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Effect of Recycled Polystyrene Polymer in Concrete as a Coarse Aggregate

Md. Golam Kibria*, Osikur Rahaman, Md. Ferdous Wahid and Abdus Salam

The research reports on experimental investigations of polystyrene polymer can be used as an alternative of coarse aggregate in partial replacement of brick aggregate. The use of polystyrene polymer is increasing day by day with economic growth. However, this polystyrene polymer is not decomposed and causes a serious environmental problem by increasing as a solid waste. Therefore, an alternative process of recycling such materials as a coarse aggregate by partial use in concrete may reduce solid waste and made lightweight concrete. The conventional coarse aggregate in concrete was replaced with 0%, 5%, 10%, 15%, 20%, 30%, and 40% (by volume) of EPS and the ordinary Portland cement was replaced with fly ash as the same percentage. A mix proportion of 1:1.68:2.49 with water/cement ratio ranges from 0.35 - 0.56 were used and polystyrene granules were cast, and specimens were tested at 7, 14 and 28 days after natural curing. Test results exhibited that the compressive strength, splitting tensile strength and unit weight gradually decreases with the increase of recycled polymer aggregate and the water absorption decreased with the higher replacement of recycled polymer aggregate.

Keyword: Polystyrene Polymer waste, Recycled, Lightweight, Compressive strength

1. Introduction

Recently, safe disposal of post-consumer waste polymers has become a serious problem due to its non biodegradable properties and large application. Plastic waste represent 11.1% from all municipal solid waste generated each year in the US (2001 US EPA characterization of municipal solid waste). Due to user friendly properties such as durabilities, low density, strength and low cost etc. the application of polymer waste annually has been growing steadily. Along with more and more plastic wastes being disposed into the environment, the problems of disposal must be overcome. Being a very lightweight materials, it is not feasible to use waste polymers for land filling, which require

Md. Golam Kibria*, Lecturer, Department of Civil Engineering, Sonargaon University (SU), Dhaka, e-mail: shamimceng@gmail.com,Cell: +8801552310700

Osikur Rahaman, Graduate, Department of civil Engineering, European University of Bangladesh, Dhaka, e-mail: osikurrahaman03@gmail.com

Md. Ferdous Wahid, Lecturer, Department of Civil Engineering, Sonargaon University (SU), Dhaka, e-mail: mdfwahid@gmail.com

Dr. Abdus Salam, Professor, Department of Civil Engineering, Dhaka University of Engineering & Technology, Gazipur, e-mail: masalam@duet.ac.bd

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huge land space area. In contact with waste plastics, the land loses its fertility which also led to environmental pollution. Incineration is the another disposal method, but locating sites for new incineration facilities has led to considerable air pollution. In fact, the ecological disposal of plastic products is presntly of great concern (Bao et al., 1995). In this consequence, big attention is being focused worldwide on the environment and safeguarding the natural resources through recycling of waste polymer materials in the recent years. A lot of reseaerch works concerning use of the several kinds of polymer have been published in the last few years. Many reseachers have been extended to study verious aspects of polymer wastes. Utilization of waste plastic materials in concrete as aggregates is considerable as the most feasible utilization to overcome the problems regarding safe disposal of increasingly huge amount of waste plastic materials. The addition of waste apart from environmental benefit aslo produces good effect on the properties of concrete (Yadav, 2008).

2. Literature Review

Extensive research work concerning ulilization of waste polymer as coarse aggregates in concrete has been conducted over the world in last decades, and many research articles have been published. Bignozzi et al. (2000) formulated polymer mortars using powdered rubber, tire rubber, tire fibers, and milled electrical cable waste as recycled filler and studied the dynamic mechanical behavior of the mortar. Ghaly and Gill (2004) utilized partial replacement of coarse aggregate by plastic chips in concrete mixtures. This study was conducted using replacement of plastic coarse aggregates by 5, 10 and 15% mass of coarse aggregates. It revealed that the increase in plastic aggregate content in the mix decreases the compressive strength and modulus of elasticity of the concrete. A relationship between plastic content and modulus of elasticity of concrete was also developed in the study. In another study by Babu and Babu, (2004) the effect of expanded polystyrene (EPS) on the compressive and splitting tensile strength, density and chloride permeability of concrete was reported in their study. It is found that both the compressive and splitting tensile strength decreases with the EPS content in the composition of concrete. The study was made using EPS up to 95% by volume of the sample. The chloride permeability of these concretes was seen to be 50–65% lower compared to that of normal concretes. The corrosion rates of the modified concretes were also lower compared to the normal concretes. It is reported that the densities were ranged from 0% to 95% of the replacements.

In the following year, Choi et al. (2005) incorporated PET bottles chips as fine aggregates in concrete replacing sand, and studied the effects of recycled PET on the compressive, splitting tensile and modulus of elasticity of concrete.With the replacement of sand by recycled PET by 0%, 25%, 50% and 75% by volume of sand, it is found that both the compressive and splitting tensile strength and modulus of elasticity of the modified concrete decreases with increase in PET aggregate content.An extensive study on energy-efficiency of buildings using recycled plastic aggregates in concrete was conducted by Elzafraney et al.(2005). Two buildings were designed and constructed using recycled (high-density polyethylene, polyvinyl chloride, and polypropylene) content concreteand found that the inclusion of recycled aggregates in the concrete of the buildings under investigation has been shown to be advantageous from an energy point of view. Results showed that dynamic stability of asphalt mixture with plastics aggregate which softened at the mixing temperature was higher than the conventional mixture.

Kumar and Prakash (2006) prepared concrete specimens using various waste plastic content replacing conventional aggregates, and investigated the effect of waste plastic on the mechanical properties. It is reported that with the inclusion of optimum amount of waste plastic (5% of aggregate), the compressivestrength of the modified concrete increases by 20% more than that of unmodified concrete. A similar type of work has been conducted by Marzouk et al. (2007). Higher volume fractions of sand, compared to Chi et al., from 2 to100% were replaced by granulatd recycled plastic bottle in composition of concrete, and it is found that replacement of sand by granulated PET at a level below 50% by volume affected both compressive and flexural strength. Similarly, the modulus of elasticity of the modified concrete was also decreased with the increase in plastic content in the composition. The author finally recommended that plastic bottle shredded in to small particle may successfully be used replacing fine aggregates in concrete.Another investigation was carried out by Batayneh et al. (2007) on the effect of recycled unknown waste plastic materials as partially replacement of fine aggregate on the compressive, splitting strength of the concrete.It is found that the addition of plastic lead to reduction in the strengths of concrete. A sharp reduction in compressive strength of up to 72% of original strength was reported for a 20 % replacement of fine aggregates by ground plastic in concrete mixes. Similar behavior was observed in the splitting tensilestrength. The author finally recommended that concrete with recycled plastic materials of lower strength can be used in certain civil engineering applications, especially in non-structural applications, where lower strength up to 25MPa is required. It is also claimed that the inclusion of waste plastic contributes to reduction in cost of using non-structural concrete.

Siddique et al. (2008) reviewed investigation on the effect of recycled plastic on the properties of fresh and hardened concrete. Reduction in strength and abrasion resistance was found with increasing plastic reinforcement content in the concrete. The decrease in airpermeability was also found with the plastic reinforcement in concrete. A feasibility of utilization of e-plastic waste (plastic materials of electronic appliances) as a partial replacement ofcoarse aggregates in concrete was reported by Lakshmi and Nagan, (2010). The study is made using e- plastic waste up to 30% volume replacing coarse aggregates. The study revealed that up to 20%volume replacement of aggregate by e-waste improved the compressive and splitting tensile strength.

However, it is observed that most of the previous research works were conducted on recycled stone aggregates and the performance of this stones were tested to know the feasibility of using it into concrete. But, this study was carried out by using locally available brick aggregate which is widely used aggregate in our country Bangladesh. This study aims to know the mechanical properties of polymer aggregate concrete, and to compare the different properties of waste polymer concrete with normal concrete.

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3. Constituents Materials

Brick aggregates andexpanded polystyrene (EPS) were used as coarse aggregates in this study.EPS is a plastic foam material that has certain desirable properties because of its structure. It is extraordinarily light and buoyant, and a good insulator against heat and sound. It can be used as a building material or a design element, and can be molded into many shapes for a number of household uses as well.It is inert in nature and therefore does not result in any chemical reactions. Since it will not appeal to any pests, it can be used easily in the construction industry. It is durable, strong as well as lightweight and can be used as insulated panel systems for facades, walls, roofs and floors in buildings, as flotation material in the construction of marinas and pontoons and as a lightweight fill in road and railway construction. In most cases, EPS foam is white and is composed of small, interconnected beads.

In ths study locally available Sylhet sand was used as fine aggreagte which fineness midulous was found as 2.59. Ordinary portland composite cement was used as binding materials. The specific gravity of cement used was 3.15. Drinking water was used in mixing of concrete and for good hydration of cement. Also fly ash was used in this study because good quality fly ash generally improves workability or at least produces the same workability with less water. The reduction in water leads to improve strength. We collected the fly ash from fresh cement factory for this study. Properly cured concrete made with fly ash creates a denser product because the size of the pores are reduced. This increases strength and reduces permeability. The properties of the constituents materials are tabulated in table 1.

Fig.1: Recycled EPS beeds

Fig 2: Mixing of EPS beeds with brick chips

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Table 1: Properties of the materials

Properties	Sand	Brick
Fineness modulus	2.59	7.41
Water absorption capacity (%)	2.01	1.0
Specific gravity	2.62	2.60
Dry rodded unit weight (kg/m^3)		1532

4. Preparation and Testing of Specimens

Most of the available mix design methods are based on empirical relationships, charts and graphs developed from extensive experimental investigations. In this study ACI mix design method has been used and the mixproportion was found as 1:2.66:3.90. The best method of water curing is immersion of specimens in water because it satisfies all the requirements of curing namely promotion of hydration, elimination of shrinkage and absorption of the heat of hydration. The test specimens were prepared with 0%, 10%, 20%, 30%, and 40% of EPS as a replacement of brick aggregate. In addition to this cement was also replaced byfly ash as the same percentage. The prepared specimens were submerged into water for 28 days and prepared for testing.

The compressive strength test was conducted according to ASTM C 39/C 39M using Ø100 mm × 150 H mm cylinder specimens and 150 mm × 150 mm cube specimens. Total 15 cylindrical and 15 cubic specimens were prepared and tested for the compressive strength test. A Universal Testing Machine (UTM) with a load capacity of 3000 kN was used in the compression test with a loading rate of 2.4 kN/s. Split cylinder test was carried out by using 15 cylindrical specimens as per ASTM standard requirements of specification C 496 (2009) for cylinder by UTM. In addition, unit weight and water absoption capacity of the EPS containing concrete were also determined to compare with different percentage of EPS.

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(a) Cylindrical specimen (b) Cube specimen

Fig.3: Compressive strength test setup

5. Test Results

5.1 Compressive strength

The compressive strengths of concrete were found from 3827.31 psi to 955.00 psi for replacement of brick chips by recycled EPS 0% and 40% respectively. The compressive strength of controll and modified concrete specimens with various contents of polymeric aggregates i.e. EPS shows that compressive strength of modified concrete decreases withthe increase of recycled polymer filler content. The reduction in compressive strength indicates poor bond between the cement and polymer materials.

Kumar and Prakash (2006) reported two times higher compressive strength of concrete using 5 wt% of waste plastic materials based on total weight of cement and sand. Lakshmi and Nagan (2010) also reported improvement in compressive strength using up to 20 volume % of e-plastic waste as aggregates in concrete. To the contrary, Yadav (2008) reported decrease in the compressive strength of concrete with the inclusion of waste plastics in concrete. Similarly, Al-Manaseer and Dalal (1997) reported 34%, 51% and 67% reduction in compressive strength of the concrete specimens containing 10%, 30% and 50 wt% plastic aggregates. Soroushian et al. (2003-2007) also reported the reduction in compressive strength with the inclusion of recycled plastic. However, in this work, as seen from the figure 4, the inclusion of recycled polymer (EPS) decreases the compressive strength of concrete. In fact, reduction in strength is justified, as mechanical strength of concrete specimens depend on mechanical properties of aggregate, size and shape of aggregate, and binding materials. In this case, recycled polymeric aggregates have lower strength properties, bonding between Portland cement network and polymeric aggregate is also weak. Thus, compressive strength of concrete specimen decreases with the inclusion of polymeric aggregate in its composition.

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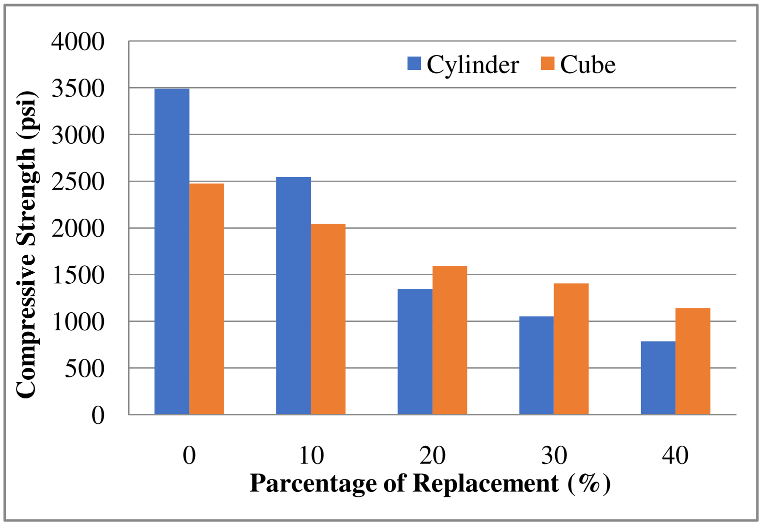

Fig. 4: Compressive strength of concrete

5.2 Splitting Tensile Strength

The average splitting tensile strengths of concretes are presented in figure 5. In this study, the 28 dayssplitting tensile strengths ranged from 336.93 psi to 83.08 psi for replacement of brick chips by recycled polymer aggregate 0% and 40% respectively. Lakshmi and Nagan (2010) reported that up to 20% replacement of coarse aggregate by e-plastic waste improved the tensile strength, and 25% replacement of aggregates reduced splitting tensile about 50%. To the contrary, in this study it isfound that tensile strength always decreases with the polymer aggregate content. Reduction in tensile strength can be explained similarly, as polymeric aggregates influences in case of reduction in compressive strength.

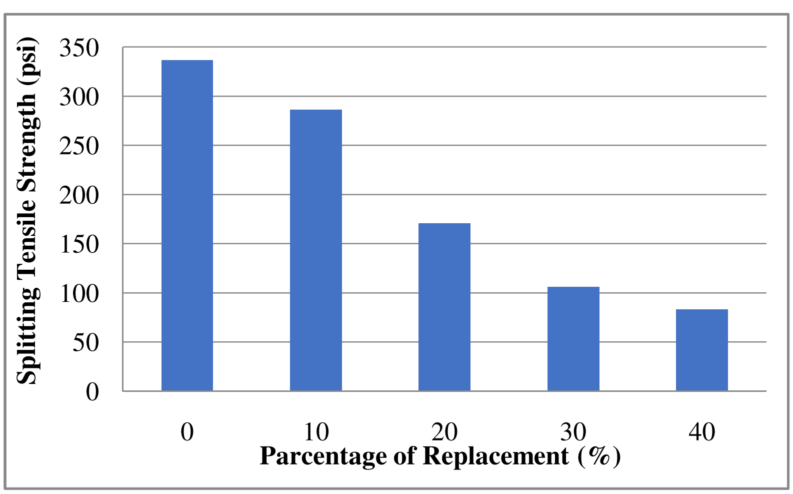

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Fig. 5: Splitting tensile strength of concrete

5.3 Unit Weight

The average unit weight of concretes is presented in figure 6. In this study, the 28 days unit weight ranged from 2469.0 psi to 1573.0 psi for replacement of brick chips by recycled polymer aggregate 0%and 40% respectively.

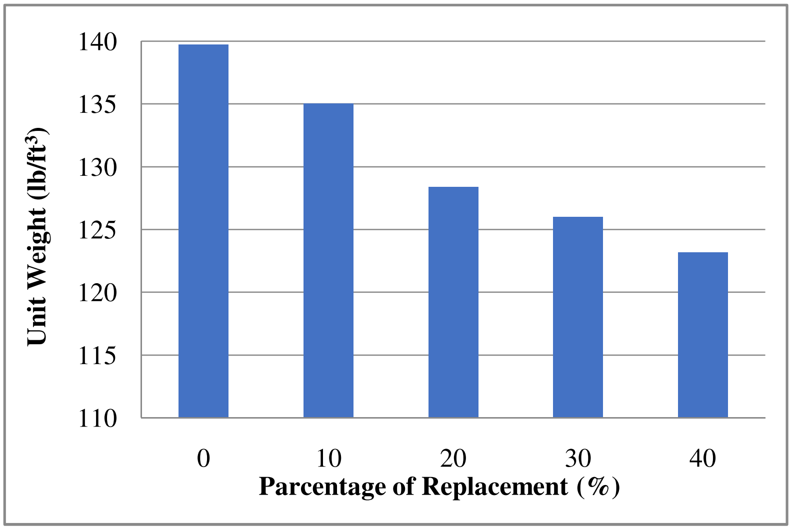

Fig. 6: Unit Weight of concrete

6. Conclusions

The following conclusions are made based on above study:

i. The compressive strength of concrete made with 10% to 40% recycled polymer aggregate were found about 35% to 77% lower than that of Control concrete. According to ACI code recommendation, minimum compressive strength of concrete for structural application should be 2500 psi. In this study we observed that, 10% replacement of coarse aggregate by EPS satisfies this criteria.
ii. In case of the splitting tensile strength of concrete made by recycled polymer these value were found about 15% to 75% lower than control concrete.
iii. The unit weight of same concrete was about 3% to 11% lower than that of control concrete.
iv. Since the compressive strength is the vital property of concrete, so considering this property 10% replacement of brick aggregate by EPS can be used for structural application. However, other percentages of replacement can be used as the roof of auditorium or cinema hall as like big span structure for lower weight. It can also be used as the footpath at park or road side where only the walking load is applicable.

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