. Locally available sand, known as Sylhet sand, was used as fine aggregates and stone chips having the maximum size of 19.05 mm (0.75 inch) and minimum size of 12.7mm (0.5 inch) was used as coarse aggregates. The specific gravity and absorption capacity of both coarse and fine aggregates were determined following ASTM C128. The physical properties of the aggregates are summarized in Table 1. Gradation of fine aggregates determined through sieve analysis according to ASTM C136 is plotted in Fig. 1.

Table 1 - Physical properties of natural aggregates

Properties	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity (OD)	2.62	2.17
Bulk Specific Gravity (SSD)	2. 65	2.23
Apparent Specific Gravity	2.68	2.32
Absorption Capacity (%)	0.8	3
Fineness Modulus	--	2.98

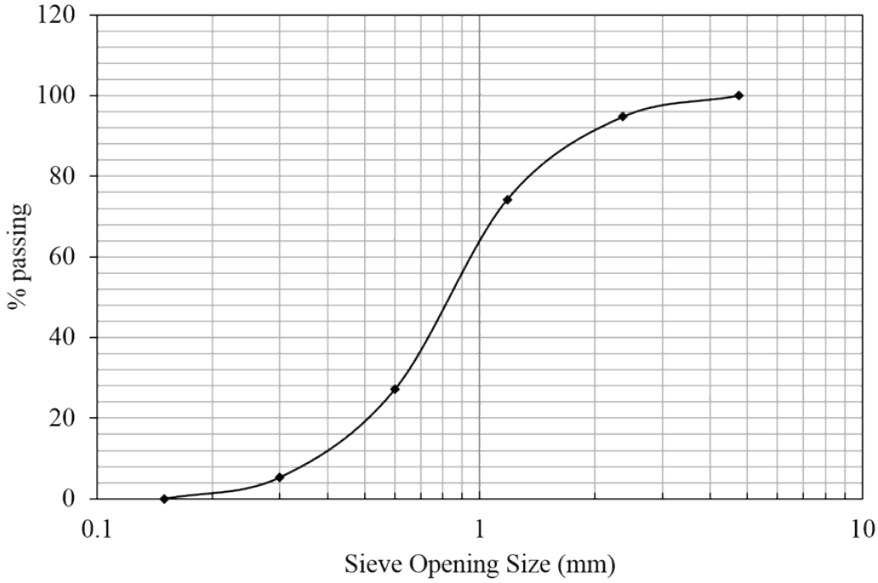


Fig. 1 – Gradation curve of fine aggregates

Left out PET water bottles and HDPE plastic containers were collected from the surroundings and then they were washed out thoroughly using tap water to remove all impurities. After a while, those things were dried out and cut into desired pieces. Some PET and HDPE plastic flakes used in this study are shown in Fig. 2. However, the surfaces of the bottles and containers were made perforated with the aid of stocky steel pin to make their surface rough. Table 2 shows different properties of PET and HDPE plastic. Digital slide calipers has been used to accurately measure the small dimensions of plastic flakes. Moreover, the size range of the plastic waste was measured using a length gauge shown in Fig. 3. Amount of plastic for different size ranges obtained from length gauge are presented in Table 3.

(a) HDPE Plastic flakes

(b) PET Plastic flakes

Fig. 2: Different types of plastic materials used in the study

Table 2- Different dimensions of plastic materials

Type of Plastic	Unit Weight (kg/m^3)	Thickness (mm)	Width (mm)	Diameter of holes (mm)	Height of Projection at holes (mm)	Spacing between holes (mm)
PET	220	0.25	10-15	2	0.6-0.85	5-8
HDPE	310	0.8	9-12	2	0.6-0.85	5-8

Fig. 3- Size measurement of HDPE and PET plastic by length gauge and scale

Table 3 - Size range of plastic materials obtained from length gauge

Range of Length (mm)	Average Size (mm)	Passing (%)	
		PET	HDPE
6.3-10	14.67	Not Passed any	Not Passed any
10-14	21.6	50%	33%
14-20	30.6	50%	67%

2.2 Test Specimens

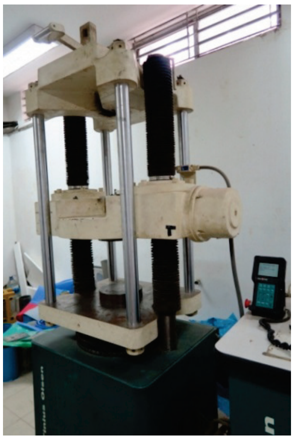
The required amount of all ingredients of concrete (cement, water, stone chips, sand, PET, HDPE plastic) were measured. The mix proportion of total four concrete mixes are summarized in Table 4. The mix proportion was based on weight of the ingredients. Sample ID's of the concrete mixes are Control (without plastic), 10% PET (10% volume of CA replaced by PET plastic), 10% HDPE, (10% volume of CA replaced by HDPE plastic) and 5% PET + 5% HDPE (5% volume of CA replaced by PET and another 5% volume of CA replaced by HDPE).

Table 4- Proportion of concrete mixes

Sample ID	Cement (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Coarse Aggregate (kg/m^3)	PET Plastic (kg/m^3)	HDPE Plastic (kg/m^3)	Unit Weight of Fresh Concrete (kg/m^3)
Control	485.6	190.8	754.4	953.9	---	---	2385
10% PET	485.6	190.8	754.4	858.5	14.3	---	2304
10% HDPE	485.6	190.8	754.4	858.5	---	20	2310
5% PET +5% HDPE	485.6	190.8	754.4	858.5	7.15	10	2307

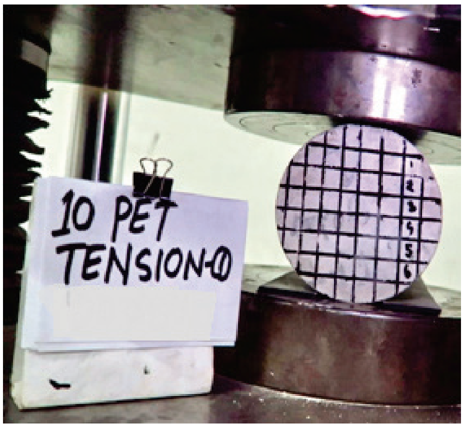
2.3 Test Setup

Compressive strength test was performed according to ASTM C39 and splitting tensile strength test was conducted following ASTM C496. For both compression and splitting tension tests, cylindrical concrete samples of 100 mm by 200 mm in size were made. The freshly consolidated concrete kept in the moulds were covered with damped clothes for one day. After one day of casting, the samples were removed from the moulds and those samples were then kept under lime water for curing up to 28days. 1,000kN capacity digital universal testing machine (UTM) (Fig. 4a) was used to apply compressive load on the specimens at a rate of 3mm/min. The vertical displacement and axial load were recorded from the load cell of UTM as illustrated in Fig. 4b. The test setup of splitting tension test and the test specimen during the failure are shown in Fig. 4c and Fig.4d respectively.



(a) Digital universal testing machine (UTM)

(b) Test setup of compression test



(c) Test setup of splitting tension test

(d) Test specimens during splitting tension test

Fig.4: Different test arrangements

3 Results and Discussion

3.1 Fresh Unit Weight

Table 4 shows that approximately 4% reduction in fresh unit weight has been observed in case of test specimens containing plastic waste while compared to control concrete since coarse aggregate has been replaced by volume rather than weight. The main advantage of using plastic is that it will produce light weight concrete which will contribute to the reduction in self-weight of a structure.

3.2 Failure Pattern

From Fig. 5, it is clearly evident that under compressive load, the failed control specimen shows more rupture tendency than concrete samples with plastic. From Fig. 6, it has been noticed that under splitting tension load, the control test specimen was divided completely into two pieces. Little gap was observed at the vicinity of cracked line for 10%PET concrete sample. A little more gap space was found in 5% PET +5% HDPE concrete sample and the highest gap in case of 10% HDPE concrete sample. This clearly indicates that PET plastic has more crack arresting capacity than HDPE plastic.

Fig.5 - Failure pattern of concrete specimens after compression test

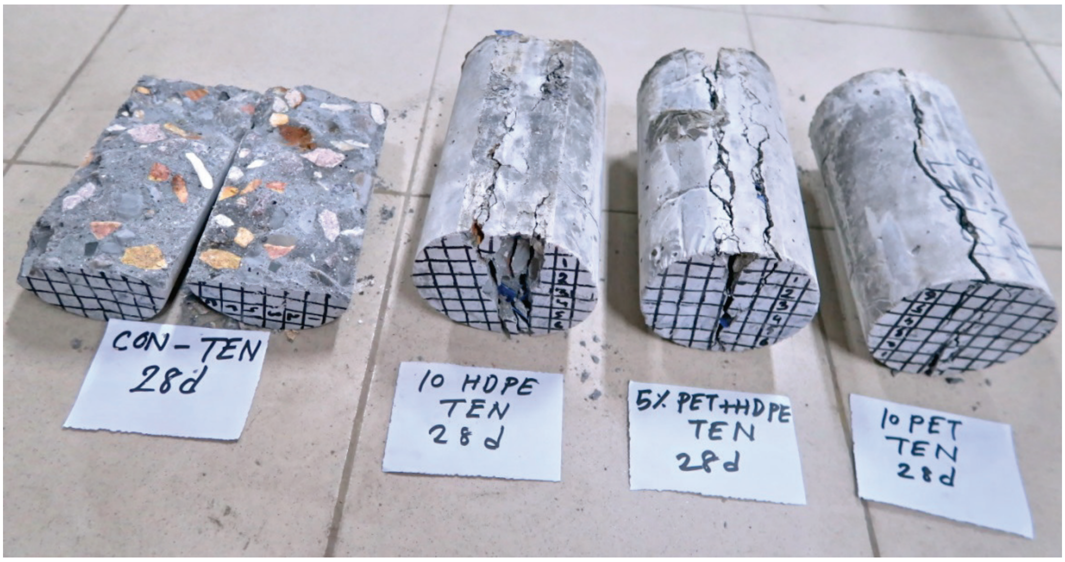


Fig.6 - Failure pattern of concrete specimens after splitting tension test

3.3 Compressive Strength

Fig. 7 presents the axial stress-axial strain responses of concrete cylinders made with and without plastic waste at 28days of curing. From Fig.7, it has been observed that concrete specimens with waste plastic have comparatively lower compressive strength than that of control concrete. This can be attributed to the decrease in adhesive strength between the surface of the waste plastic and the cement paste. Additionally, plastic is considered to be a hydrophobic material, so this property may restrict the water necessary for cement hydration during the curing period. Fig.8 presents the relative comparison of compressive strength test values between the control specimen and concrete with different percentage of plastic. From Fig.8, it has been clearly noticed that compressive strength values for 10% PET, 10% HDPE, and 5% PET +5% HDPE replaced concrete specimens were decreased by 35%, 48% and 40% respectively with respect to control concrete. It indicates that under compression, concrete with PET plastic is stronger than that of concrete containing HDPE plastic.

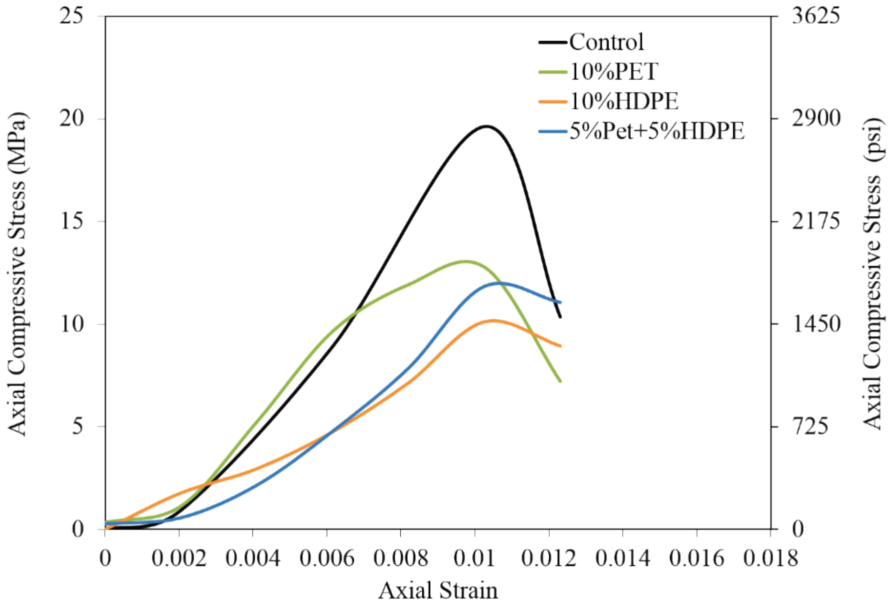


Fig. 7 - Axial stress - axial strain responses for different test specimens

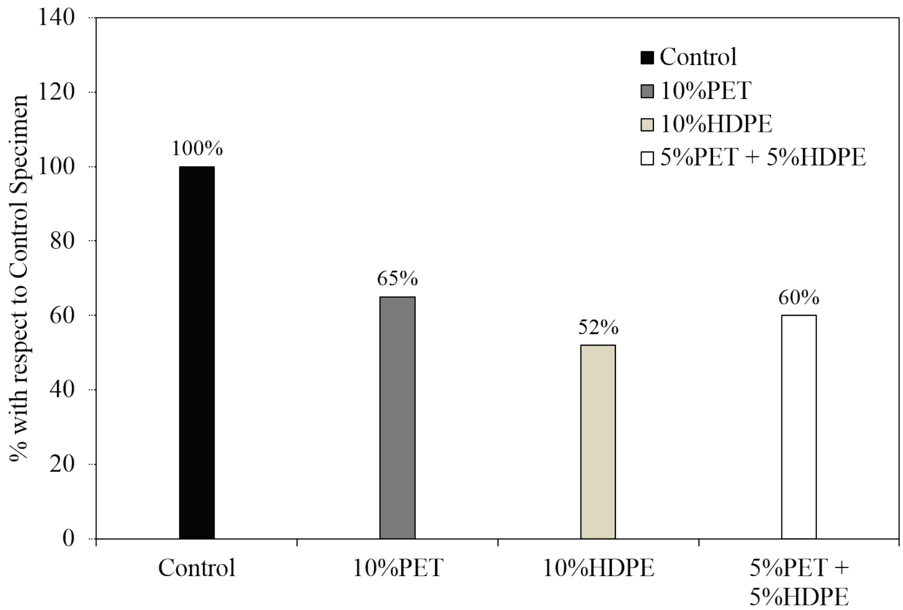


Fig. 8 - Comparison of compressive strength test values for test specimens

3.4 Splitting tensile Strength

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 can be determined by indirect test method called Split tensile test and it was used in this study for determining tensile properties of concrete specimens. The split tensile strength test values of the test specimens at 28days are shown in Fig.9. Fig.10 presents the relative comparison of splitting tensile strength test values between the control specimen and concrete with different percentage of waste plastic. From Fig. 10, it is evident that splitting tensile strength values for 10% HDPE, and 5% PET +5% HDPE replaced concrete specimens were decreased by 37%, 7% respectively and the test value for 10% PET concrete specimen was increased by 21% with respect to control specimen. It indicates that PET plastic has more tensile carrying capacity than HDPE plastic. Thus it can certainly be recommended that PET plastic can be incorporated into concrete to enhance the tension carrying capacity of concrete.

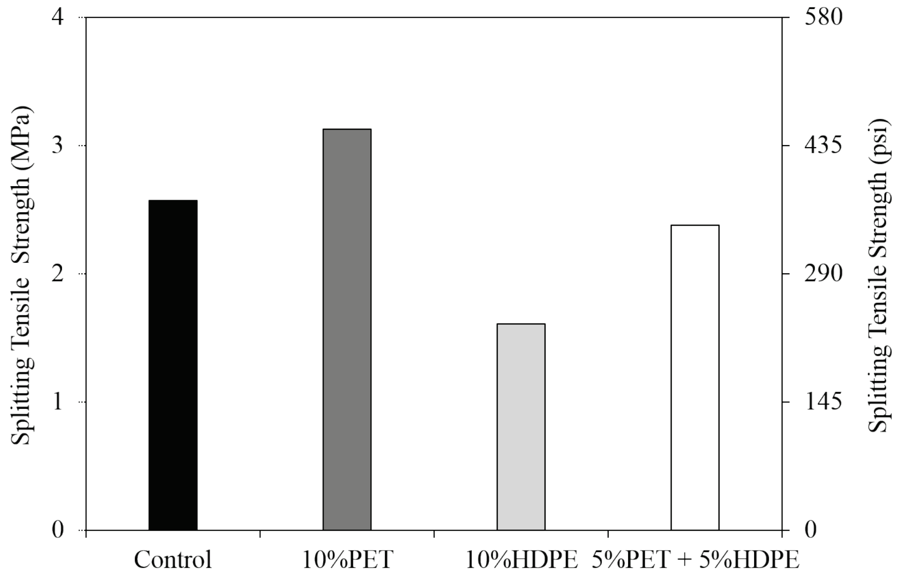


Fig. 9 - Splitting Tensile strength test results for test specimens

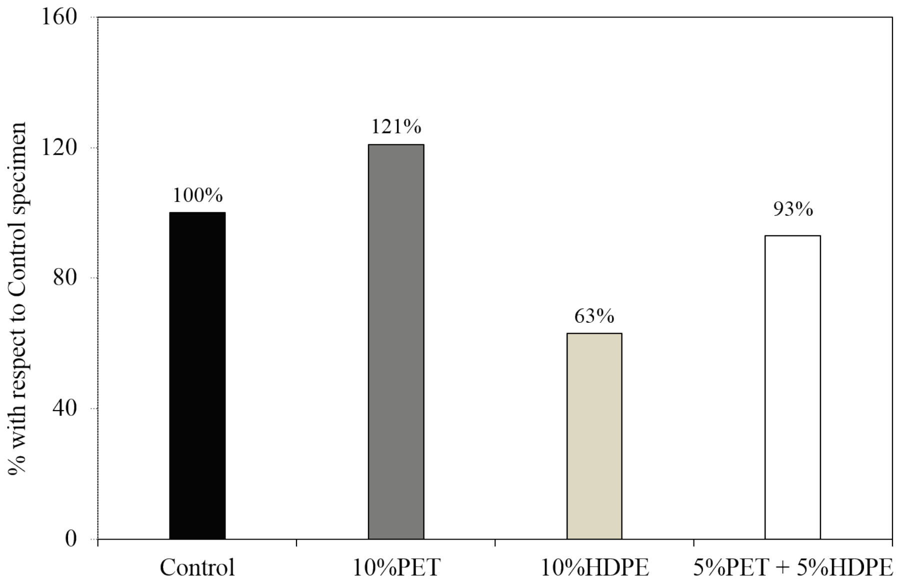


Fig. 10 - Comparison of Splitting tensile strength test values for test specimens

4 Conclusion

It has been found from the present study that replacing coarse aggregate by plastic waste has significant effect on the strength characteristics of concrete. Fresh unit weight of concrete specimens with plastic waste was decreased by 4% while compared to control specimen. Most importantly, compressive strengths of concrete specimens containing plastic waste were found to be less than that of control sample. The compressive strength values for 10% PET, 10% HDPE, and 5% PET + 5% HDPE replaced concrete specimens were decreased by 35%, 48% and 40% respectively while compared to control concrete. Based on the test results, it can be certainly said that PET plastic shows slightly higher compressive strength than HDPE plastic. In addition, splitting tensile strength values for 10% HDPE, and 5% PET + 5% HDPE replaced concrete test specimens were decreased by 37%, and 7% respectively and the test value for 10% PET concrete specimen was increased by

21% with respect to control specimen. Based on the test results, it is suggested to use PET plastic waste in concrete to improve the tensile characteristics of concrete.

Plastic waste consumed in concrete as a partial replacement of coarse aggregates can be used in non-structural concrete found in numerous non-structural components like sidewalk, handicap ramp, stair, interior partition wall, low rise concrete wall building, storage tank, cladding, non-structural slab etc. since the strength properties of concrete having plastic is not very great. However, future study can be carried out for better understanding of the effect of plastic waste on different properties of concrete mix. For instance, thermal conductivity, specific heat capacity, impact resistance, permeability of plastic waste concrete can be determined through laboratory tests to get a broad idea of various characteristics of concrete having plastic.

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