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Concrete production using recycled waste plastic as aggregate

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Abstract

Abundant quantities of polymeric materials are generated by manufacturing process from different industries which produce huge amount of municipal solid wastes. Among these broken plastic bottle, bucket, basket and thin container made by High Density Polyethylene (HDPE) are a large part of these wastes. These plastic wastes can be utilized under proper condition as an ingredient of concrete. This study was carried out to determine the compressive strength, tensile splitting strength, flexural strength and dry density of recycled plastic concrete. In this study, total 90 cylinders and 5 beams were prepared with stone aggregate and 5%, 10%, 15% and 20% replacement of stone by recycled plastic aggregate at w/c ratio of 0.50. Tests were performed after 7, 14, and 28 days of curing ages. Test results revealed that maximum reduction in compressive strength was 44% for 20% replacement of stone by recycled plastic. Tensile splitting strength and flexural strength of concrete were decreased with the increase of percentage of recycled plastic. Dry density was reduced by about 8% from reference concrete for 20% replacement of stone by recycled plastic. It can be concluded that the recycled plastic aggregates may be used up to 15% replacement of stone aggregates in concrete and may be used in non-load bearing structures where lightweight materials are recommended.

Keywords: Recycled plastic, high density polyethylene, compressive strength, dry density, curing.

1. Introduction

The consumption of plastic is increasing significantly over the world in the recent year which creates a massive quantity of plastic based waste. In the Dhaka City Corporation (DCC) area, about 3,315 tons/day of solid waste had been generated, of which 4.15% was composed of plastic materials during 2005 (Rahman et al. 2012; Waste Concern Consultant 2006) and 5.46% during 2014 (Haque 2015). The report indicates that plastic waste generation increases at the rate of 10.43% per year in the amount of plastic waste (Rahman et al., 2012; Waste Concern Consultant 2006). 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 (Haque 2015). These wastes are almost non-degradable in the natural environment even after a long period of exposure. So, plastic waste is now a serious environmental threat to the modern way of living. It is not feasible to use waste plastic for land filling, which require huge land space area and as well land loses its fertility. It also causes serious problems such as clogging in drainage system, wastage of resources and environmental pollution. In this consequence, big attention is being focused worldwide on the environment and safeguarding the natural resources through recycling of waste plastic materials in the recent years. It may appear to be valuable property as construction material. 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 (Youcef et al. 2009). Thus, utilization of waste plastic materials in concrete as aggregates may be considered one of the most feasible utilization to overcome some safe disposal problems of waste plastic materials.

2. Environmental considerations

The recycling process of waste plastic deals emission of certain amount of greenhouse gases (CO_2, CH_4, N_2O). However, if this recycled plastic is used in a concrete that would be permanent for at least 50 years which will produce no greenhouse gases anymore in this period. In this point of view, use of waste plastic in concrete production can be a sustainable solution for environmental pollution.

3. Properties of materials

3.1 Cement

The Portland composite cement (fly ash based), type CEM II/B-M (S-V-L), strength class 42.5 N, was used in this study. The properties of cement used in this study are given (Table 1).

Table 1
Properties of cement

Physical properties	Test Results
Standard Consistency	31%
Specific Gravity	3.15
Initial Setting Time	210 min
Final Setting Time	330 min
Compressive Strength:	
after 3 days of curing	13.92 MPa
after 7 days of curing	19.12 MPa
after 28 days of curing	64.30 MPa

3.2 Fine aggregate

Locally available Sylhet sand was used in this study as fine aggregate. The properties of fine aggregate are given (Table 2).

Table 2
Properties of fine aggregate

Properties	Test results
Fineness Modulus	2.57
Specific Gravity:	
Oven-Dry Basis (OD)	2.54
Saturated Surface-Dry Basis (SSD)	2.57
Water Absorption Capacity (%)	2.04

3.3 Coarse aggregate

3.3.1 Stone

Locally available stone aggregate having the maximum size of 19 mm were used in this study as coarse aggregate. The properties of stone are given in Table 3.

3.3.2 Recycled plastic

Recycled High Density Polyethylene (HDPE) type plastic aggregate (maximum size 19 mm) was used in this study. The properties of recycled plastic are given in Table 3.

Table 3
Properties of coarse aggregate

Common properties	Stone	Recycled plastic
Fineness Modulus (FM)	7.39	7.08
Bulk specific gravity:		
Oven Dry Basis (OD)	2.8	0.86
Saturated Surface Dry Basis(SSD)	2.82	0.87
Absorption capacity (%)	1.08	0.47
Bulk density (kN/m^3)	14.0	4.17
Aggregate crushing value (%)	30.40	0.83

3.4 Water

Potable water was used for mixing and curing of specimens.

4. Recycling of waste plastic as coarse aggregate

There are various methods of recycling of waste plastic. In this study mechanical recycling was applied to prepare recycled plastic aggregate. At first the post-consumer waste plastic materials such as broken plastic bottle, bucket, basket and thin container made by High Density Polyethylene (HDPE) had been collected, shredded and washed. Secondly, dried shredded materials were melted and cooled at room temperature. Then these molten plastic were again shredded into small pieces within the size range of 12-19 mm. Photo view of shredded raw plastic materials and recycled plastic aggregate are presented in Figure 1.

Fig. 1. Shredded raw plastic materials to Recycled plastic aggregate.

5. Experimental plan

Total 90 cylinder specimens of size 100mm diameter and 200mm height and 5 beam specimens of size 150mm x 150 mm x 450mm were casted with 5%, 10%, 15% and 20% volumetric replacement of stone to test the strength properties of recycled plastic concrete. For the preparation of concrete specimens, cement: fine aggregates (sand): coarse aggregates (stone chips and recycled plastics) ratio of 1:1.8:3 in volume basis and w/c ratio of 0.50 was used. Specimens were immerged in water intended to cure them for a period of 7, 14 and 28 days.

6. Test results and discussion

6.1 Dry density

In this study, the minimum dry density of concrete was 21.71 kN/m^3 (2213 kg/m^3) for 20% replacement of stone by recycled plastic. At 28 days curing age, the lowest dry density was 2225 kg/m^3 by (Rai et al. 2009) and 2223.7 kg/m^3 by (Ismail et al. 2008) which exceeds the range of the dry density for structural lightweight concrete. By (Rahman et al. 2012), the rate of reduction of dry density was 0.2% per volume percent of waste polymer. (Al-Manaseer and Dalal 1997) reported that the bulk density of concrete was reduced by 2.5%, 6% and 13% for the concrete containing 10%, 30% and 50% plastic aggregates respectively. The values of dry density with percentages of plastic are tabulated in Table 4.

Table 4
Dry density test results

Test name	Percentages of plastic				
	0%	5%	10%	15%	20%
Dry density (kN/m^3)	23.20	22.91	22.58	22.13	21.79

6.2 Compressive strength

From the compressive strengths test result after 7 days, 14 days and 28 days of curing presented in Figure 2, it is clear that the compressive strength of concrete goes on decreasing with increase in percent of recycled plastic aggregates.

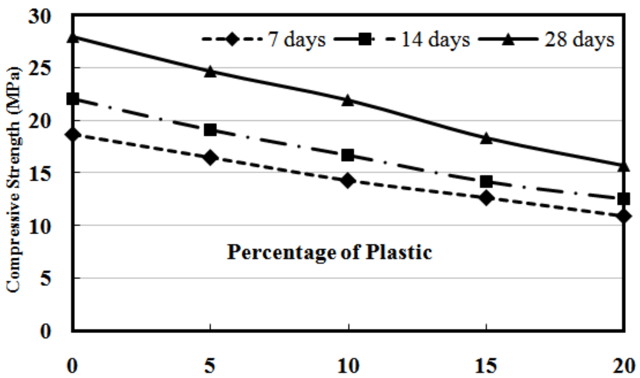

Fig. 2. Variation of compressive strength with various % of plastic.

The compressive strength values were decreased by 11.6%, 21.5%, 34.4% and 44% for 5%, 10%, 15% and 20% replacement of stone by recycled plastic respectively. The rate of reduction was about 0.61 MPa per every percent of recycled plastic added.

It has been observed by (Rahman et al. 2012) that the inclusion of waste polymer (HDPE) by 10%, 15%, 20% and 25% of stone aggregate were found to decrease at a rate of about 0.6 MPa per volume for every percent of HDPE added. (Al-Manaseer and Dalal 1997) found 34%, 51% and 67% reduction in compressive strength for concrete containing 10%, 30% and 50% plastic aggregates respectively. In other study, (Raghatate 2012) and (Kumar and Prakash 2006) observed that the compressive strengths of concrete were decreased with the increase of waste plastics in concrete.

6.3 *Tensile splitting strength*

Tensile splitting strength of concrete with various percentages of plastic is presented in Figure 3.Test result shows that the tensile splitting strengths were decreased from 6.7% to 30% for concrete containing 5% to 20% recycled plastic aggregates respectively. (Al-Manaseer and Dalal 1997) concluded that the tensile splitting strength was decreased by 17% for concrete containing 10% plastic aggregates. (Choi et al. 2005) studied the influence of polyethylene terephthalate (PET) bottles and found tensile splitting strength of concrete mixtures decreased with increase in PET aggregates.

Also, by (Siddique et al. 2008) tensile splitting strength of concrete mixtures decreased with the increase in PET aggregates but for a particular PET aggregate content (25% and 50%) tensile splitting strength increased with the reduction in w/c ratio.

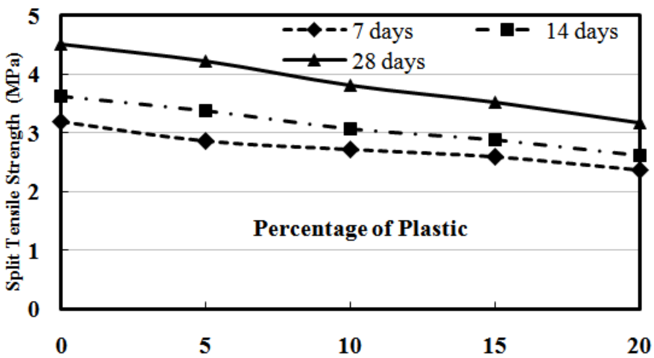

Fig. 3. Variation of tensile splitting strength with various % of plastic.

6.4 *Flexural strength*

Flexural strengths of concrete were decreased from 5.3% to 24.4% for concrete containing 5% to 20% recycled plastic aggregates respectively. Variation of flexural strengths is presented in Figure 4 from which it is clear that the rate of decreasing of flexural strength with percentage of plastic is very low. (Rai et al. 2009) demonstrated that the flexural strength of waste plastic mix concrete is prone to decrease with the increase of the waste plastic content. Also, (Choi et al. 2005) investigated that for a 50% replacement of sand by recycled PET, the flexural strength of concrete decreases to only 32% of that of unmodified concrete.

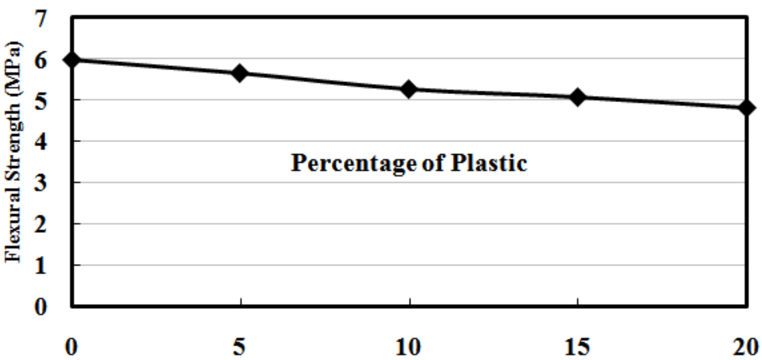

Fig. 4. Variation of flexural strength with various % of plastic.

7. Cost

The estimated cost for producing concrete using waste plastic aggregate (15% replacements) is shown in Table 5 for one (01) cubic meter concrete production.

Table 5
Cost of concrete production using 15% waste plastic aggregate.

Sl No.	Materials	Quantity	Unit cost, BDT	Total cost, BDT (USD)
1	Waste plastic aggregate (Including processing)	0.12 m^3	1,61,290.0	19354.0 (241.0)
2	Stone chips	0.66 m^3	5,650.0	3729.0 (46.6)
3	Coarse sand	0.465 m^3	1,415.0	658.0 (8.22)
4	Cement	7.76 bags	450	3,492.0 (43.65)
				Total =27,233.0 (340.0)

8. Conclusion

The dry density of concrete was reduced by about 1.5% for each 5% replacement of stone by recycled plastic aggregates. Therefore, recycled plastic aggregates can be used in concrete to reduce the total weight of structure. The compressive strength was tended to decrease with increase in recycled plastic aggregates. The minimum value of compressive strength after 28 days of curing was 15.66 MPa (2270.5 psi) for 20% replacement of stone aggregates which was lower than the minimum value of 17.0 MPa (2500 psi) for structural application. But obtained compressive strength value of 18.34 MPa (2656 psi) for 15% replacement of aggregate was higher than this recommended value. Therefore, up to 15% replacement of stone aggregate by recycled plastic is applicable for structural application. The tensile splitting strength was decreased with increase in percentage of plastic.

However, concrete containing plastic aggregates revealed more ductile behavior than conventional concrete. This ductile behavior can be provided significant advantage in reducing crack formation and propagation. The flexural strength of concrete was found to come down with increase in waste plastic aggregates content. The lowest flexural strength at 28 days of curing age for concrete made of 20% waste plastic aggregates was 24.4% lower than the value of reference concrete. Finally, it can be concluded that the recycled plastic aggregates may be used up to 15% replacement of stone aggregates in concrete. Production cost of concrete is too high but its advantage on the environmental issue is significant.

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