Use Of Plastic As A Partial Replacement Of Coarse Aggregate In Concrete For Brick Classifications

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ABSTRACT: In this study, plastic waste is used as the partial replacement of coarse aggregate in concrete. For that four volume based mix proportions (1:1:1, 1:1.25:2.5, 1:1.5:3 and 1:2:4) were taken. For each ratio 0%, 25% and 50% stone was replaced by plastic. Waste of high density polyethylene (HDPE) type plastic was used. Compressive strength and unit weight of concrete was measured after 28 days curing. The test result revealed that, addition of 25% and 50% plastic as coarse aggregate reduces unit weight of concrete up to 9.8% and 12.4% respectively. But such in case, reduction of compressive strength was up to 29.17% and 48.5% respectively. Linear regression model was also developed using SPSS modeler and its accuracy was judged by statistical parameters.

Keywords: Compression, concrete, plastic, brick, empirical equation.

1. Introduction:

Plastic is a very common material in our daily life. The use of plastic has increased substantially over the last decade as it is lightweight, moisture and corrosion resistant, durable and relatively inexpensive. They already have replaced many traditional materials such as wood, stone, horn and bone, leather, paper, metal, glass and ceramic. Now a days almost all aspects of life thrust into plastic. As a result, the production of plastic increased exponentially. From 1964 to 2014, plastics production has increased from 15 million metric tons to 311 million metric tons. If this trend continues, it is expected that plastic production will double in 20 years and almost quadruple by 2050 (World Economic Forum, 2016). Along with production the amount of waste plastic is also increasing exponentially.Due to insufficient recycling, millions of tons of plastic wastes are generated each year which end up in landfills and oceans. In landfills between 22-43% plastics are disposed and at least 8 million tons of plastics are disposed into the ocean (Gourmelon, 2015).In Bangladesh, first plastic industry started in 1960. Since then plastic consumption has been increasing day by day. Alone in Dhaka city, among the total solid waste, plastic was4.15% in 2005 and 5.46% in 2014 (Hasan et al 2015); which indicates the increased rate of waste plastic.Waste plastic can turn into a potential resource if it can be recycled. One of such attempts is that waste plastics can be used in concrete which can solidify this waste. Several studies have been conducted to evaluate the applicability of different types of plastics for constructional purpose. Abu Hasanet al.(2015) evaluated the properties of concrete with recycled plastic as coarse aggregate by 5%, 10%, 15% and 20% replacement of stone. They used HDPE plastic and prepared total 90 cylinders and 5 beams. Then at 7, 14, and 28 days of curing age, the compressive strength, split tensile strength, flexural strength and dry density of the specimens were evaluated. The water/cement ratio was 0.5 and mix proportion was 1:1.8:3 in volume basis. According to their result the maximum reduction in compressive strength was 44% for 20% replacement of stone by recycled plastic. Split tensile strength and flexural strength of concrete were decreased with the increase ofpercentage of recycled plastic. Dry density was reduced by about 1.5% for each 5% replacement of stone. They concluded the study by remarking that up to 15% replacement of stone aggregate by recycled plastic is applicable for structural application. Another experiment was conducted by SubramaniandPugal (2015) on partial replacement of coarse aggregate with polyhydroxybutyrate (PHB) which is a biodegradable plastic. 5%, 10% and 15% of coarse aggregate was replaced by plastic and the water/cement ratio was 0.46. It was observed that 20% of plastic waste aggregate can be replaced without any long term detrimental effects and with acceptable strength development properties.Ghernoutiet al. (2014) studied the applicability of plastic bags as fine aggregate in concrete. Fine aggregate of plastic was produced by heating the plastic bags followed by cooling of liquid waste which was then cooled and crushed. The finesse modulus was 4.7. Then 10%, 20%, 30% and 40% fine aggregate was replaced with plastic fine aggregate. After 28 days curing, the workability, bulk density, ultrasonic pulse velocity testing, compressive and flexural strength of the specimens were evaluated. On the other hand, workability significantly increased with the presence of plastic bag wastes. The conclusion was drawn by remarking that plastic bag can be used successfully to replace conventional fine aggregates in concrete. In another study, plastic scrap used was leftover pieces of bottles, cans etc. So, as a trial the plastic was chopped into small pieces and heat was supplied from below. In to the molten plastic paste, sand was added in suitable proportions. The paste contained noting more than sand, plastic and thermocol. After thorough mixing, the paste was poured into a rectangular mould with standard brick dimensions. The paste took only 20 minutes to settle and harden. Cooling of the set was done by water cooling and after 5 more minutes the brick was extracted from the mould. It had a dark grey texture and increased weight by the initial analysis. Local brick testing methods were conducted such as free fall of the brick and scratch test. In both of those tests, our brick showed increased strength. The brick was subjected to compressive test, water absorption test. The results showed promise, that the Plastic Composite Brick was efficient than the clay brick and cement brick (Kamble and Karad, 2017). Similar study with propising result was achieved by Singhal and Netula (2018) and Shah et al (2017). Merbouhet al. [2014]used low density polyethylene (LDPE) to replace aggregate. The water/cement ratio was 0.54. They replaced 0%, 0.25 to 0.50 and 1.0% of aggregate by LDPE. After 28 days curing, there occurred a slight decreasein compressive strength marking an optimum at 0.5 % LDPE. Noticeable ductility in fracture was recorded, which is advantageous during cracking along associated with a significant reduction in density. It was opined to use LDPE in concrete where less compressive strength and tensile strength is required. In this study, compressive strength and unit weight of concrete were sorted out where four mix ratios (volume based) were used with plastic as partial replacement (25% and 50%) of coarse aggregate. It was tried to find out the mix ratios which can be used as per Local government of engineering department of Bangladesh (LGED) and Bangladesh standard (BDS) 208:2002. According to BDS208:2002 and LGED (2005) the classification of brick is given below (**Table 1and 2**). It is expected that the study will contribute to have an idea in using plastic waste in brick as per the standard of Bangladesh. This can encourage another form of reuse of plastic waste in sustainable way. Also the range of use of plastic waste is up to 50%, which is rarely used in many studies. Also mathematical model to find brick strength was proposed whose adequacy was evaluated using different statistical parameters.

***Table1**: Classification of brick (BDS 208:2002)*

Grade	Minimum compressive strength for individual brick(MPa)
S	24.13
A	15.17
B	10.34

***Table2**: Classification of brick according to LGED (2005)*

Type	Minimum compressive strength for individual brick(MPa)
First class brick	13.7
Picked jhama brick	16.7
First class machine made brick	20.6
Perforated brick	20.6
Clinker brick	55.1

2 METHODOLOGY

To conduct the study the raw materials which are Composite cement (65% clinker, 35% Gypsum), fine aggregate (Fineness Modulus: 2.71), coarse aggregate (19mm downgraded),plastic waste (Thermoplastic type high density polyethylene(HDPE) having Fineness Modulus: 5.91, unit weight: 3.5KN/m^3, **Figure 1**), water were selected. To mix the materials, cement: fine aggregate: coarse aggregates (stone chips and recycled plastics) ratio of 1:1:1, 1:1.25:2.5, 1:1.5:3 and 1:2:4 were selected in volume basis. For each ratio, coarse aggregate was replaced with 0%, 25% and 50% plastic.In order to prepare the samples, clean and dry cylinder mould of 100mm diameter and 200 mm height was used. Three specimens were made for each replacement. The concrete was mixed by hand mixing. After 24 hours at room temperature, the specimens removed from the mould carefully. Just after removal from mould, the specimens were fully submerged in a curing tank for 28 days. The whole procedure of preparing specimens were conducted following ASTM C39 standard.After 28 days curing, the specimens were removed from the curing tank. After that weight and compressive strength of the specimens were measured. The results were compared with the standards of LGED and BDS 208:2002.

***Figure 1**: HDPE plastic*

4. Result Analysis

After 28 days curing it is found that both compressive strength as well as unit weight were reduced as the plastic percentage increases for all four mix ratios (**Figure 2 and Figure 3**). Based on the result obtained,as per LGED (2005) and BDS208:2002 the proposed purpose of use of the samples of Figure 2is shown in **Figure 4 and 5**.In **Figure 4** it is presented that, concrete samples with 25% plastic (ratio 1:1:1), concrete samples with 25% plastic (ratio 1:1.25:2.5), and concrete samples with 25% plastic (ratio 1:1.5:3) has the strength of Grade-A brick. Concrete samples with 25%, 50% plastic (ratio 1:1:1), concrete samples with 25%, 50% plastic (ratio 1:1.25:2.5), concrete samples with 25%, 50% plastic (ratio 1:1.5:3) and concrete samples with 25% plastic (ratio 1:2:4) has the strength of Grade-B brick.Similarly, in **Figure 5** it is presented that, concrete samples with 25% plastic (ratio 1:1:1) and concrete samples with 25% plastic (ratio 1:1.25:2.5) has the strength of Picked Jhama brick. Concrete samples with 25%, 50% plastic (ratio 1:1:1), concrete samples with 25%, 50% plastic (ratio 1:1.25:2.5), concrete samples with 25%, 50% plastic (ratio 1:1.5:3) and concrete samples with 25% plastic (ratio 1:2:4) has the strength of First class brick.

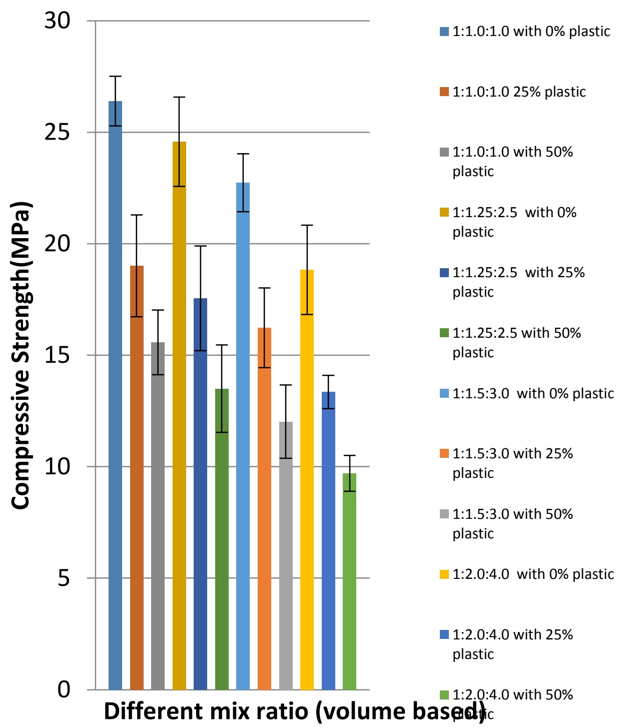

***Figure 2**: Compressive strength variation with the increase of plastic percentage for each proportion.*

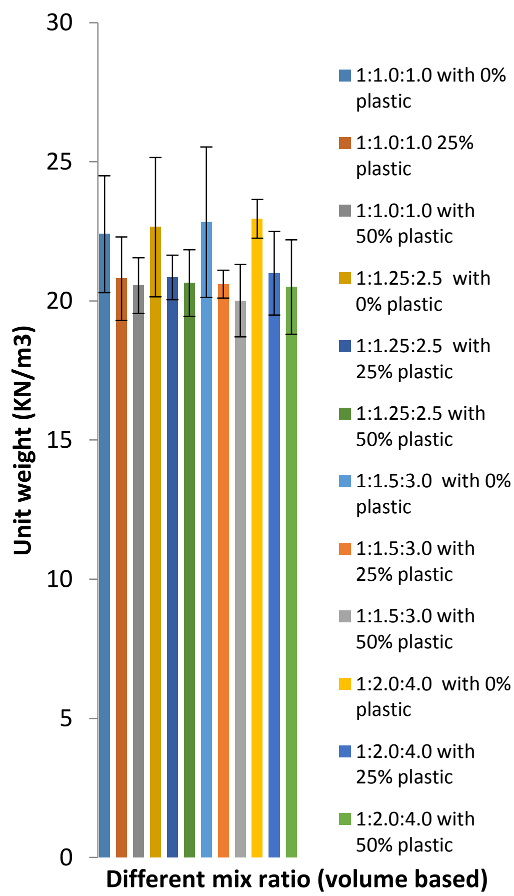

***Figure 3**: Unit weight variation with the increase of plastic percentage for each proportion.*

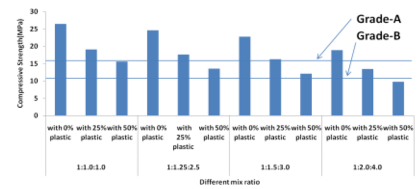

***Figure 4**: Use of the samples as per BDS 208:2002*

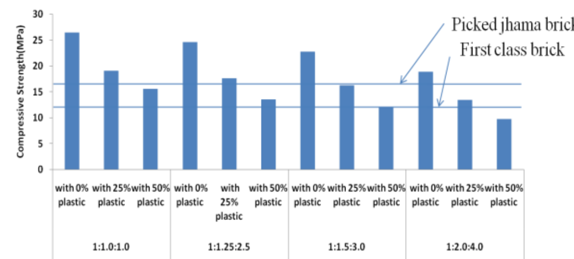

***Figure 5**: Use of the samples as per to LGED (2005)*

5. Empirical Equation Development

From the test result a linear empirical equation (**Equation-1**) is proposed using the software- IBM SPSS Modeler (version 23). In that equation 28 day compressive strength (f'_cin MPa) was kept as the function of the volume (in m^3) of cement (V_C), sand (V_{FA}), stone (V_{CA}) and plastic (V_{PL}). The values input variables are shown in **Table 3** (as used in the experiment). It should be noted that all the volumetricvalues in **Table 3** are for one specimen of concrete cylinder having the diameter 100 mm and the height 200 mm.The accuracy of the proposed linear empirical equation (**Equation-1**) is shown in the **Table 4**, from which it can be said that the **Equation-1** is a good fit with the experimental values. It is to be noted that, **Equation-1** is expected to be valid under the applicable parameter range shown in **Table 5**.

$$f'_c = -35520.662V_C - 98859.504V_{FA} - -55353.743V_{CA} - 71313.926V_{PL} + 181.29 \ldots\ldots [1]$$

***Table 3:**Input variables (volume in m^3) and Compressive Strength (in MPa)*

Mix Ratio	Plastic content	Cement (m3)× 10-4	Sand (m3) × 10-4	Stone (m3) × 10-4	Plastic (m3) × 10-4	Compressive Strength (MPa)	
						From Experiment	From Equation
1:1.0:1.0	with 0% plastic	8.3	8.3	8.3	0	26.40	23.81
	with 25% plastic	8.3	8.3	6.3	2	19.01	20.62
	with 50% plastic	8.3	8.3	4.2	4.2	15.57	16.56

1:1.25:2.5	with 0% plastic	5	6.7	13.3	0	24.57	23.68
	with 25% plastic	5	6.7	9.9	3.4	17.55	18.25
	with 50% plastic	5	6.7	6.65	6.65	13.50	13.06
1:1.5:3.0	with 0% plastic	4.5	6.8	13.6	0	22.73	22.80
	with 25% plastic	4.5	6.8	10.1	3.5	16.23	17.22
	with 50% plastic	4.5	6.8	6.8	6.8	12.02	11.95
1:2.0:4.0	with 0% plastic	3.6	7	14.4	0	18.83	19.59
	with 25% plastic	3.6	7	10.8	3.6	13.35	13.85
	with 50% plastic	3.6	7	7.2	7.2	9.70	8.10

Table 4: *Value of efficiency criteria*

Efficiency criteria	Values
Pearson Coefficient, r	0.97
Coefficient of determination, R^2	0.94
Mean absolute error, MAE	0.93
Mean square error, MSE	1.34
Root mean square error, RMSE	1.26
Coefficient of Efficiency, E	0.94
Modified Coefficient of Efficiency	0.77
Index of Agreement, d	0.99
Modified Index of Agreement	0.88

Table 5: *Applicable parameter range for Equation 1 (for one specimen of concrete cylinder having the diameter 100 mm and the height 200 mm)*

Parameter	Range of volume in one sample [(m3)×10-4]
Cement	$3.6 \leq V_C \leq 8.3$
Sand	$6.7 \leq V_{FA} \leq 8.3$
Stone	$4.2 \leq V_{CA} \leq 14.4$
Plastic	$0 \leq V_{PL} \leq 7.2$

6Conclusions

The study was conducted to find an effective solution to reduce the environmental pollution due to rapid increase of plastic waste. The study can be concluded by the following remarks:

- Recycling waste plastic in concrete as coarse aggregate can be an effective solution to dispose large amount of plastic which can reduce environmental pollution to a large extent and produce green concrete. But for that assurance of strength is also a major concern. This study experimentally tries to find the applicability of waste plastics as partial replacement of coarse aggregate.
- As, addition of plastic decreases the unit weight of concrete, it can be used to produce light weight concrete. But the strength of concrete using 25% and 50% plastic as course aggregate is not sufficient for structural purpose. So, this concrete can be used for non-load bearing purpose.
- Different types of bricks can be produced using plastic as mentioned in **Figure 4 and 5.** By material cost, per brick costs 10 BDT (1$≈90 BDT, approx)whereas, conventional first class brick costs in total 8-10BDT each. Though cost seems to be higher yet with the concern of utilizing waste plastic, it will benefit the environment through solidifying with cement.
- From the compressive strength test, **Equation 1** is proposed under the boundaries shown in **Table 5**.

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