Development of Recycled Air-filled PET Bottle Blocks for Cavity Wall Construction

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Abstract - This study examines the prospect of using PET bottles in mortar block for cavity wall construction in respect of compressive strength and cost. 500-mL air-filled waste plastic bottles encased by mortar plaster worked as the voids in the masonry units. Three different type of blocks B1, B2, B3 were prepared with the cement sand proportion 1:3, 1:3.5 and 1:4 respectively. Result shows that the strength decreased with the reduction of the proportion of cement. The maximum compressive strength found in B1which was 5.21 MPa after 7 days and 9.29 after 28 days of curing. B2 and B3 also shows 74% and 71% increase in strength as they reach the curing age of 28 days. The comparison of cost for wall construction with both bottle block and hollow concrete block shows, for external wall, the material cost can be reduced by 27% in the case of bottle block. So it can be used as a sustainable alternative of hollow concrete blocks in terms of strength and cost for cavity wall construction and have a great effect on plastic waste management.

Key Words: *Waste PET Bottles, Hollow Block, Compressive strength, Cost analysis.*

1. INTRODUCTION

The benefit of plastic materials such as durability, compactness and lightweight has made it a widely used material all over the world. As a result, the amount of plastic waste dumped into environment is so huge that it became a major alarm for today's world. The concept of "World Environment Day, 2018" was "Beat Plastic Pollution" that seeks government, manufacturers, communities and individuals to combine against this pollution [1]. From 1950 to 2015 plastic fabrication raised from 2 million tons to 380 million tons. If the trend follows the same path, by 2050, around 12 billion tons of plastic is predicted in landfills and in the environment [2].

Bangladesh is already endangered by the unfavorable climate change, the growth of plastic wastes will create an unacceptable situation in both land and water. There are several methods to dispose plastic wastes, like -- recycling, discarding at landfill sites and reusing. But, for several reason, all this methods turned out very insufficient in comparison to the amount of waste generated. The country makes almost 381 tons of plastic waste each day, whereas only 143 tons which is only 38 percent of the plastic waste is recyclable [3]. Although the total national plastic consumption has increased by 16.2 percent from 2005 to 2014, in urban areas the projection is by 169 percent" [3]. The portion of plastic waste in Dhaka city has raised from 1.74% in overall landfills in 1992 to 4.1% in 2005 and to 6.5% in 2014 [4].

An alternative solution for this problem is, using PET bottles in construction. Andreas Froses initiated this idea where PET bottles were fitted within the walls along mortars [5]. This idea is also being popular al around the world including Bangladesh. Further compressive strength tests of concrete units with plastic bottles were conducted at Kansas State University and found reasonable compressive strength [6]. According to Public Work Department (PWD) Standard Specification for Building Works (2008), the least allowable average strength is 5.2N/mm2 for bricks and 2.8 N/mm2 for hollow blocks per 10 specimens selected at random [7].

Some researcher examined the thermal comfort of concrete masonry units using plastic bottles [8]. Bangladesh has hot temperatures all over the year, with very little winter period. To withstand the unbearable heat in summer to pass towards indoor, cavity wall has been proven as an effective solution for improving comfort of indoor environment [9, 10]. But because of the high cost of material and the width of the cavity very few people are interested in it. Now a days concrete hollow blocks are being popular as a cheaper solution of cavity wall. It also reduces the wall with and provides good thermal insulation. Hollow blocks in Bangladesh comes with 5 different sizes. The length (390mm) and width (190mm) are same for each, but the depth varies from 90mm to 240mm [11]. The price of 90mm, 100mm and 140mm thick blocks varies from 33-39 BDT and for 190mm and 240 mm the price ranges from 65-80 BDT. For the construction of the exterior wall of residence and other construction minimum 390 X 190 X 190 mm blocks are required. For partition wall, thinner blocks can be used [12].

The goal of this research is to analyze the compressive strength of the air-filled PET bottle blocks to understand whether they can satisfy the standard load and also make comparison of cost with the locally available hollow concrete block. This study showed that waste PET bottles block have the potential to be used as a partial replacement of hollow concrete block. This alternative use of plastic bottles as the building materials can have significant effects on plastic waste management by using them instead of bricks or hollow concrete blocks in walls.

2. Materials and Methods

2.1. Materials

The materials used in this research for bottle block production were 500 ml Polyethylene Terephthalate (PET) Bottles as the hollow spaces in the block and cement (Fineness

4000 cm^2/gm and initial setting time 1 hour 34 minutes) and sylhet sand (FM 2.7 and surface moisture 1.8%) mixture to adhere and bind them together. Physical appearance of the bottle, cement and fine aggregate samples is shown in Figure 1. The bottle blocks were prepared the material laboratory of Civil engineering department at the Chittagong University of Engineering and Technology.

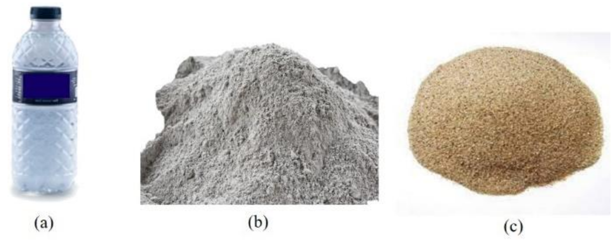


Fig-1: Physical appearance of the materials (a) 500ml PET bottle (b) Cement and (c) fine aggregate

2.2. Mold Preparation

The size of the block was derived from the arrangement of 8 plastic bottle with 10mm gap for cement mortar infill in between all the bottles and from the mold. The inner side of wooden mold was 170mm wide, 210mm high and 330mm long. Five wooden board with proper dimension was joined with 38mm steel screw to hold the mold in shape. All boards were separable for easily taking the sample off. In the middle of two long sides there were 8 small punches and at the short side there were 4 small punches for the ease of inserting thin metal bars to put the bottles in place during the casting and compaction procedure. The dimensional properties of the mold with the placement of eight PET bottles are presented in Figure 2.

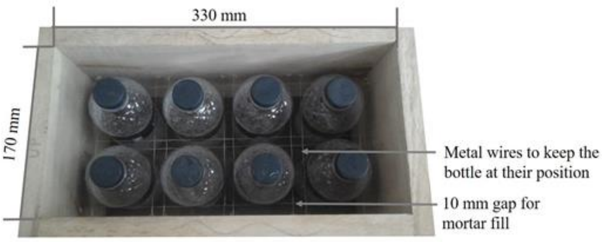


Fig-2: Dimension and arrangement of the mold

2.3. Mix preparation and Casting

In Bangladesh, cement- sand ratio in cement plaster and mortar having 6 mm to 10 mm thickness is recommended from 1:3 to 1:4. So, we decided to take three different ratios of cement-sand to find out the most suitable ratio in respect to strength and cost. After the selected three different ratios of Ordinary Portland Cement, for each ratio three block samples were prepared. For each sample, water cement ratio was 0.50. The composition of 3 different samples are shown in Table 1.

Table -1: Sample Table format

	Cement :Sand :Water	No. of specimen
B1	1:3:0.5	03+03
B2	1:3.5:0.5	03+03
B3	1: 4: 0.5	03+03

Fig-3: (a) Preparation for mixing; (b) Casting of the block

After weighing, the required amount of cement and sand placed in the trough to mix evenly using the standard procedure for hand-mixing. Then water was poured gradually and mixed continuously until it achieved an uniform color. The wooden molds were filled with the mix in layers by trowel. The initial 10mm thick layer of mortar was positioned in the mold and compressed with 20 uniform blows of the tampering rod. After the compaction, eight 500ml air-filled plastic bottles were arranged on the initial layer of mortar. Then 3 more layers of mortar is poured until the tip and about 10 blows were provided for each layer. The surfaces were smoothed and the upper surface of the specimen was marked for identification. Other samples were also prepared by the same procedure. Figure 3 shows the mix preparation and the casting process. The molds were concealed with damp mats while the blocks samples were left in the molds for 24h at laboratory temperature. Figure 4 shows the final outlook of the samples before and after removing the mold.

Fig-4: Appearance of the samples (a) with mold; (b) without mold

2.4. Curing

After moulding, the specimens were kept in the laboratory temperature for 24 hours and after that the molds were removed. Then the samples kept under clean fresh water to be cured for 7 days and 28 days. The sample in the bath during their curing process is shown in Figure 5.

Fig-5: Curing of the bottle block

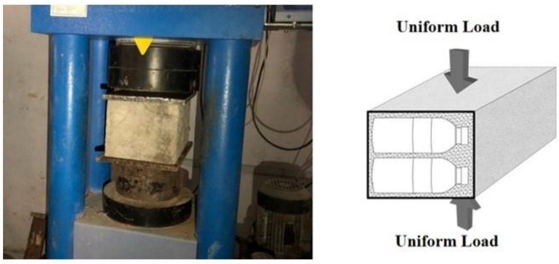
3. Compressive Strength Test

3.1. Procedure

The compressive strength test was conducted according to the ASTM C140 standard. There were 09 specimens (3 set of 3 different mixtures, cured for 7 days) in the first batch. The bottles blocks were placed keeping the bottles horizontal inside. The second batch (another 3 set of each mixture) was tested after 28 days of curing keeping the bottles at the same direction inside. The compressive strength was determined by dividing the maximum load of each block by the area of contact surface. The test and the direction of the bock is shown in Figure 6.

3.2: Result and Discussion

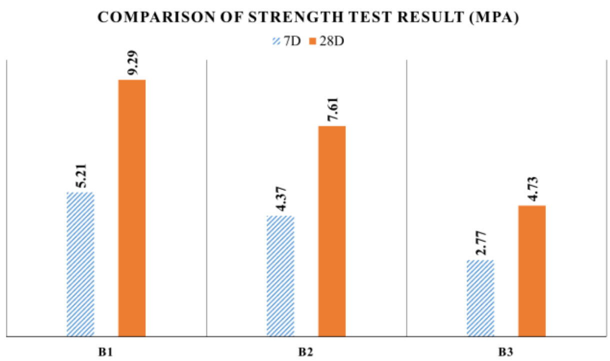
For every test consecutive 3 similar samples (A,B,C) were tested and the average was taken as the result. The average compressive strength of all the samples after 7 and 28 days are accumulated in Chart 1.



(a) (b)

Fig-6: Compressive strength test

Chart -1: Compressive strength comparison of the samples



From the results it is found that with the growing amount of cement in the mortar the compressive strength increases. Figure 7 shows that for the 7 days curing, the maximum compressive strength found in B1was 5.21 MPa, where the cement: sand ratio was 1:3. As the amount of cement started decreasing in the cement- sand ration the strength also started to decline. The compressive strength for B2 and B3 was found 4.37 MPa and 2.77 MPa respectively. For the 2nd batch after 28days of curing, result was found quite high from the previous batch. The average compressive strength for B1, B2 and B3 was found 9.29 MPa, 7.61 MPa and 4.73 MPa respectively which is almost 78%, 74% and 71% higher than their result of the first batch. From the result it is clear that every composition of the blocks satisfy the PWD Standard Specification for Building Works of hollow blocks after 28days of curing [7].

4. Cost analysis and Comparison

Here, we considered the 3.4m X 2.7m wall for the cost comparison. For each case the width of the block was considered as the width of the wall. As, aster 28 days of curing all the blocks satisfies the PWD standard of Hollow block construction, here the composition of block B3 was considered for cost calculation. The total cost of materials are shown in Table 2 and Table 3.

4.1: Bottle block Masonry Wall

Actual size of the block
= (0.33 x 0.17 x 0.21) m^3 = 0.011781 m^3
Size of the block with mortar
= (0.33+0.01) x (0.17+0.01) x 0.21= 0.012852 m^3
Volume of the wall= Length X Height X Width
= (3.4 x 2.7 x 0.21) m^3 = 1.9278 m^3
Number of Blocks needed
= Volume of wall/ Size of the block with mortar
= 1.9278 m^3/ 0.012852 m^3 = 150

Volume of wet mortar in the wall
= Total wall volume- Volume of blocks
= 1.93 m^3- (150 x 0.011781) m^3 = 0.16 m^3
Frog filling, bonding, wastage etc. increases this quantity by 15%, Volume of wet mortar
= (0.16 x 1.15) m^3= 0.184 m^3
Volume of wet mortar in one block
= Actual size of the block- 8(Volume of air filled bottles)
= (0.011781- 8x 7.31 x 10 -4) m^3 = 0.00593 m^3

Volume of wet mortar in 150 blocks
= 0.00593 m^3 x 150 = 0.89 m^3
Total wet mortar in the wall
= (Wet mortar in blocks+ Wet mortar for joining the blocks)
= (0.89 + 0.184) m^3 = 1.074 m^3
After the addition of water, volume of dry mortar reduces by 25%, Volume of dry mortar in 1 bottle block
= 1.25 x 1.074 m^3 = 1.343 m^3

For, cement sand proportion of 1:4
Required Cement = (1/5) x 1.343 m3= (0.269 m3/0.034722) bags = 7.74 bags
Required Sand = (4/5) x 1.343 m^3= 1.074 m^3

Table -2: Cost calculation of Bottle block wall

No	Material	Quantity	Rate (BDT)	Per	Amount (BDT)
1	Bottle	1200	0.5	1 no	600
2	Cement	8	450	1 bag	3600
3	Sand	1.074	500	1 m^3	537
4	Labour cost	3	500	1no.	1500*
	Total (tk) cost for wall construction =				6237

*A skilled labour can make 50 blocks a day and the daily charge for a skilled labour is 500 BDT.

4.2 Hollow block Masonry Wall

Actual size of the hollow block
= (0.39 x 0.19 x 0.19) m^3 = 0.01408 m^3
Size of the block with mortar
= (0.39+0.01) x (0.19+0.01) x 0.19= 0.0152m^3
Volume of the wall= Length X Height X Width
= (3.4 x 2.7 x 0.19) m^3 = 1.744m^3
Number of Blocks needed

= Volume of wall/ Size of the block with mortar
= 1.744 m^3/ 0.0152 m^3 = 114. 75 ≈115

Volume of wet mortar in the wall
= Total wall volume- Volume of blocks
= 1.744 m^3- (114.75 x 0.01408) m^3 = 0.128 m^3

Frog filling, bonding, wastage etc. increases this quantity by 15%, Volume of wet mortar = (0.128 x 1.15) = 0.1472 m^3
After the addition of water, volume of dry mortar reduces by 25%, Volume of dry mortar in 1 bottle block = 1.25 x 0.1472 m^3 = 0.184 m^3

For, cement sand proportion of 1:4
Required Cement = (1/5) x 0.184 m^3= (0.037 m^3/0.034722) bags = 1.065 bags ≈1 bag
Required Sand = (4/5) x 0.184 m^3= 0.1472 m^3

Table -3: Cost calculation of Bottle block wall

No	Material	Quantity	Rate (BDT)	Per	Amount (BDT)
1	Hollow block	115	70	1 no	8050
2	Cement	1	450	1 bag	450
3	Sand	0.1472	500	1 m^3	73.5
	Total (tk) cost for wall construction =				8573.5

Comparison between the walls by Plastic Bottles wall and hollow block for cost estimation shows for the same size wall construction, the cost was 27% lower for the bottle block which proves its potentiality to be used cavity wall construction as an alternative of hollow blocks. This is because, less mortar is required in the bottle block due to the inclusion of plastic bottles.

5. Conclusion

After all the analysis, the following conclusion can be drawn:

1. After 7 days of curing, all the samples (except B3) showed the strength which satisfies the PWD standard for hollow block construction. The average compressive strength for B1, B2 and B3 was found 9.29 MPa, 7.61 MPa and 4.73 MPa respectively which is almost 78%, 74% and 71% higher than their 7-day curing age. So, these blocks are high in strength and can be successfully used as wall materials.
2. Constructing a similar volume of wall by air filled plastic bottles block offers us 27% reduction in the total material cost. This means the use of local manpower in making bottle block walls can lead to cost reduction compared to building the walls using the concrete hollow blocks available in the market.

The most important benefit of these innovative material compared to conventional materials are recycling the plastic wastes which causes a major problem in the waste management sector as it takes almost 1000 years to biodegrade. This material can lead to a better reuse of the waste PET bottles and can enhance the green construction by saving energy and resources, minimizing the CO2 emission and reducing the cost of construction.

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