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Utilization of waste PET bottles as aggregate in masonry mortar

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Abstract

This paper presents utilization of waste PET (Poly Ethylene Terephthalate) bottle granules as a partial substitute for conventional aggregates in the masonry mortar. Waste PET bottles were collected, and subjected to size reduction before addition in the composition of masonry mortar. Test specimens were prepared using PET materials as a replacement of sand in the composition. The effect of the PET fillers on the mechanical, physical and morphological properties of the mortar has been investigated. The experimental result shows that inclusion of waste PET fillers as replacement of sand in the composition of masonry mortar decreases compressive strength, and increases water sorption and porosity of the mortar.

Key words: *PET, mortar, compressive strength, water sorption, porosity*

1. Introduction

Poly-ethylene Terephthalate (PET) is a plastic resin and a form of Polyester. Huge amount of PET have been used in packaging applications, it has achieved acceptance and playing a growing role in PET bottle growth in the world as well as in Bangladesh. In respect to huge production, PET is not being recycled at the same rate. As a result significant amount of waste PET bottles have been remained abandoned, considerable amount of them are dumped on the roadside, bank of river and sewerage in the city, which block the flow in the drain of sewerage system of Dhaka City, a portion of it is being incinerated that led to environmental pollution.

These polymer wastes are almost non-degraded in the natural environment even after a long period of exposure. The slow degradation property of waste polymer materials causes a waste disposal crisis from environmental view point, but it may appear to be valuable property as constructional material [1]. Utilization of waste PET as aggregates in masonry mortar/ concrete would be good solution to this environmental hazard [2]. Few numbers of studies focusing on uses of PET in mortar and concrete have been reported in the literature. A brief account of the studies is presented in the following paragraph.

Akcaozoglu used Poly-ethylene terephthalate (PET) bottle granules as a lightweight aggregate in the composition of mortar, and studied the effect of PET aggregates on the unit weight, porosity and strength properties. It is reported that the compressive strengths of the mixtures containing sand and PET together were higher than the mixtures containing PET without sand. However, porosity ratios of mixtures containing PET and sand aggregate together were higher than mixtures containing only PET. It also refers that the use of PET results in an increase in the shrinkage [3].

Hannawi et al. used PET waste as partial replacement of sand in mortar with percentage volume fractions of 3%, 10%, 20% and 50%. It is reported that inclusion of PET decreases compressive strength and specific weight of the mortar, and improve post-peak flexural behavior. Additionally, use of PC and PET plastic aggregates in cementation material would give good energy absorbing property which would be very interesting for several civil engineering applications like structures subjected to dynamic or impact efforts [2].

Reis et al. also reported significant improvement in post-peak flexural behavior of mortars using PET waste from beverage containers as partial replacement (by weight fractions of sand 5%, 10%, 15% and 20%) of sand in mortar. It is also observed that addition of shredded PET waste decreased the dry density of polymer mortars, fracture mechanics were altered by shredded PET and materials appeared to be more ductile. In addition, shredded PET aggregates were found producing a composite material with high energy absorbing capability [4].

Literature survey shows that significant numbers of studies also have been conducted on use of waste PET as aggregates in concrete [5-11]. The studies highlighted fresh and hardened concrete properties such as, slump density, compressive strength, tensile strength, flexural strength, elasticity modulus, shrinkage, water absorption, water sorption, chloride ion migration, fire behavior, microstructure, thermal properties, freeze–thaw resistance, etc.

It is found from the literature that use of PET as a lucrative construction material has been a topic of profound interest among the researchers since the last decade. Many have explored the potentials of PET to be considered as a new affiliate to concreting technology. In fact most of the studies tend to focus on possibilities of using PET in structural conventional concrete. A few of them have also reported on use of PET as fine filler in masonry mortar to improve its performance to be promising. Synthetic polymers generally add to improve mechanical properties and durability of concrete but for mortars they seem to act differently. Surprisingly, only a few studies have put emphasis on this topic. Yet, what’s missing is a holistic approach. It is observed that the behavior of PET incorporated mortar; reported in different studies; is not exactly congenial. Also, the effects of size and shape of PET aggregates in cement mortar are still unexplored. That’s why; the studies regarding usage of PET in cement mortar deserve much attention. This paper offers a simple and straightforward behavior of masonry mortar modified with PET as fine filler. Different mechanical (compressive) and physical (water uptake, porosity,) properties of modified mortar (using PET as fine fillers) have been evaluated, and compared with those of unmodified conventional cement mortar. As expected, physical properties of the modified mortars have been improved as compared to conventional mortar (CM). This work reports mainly the bulk property of the mortar. Sophisticated experiments are still required to study the thermal properties, nature of bonding, morphology of inner structure, pore-size distribution and so on to explain the reason behind the improvement in properties. Thus, the present study is a mere small step to removing the mentioned inadequacies

2. Experimental

2.1. Materials

The components of the masonry mortar are Portland cement, sand and water. Waste PET materials from scraped PET bottles are used partially replacing conventional fine aggregates (sand). Portland cement and sand used in the experiment were collected from localities and waste PET used in this study has been collected from waste plastic whole seller. The particle size of sand used as fine aggregate (sand) is in the range of 0.15 - 4.75 mm. Some of the basic properties of PET used in the experiment are presented in Table 1.

Table 1: Properties of waste PET

Types	Density, gm/cc	Water absorption, %	Elongation (average), %	Fineness, mm
PET	1.38	0.15	130%	1.00-7.00

Recycling of waste PET

The post-consumer waste PET bottles were collected and shredded. Shredded materials were sieved and particles sizes of PET ranges of 1-7 mm, and particle as aggregate for the preparation of used as aggregate in the formation of mortar. The particles of larger sizes were sent to shredder for further size reduction. Thereafter, shredded PET materials were subjected to a manual batch water wash with no added chemicals used. The particles were allowed to dry up for 24 hours in open sun. As a result significant amount of dust particles were still present in the aggregates. This ensures the PET aggregates which are termed as 'wastes' are used without being subjected to pricy treatment process. This might be a possible reason for reduces compressive strength achieved by other authors. Akcaozoglu also used this technique to recycle waste PET [12].

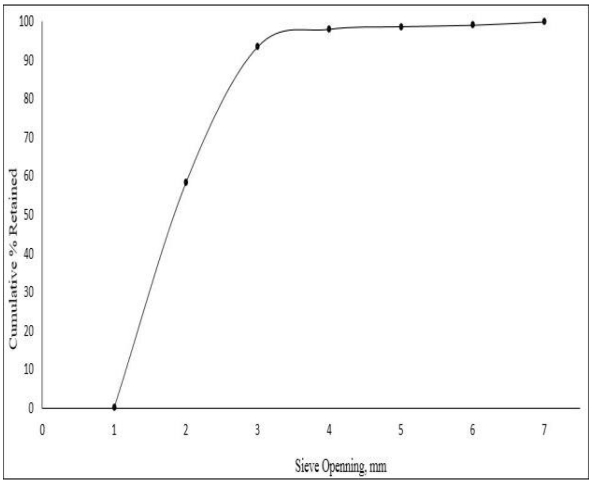

Fig. 1 Cumulative % retained as a function of sieve opening (PET particles)

PET particles used in the experiment are fine graded as shown in figure 1. More than half (around 60%) of the PET aggregates were found to be within a size range of 2 mm. While almost 90% of the particles ranged within 3 mm particle size

Portland cement

The cement used in this study was a commercial ASTM type I ordinary Portland cement. The standard test-properties of the cement used as binder in the experiment is presented in Table 2

Table 2 The standard test-properties of the used cement

Test performed		Result
1. Fineness test		0.068%
2.Setting time	Initial	2 hours
	Final	3 hours
3.Compressive strength	7 day	15 MPa
	28 day	19 MPa

2.2. Preparation of mortar specimens

For the preparation of masonry mortar, the ratio of cement: aggregates (sand and PET) was kept constant at 1:3, and waste PET were used as fine fillers replacing sand by 0, 3, 7, 20, and 30 wt%. Water cement ratio used in the experiment was of 0.45. To prepare the fresh mortar, calculated amount of cement, sand, waste PET and water were mixed following a method and technique as prescribed by ASTM C 109. To examine the workability (or flow-ability) of mortar, flow% were measured for the fresh mortar. The fresh mortar was cast into 50.8 mm × 50.8 mm × 50.8 mm cube size steel mold following ASTM standard method. The mortar specimens were separated out from the mold after 24 hours of molding and kept in water for 7-28 days for curing.

2.3 Methods

For the characterization of the mortar, the compressive strength of the specimens was determined as representative parameters of the mechanical properties, water absorption as representative parameter of physical properties and porosity as morphological properties of the modified mortar.

Determination of water uptake

The mortar samples of size 51 mm^3 were dried in oven at 100^0 C temperature until a constant weight W_0 of the specimens is attained. Then the dried sample was immersed in water in a bowl at room temperature. At a predetermined time of interval, the samples were taken out and the water adhered to the surfaced were wiped out by cloth and weighed. Then the sample is returned in the bowl. In the beginning, the measurement was done at an interval of 1 hour. The equilibrium was reached in 48 hours.

The water absorption at a given time t and equilibrium water uptake A_∞ at $t \rightarrow \infty$ are calculated by the following formulae:

$$A_t = w_t / w_0 - 1 \text{ and } A_\infty = w_\infty / w_0 - 1 \qquad (1)$$

Where w_t is the weight of the wet sample at time t and w_∞ is the weight at equilibrium.

The porosity β of the poly blocks was calculated based on the water uptake data (Eqs. 2-4).

$$\rho_a = w_0 / V_0 \qquad (2)$$

$$\rho_T = \frac{w_0}{V_0 - (w_\infty - w_0)/\rho_w} \qquad (3)$$

And

$$\beta = 1 - \rho_a / \rho_T \qquad (4)$$

Where ρ_a and ρ_T are respectively the apparent and the true density, V_0 is the bulk volume of the sample, and ρ_w is the density of water.

Measurement of compressive strength

The compressive strengths of different mortar specimens were determined using Universal Testing Machine (Model No. TIB/ M. C; Capacity-300 ton).

3. Results and Discussion

The properties measured for different sets of mortars consisting of different PET/sand ratio seem to follow a definite pattern. The addition of PET to cement mortars decreased compressive strength, while, it did not show any specific pattern in water absorption kinetics.

3.1 Compressive strength

The variation in compressive strength as a function of PET filler content in the composition of the mortar is presented in the Figure 2. The figure 2 shows that inclusion of waste PET fillers in the mortar composition results initially a sharp decrease in compressive strength of the test specimens from 19.5 MPa (unmodified mortar) to 8 MPa (mortar containing 3 wt% PET replacing sand). But it is optimistic that the reduction is found lower with increasing PET filler content in the mortar composition. Mortar specimens with 30 wt% PET filler replacing sand exhibited 6 MPa which is consistent to that of mortar containing 20 wt% PET filler. The consistency in compressive strength for more than 16% replacement is unique to this study. It can be attributed by the the fineness (more than 85% particles were within 0≤3mm size) of PET particles helped uniform bonding and better compaction which again caused the mortar samples to act indifferently with increased percentage of PET content.

Akcaozoglu and Hannawi et al. also reported similar decrease in compressive strength. Akcaozoglu reported the compressive strength of modified mortar (containing PET and sand as aggregate) as high as 27 MPa. On another study, Hannawi et al. found that 10%, 20% and 50% replacement of sand by PET, decreased compressive strength by 4%, 22% and 90% respectively. Our study also indicates that with the replacement of sand with PET by 3.3% and 23.3%, the compressive strength of the modified mortars decreases by 62% and 69% respectively. That means, the compressive strength of modified mortar containing PET decreases with increasing amount of PET. However, in our experiment we found the compressive strength more lower than Akcaozoglu and Hannawi et al.. The probable reason, as mentioned earlier, could be; the PET aggregate being untreated as well as poor bonding/ cementation, which might be attributed to presence of significant amount of heterogeneous dust particles adhering to the PET aggregates.[3];[12];[2].

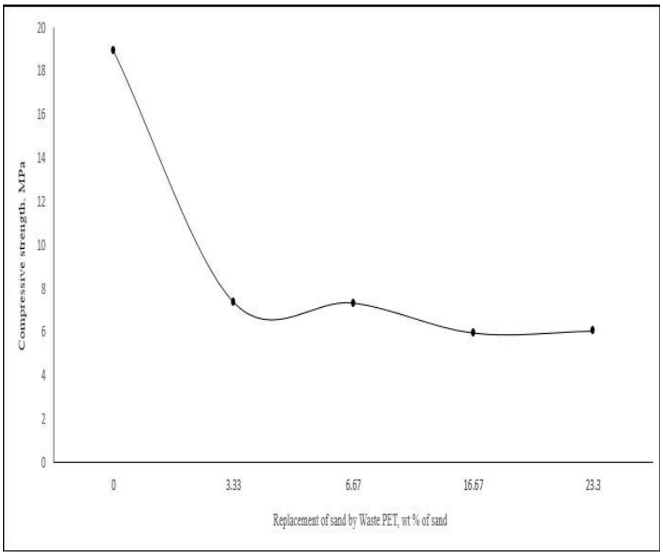

Fig. 2 Compressive Strength as a function of replacement of sand by waste PET, wt % of Sand

3.2 Water sorption

Effect of PET fillers in the composition of mortar on water sorption properties is presented in the Figure 3. The figure 3 shows that inclusion of waste PET fillers in the mortar composition results initially increase in water absorption percentage of the test specimens. Water absorbed by sample without PET was the minimum of 3.5%. Followed by, a 9% in sample U1 (3.33% of sand replacement by PET), 9.5% in sample U2 (6.67% of sand replacement by PET), 11% in sample U5 (16.67% of sand replacement by PET) and 13% in sample U7 (23.33% of sand replacement by PET). The abrupt change observed in U2 might be the cause of slight over-compaction.

The increase in water absorption can be explained by increased amount of porosity. Samples containing increased amount of air voids let through increased amount of water compared to samples containing lower amount of voids.

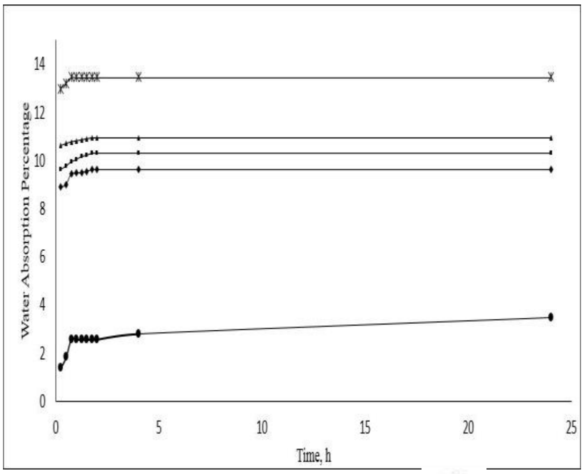

Fig. 3 Water sorption kinetics of conventional mortar (composition: Portland cement, sand, PET at the ratio of 1:3:0, modified mortar (composition: Portland cement, sand, PET at the ratio of 1:2.9:0.1, modified mortar (composition: Portland cement, sand, PET at the ratio of 1:2.8:0.2, modified mortar (composition: Portland cement, sand, PET at the ratio of 1:2.5:0.5 and modified mortar (composition: Portland cement, sand, PET at the ratio of 1:2.3:0.7

3.3 Porosity

Among the other physical properties of cement mortar, porosity has also been studied. Table 3 shows the porosity (in percentage) of the mortar samples. The results are self-explanatory. The porosity gradually increased from 16.78% in the sample contains lowest percentage of PET (3.33wt% of sand) to 20% in the sample containing highest percentage PET (23.3 wt % of sand). The likely reason could be, the increased amount of PET flakes resulted in poor bonding and caused air voids to adhere to their vicinity.

This attribute of the material represents it's potential as an insulating material. The air trapped in the pores of the mortar would make resist heat conduction and thus will ensure thermal comfort. Surprisingly the increased porosity does not seem to cause significant decline in compressive strength, which indicates increased use of PET as well as greater porosity has no further adverse effect on the compressive strength of the material.

Table 3. Porosity of different types of mortar specimens

Sample	Porosity
Portland cement mortar	23.0%
Modified mortar containing 3.33 wt% PET	16.8%
Modified mortar containing 6.67 wt% PET	17.0%
Modified mortar containing 16.67 wt% PET	18.5%
Modified mortar containing 23.3 wt% PET	20.0%

4. Conclusion

The results indicate a high level of uncertainty in the behavior of PET induced cement mortar. When compared with other studies, this study reveals remarkable deviation in behavior of mortar samples. The high amount of fluctuations in PET aggregate size and shape could be a possible reason. The physical properties of sands used could also be a reason. Last but not the least, cement that are used could vary significantly, which results in diversity of bonding behavior. Some studies have found that PET induced cement mortar samples fall under structural light-weight material's quota. But due to the level of diversity in the behavior of mortars, caused probably by above mentioned reasons, the use of PET aggregates in important (non- load bearing) structural applications cannot be recommended. Thus, these compositions of PET in mortar can only be used for non-structural applications. Yet, PET possesses thermal insulation properties therefore inclusion of PET in masonry mortar may improve the thermal property of this material. Thus utilization of PET as partial replacement in masonry mortar have high prospect in the field of construction practices. Despite, the fact that existing studies has already explored a remarkable number of properties of this material, there is still scope for studies of behavior like fire resistance, sound insulation and PET aggregates in finer form. PET flakes now a day have good export value and are recognized export quality products. As this industry grows, the discarded smaller sized PET aggregates might become a serious concern, for they need costly treatment. Successful use of these discarded PET particles in construction industry could be a brilliant solution to this immerging crisis. Hence the necessity of further study to standardize its application in building construction practices

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