Effect of Plastic Waste as Partial Replacement of Fine Aggregate in Concrete and Cost Analysis

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***Abstract* – Advancements in technology enhance not only human comforts but also damage the environment. Numerous waste materials are generated from the process of manufacturing, industry services and municipal solid wastes. The rapid increase in awareness about the environment has greatly contributed to the concerns related with disposal of the wastes. The management of solid wastes is one of the substantial environmental concerns in the world. With the decreasing space for creation of landfills and due to increments in costs, waste utilization has become a viable alternative to disposal of wastes. Extensive research is being done to ascertain the utilization of waste products in concrete. The use of waste materials in concrete not only makes it cost effective, but also helps with the problem of disposal [1]. The reuse of the waste material is considered to be the best alternative solution to the problem of disposal.**

Waste plastic bottles are major cause of solid waste disposal. Polyethylene Terephthalate (PET, PETE or polyester) is commonly used for carbonated beverage and water containers (bottles). This is of concern to the environment, waste plastic bottles are difficult to degrade and involve extensive processes for both recycling and reuse. The construction industry these days is in need of finding cost effective and reliable materials for increasing the strength of concrete. The scope of this project is to ascertain ability of using the waste PET bottles as a partial replacement agent for fine aggregate in concrete with 1%, 2% and 3% replacement of PET bottle fibers for fine aggregate are produced and compared against control mix with no replacement [2].

Keywords: PET, flakes, fibers, waste

I. INTRODUCTION

Plastics have become an inseparable and integral part of our lives. The amount of plastics consumed annually has been growing steadily. In India approximately 40 million tons of solid waste is produced annually. This is continuously increasing at the rate of 1.5 to 2% every year [3]. Plastics constitute 12.3% of total waste produced most of which is from discarded water bottles. The PET bottles cannot be just disposed of by dumping or burning, as they can produce uncontrolled fire or contaminate the soil and vegetation. Its low density, high strength, fabrication capabilities, user friendly designs, long life, light weight, and more importantly low cost are the factors behind such phenomenal growth. Plastics have been used in automotive and industrial applications, packaging, medical delivery systems, other healthcare applications, land/soil conservation, preservation and distribution of food, communication materials, security systems, and some other uses. With such large and varying applications, plastics dominantly contribute to an ever increasing volume in the solid waste stream.

In 2007, it is reported a world's annual consumption of PET drink covers of approximately 10 million tons, which presents perhaps 250 million bottles. This number grows about up to 15% every year. On the other hand, the number of recycled or returned bottles is very low. The empty PET packaging is generally discarded by the consumer after use and becomes PET waste (WPET). The major problems that this level of waste production generates initially entail storage and elimination. Hence an attempt on the utilization of waste Poly-ethylene Terephthalate (PET) bottle granules as fine aggregate is done and its mechanical behaviour is investigated.

II. OBJECTIVE

The main objectives of this research proposal are to evaluate the possibility of using PET flakes. The following needed to be accessed

- Partial substitute for the fine aggregate (sand) in concrete components.
- To determine the structural and mechanical behaviour of such replaced concrete components.
- To determine the optimum percentage of plastic fibre which gives more strength when compared to control concrete.
- To determine the utilisation of waste plastic bottles.
- Cost analysis.

III. NEED FOR RESEARCH

There are two primary problems this project addresses. First is the shortage of river sand to be used as fine aggregate and second is the problem of disposal of waste plastic bottles. The crackdown on the illegal sand mafia in Uttar Pradesh affected the construction industry severely. The effects were so widespread that several large scale projects came to a standstill. The construction industry in India faced a practical slowdown situation. Studies then showed that of the entire construction industry in India 78% of the construction projects were based on illegal sand. The construction industry was now faced with the issue of finding viable and practical alternatives to river sand as fine aggregates.

In today's age a very large number of waste plastic bottles are generated in each city. The plastic bottles are not easy to dispose off as they are non-biodegradable and chemical treatment requires a large amount of chemical process and energy and hence is not cost effective. The municipal corporations have an elaborate waste segregation system through which the segregate wastes and the non-biodegradable wastes are used to make landfills. The use of plastics in landfills is harmful as under high pressure these generate harmful compounds which leach into the ground and contaminate the ground water. Another drawback of using plastics in the landfills is that they create an impermeable layer over the ground surface, which gets filled with water in the rainy season. This causes several problems like water stagnation, hindrance in ground water replenishment, compromise in the integrity of the landfill, etc. This presents an immediate need to find a pragmatic way to dispose off waste plastic bottles.

IV. LITERATURE REVIEW

Banthia and Trottier (1995) stated that the enhanced performance of fiber reinforced concrete over its unreinforced counterpart comes from its improved strength to absorb energy during fracture whereas a plain unreinforced matrix fails as a brittle matter at all occurrences of cracking stress. This energy-absorption attribute of fiber reinforced concrete is often termed as ''toughness''. Considerable flexural strength can be obtained with reinforced polymer concrete (PC) using unsaturated polyester resins based on recycled polyethylene terephthalate (PET) [4]. Soroushian et al. (1995) stated that polypropylene is used only as synthetic fibers to increase the toughness of concrete. Hınıslıog˘lu and Ag˘ar (2004) investigated the possibility to use various plastic wastes containing high density polyethylene (HDPE) as polymer additives to asphalt concrete. The results indicate that waste HDPE-modified bituminous binders provide better resistance against permanent deformations due to their high stability and high Marshal Quotient and it also contributes to the recycling of plastic wastes as well as in protection of the environment. Rebeiz (1995) reported that compressive strength increased with age and decreased with the increase in temperature when recycled polyethylene terephthalate (PET) was used.Al-Manaseer and Dalal (1997) investigated the effects of plastic aggregates on the modulus of elasticity of concrete. They concluded that the modulus of elasticity decreased with the increase in plastic aggregate content. Jo et al. (2006) investigated the mechanical properties such as compressive strength and flexural strength of polymer concrete using an unsaturated polyester resin based on recycled PET which contributes to reducing the cost of the material and saving energy. Pezzi et al. (2006) used plastic material particles as aggregate in concrete and evaluated the physical, mechanical and chemical properties. The results proved that the addition of polymeric materials in fractions 6 - 10% in volume inside of a cement matrix does not imply a significant variation of the concrete mechanical features [5]. Within the research area of adding PET to concrete Rebeiz et al. (1991), Silva et al. (2005) and Choi et al. (2005), investigated the use of recycled polyethylene terephthalate as light aggregate.Marzouk (2007) studied the innovative use of consumed plastic bottle waste as sand-substitution aggregate within composite materials for building application. Polyethylene terephthalate (PET) were used as partial and complete substitutes for sand in concrete composites. Sand was substituted for 2% to 100% by volume with the same volume of granulated PET aggregates for different sizes.

In this paper, the attention was focused on the use of PET flakes incorporated as aggregate in concrete in partial substitution of an equivalent weight of fine aggregate that is sand. This research also takes into purview the cost effectiveness of the replacements.

V. EXPERIMENTAL ARRANGEMENT

A. *Methodology*

- To procure the PET bottles needed for research
- To obtain the equipment needed
- Shredding of the waste bottles into flakes
- Granulating the pieces to smaller size as that of sand
- Casting and curing of the basic test specimens (cubes, cylinders, prisms) for determination of strength
- Casting and curing of the structural elements.
- To test the structural models (with various percentage of plastic waste) for the results

B. *Experimental Plan*

In this project, 1%, 2% and 3% of traditional fine aggregate is replaced for M40 grade concrete. The replacement percentage is by weight of total fine aggregate content derived from the mixture proportioned. Cube specimens of size 100 mm x 100 mm × 100 mm, cylinder specimens of 150 mm diameter and 300 mm height and prism specimens of size 100 mm × 100 mm × 500 mm to be casted for different proportions with PET bottles (grounded) and compared against a control mixture. The tests to be performed on hardened concrete after 7, 14, 28 and 56 days of curing are compression test, flexural test and split tensile test.

VI. RESULTS AND DISCUSSIONS

A. *Strength Results*

TABLE I: Compressive Strength

	0% (MPa)	1% (MPa)	2% (MPa)	3% (MPa)
7 Days	29	28.8	28.7	28.4
28 Days	42.02	41.7	40.54	36.39
56 Days	49.89	49.17	46.68	41.21

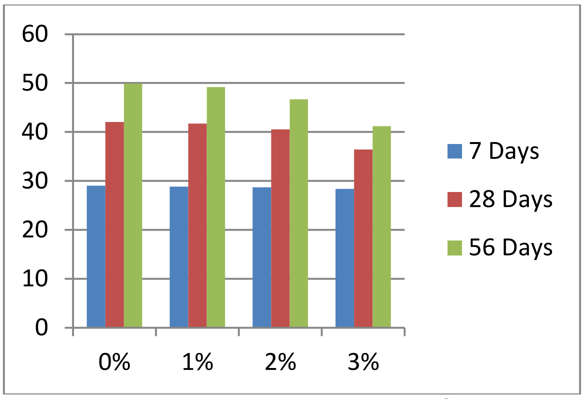

Fig. I: Compressive Strength

TABLE II: Flexural Strength

	0% (MPa)	1% (MPa)	2% (MPa)	3% (MPa)
7 Days	6.32	6.18	5.95	5.72
28 Days	6.75	6.5	6.41	6.2
56 Days	7.02	6.76	6.61	6.43

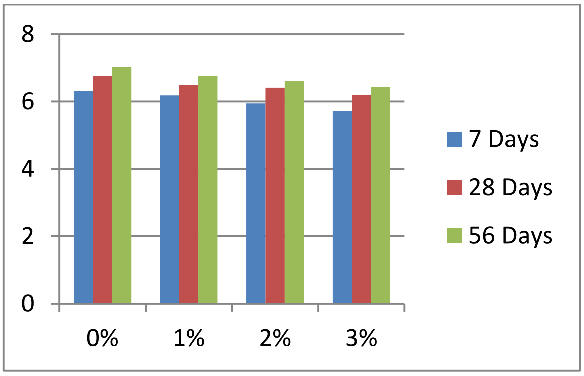

Fig. II: Flexural Strength

TABLE III: Split Tensile Strength

	0% (MPa)	**1% (MPa)**	**2% (MPa)**	**3% (MPa)**
7 Days	2.61	2.52	2.43	2.29
28 Days	3.21	3.11	3.02	2.82
56 Days	3.71	3.58	3.4	3.13

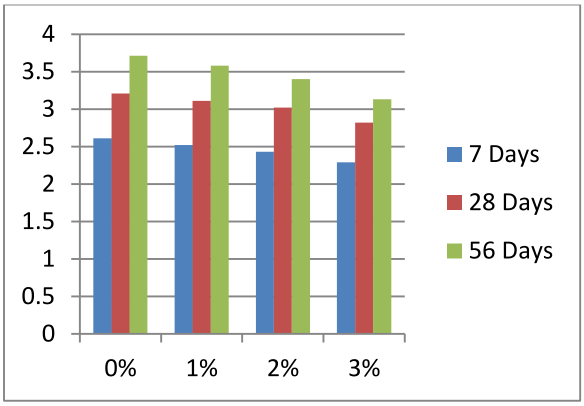

Fig. III: Split Tensile Strength

B. Cost Analysis

It was noted that there was a marginal reduction in the strength of the concrete upon replacement of sand with different percentages of shredded plastic. It was thus decided that an analysis of the cost efficiency and the waste reduction be done to measure the benefits in terms of cost and reduction of waste plastic.

TABLE IV: Standard Cost of materials

Materials	Quantity	Price (Rupee)
Water	1000 litres	400
Cement	50 Kg	340
Sand	1 Cu. Feet	55
Coarse Aggregate	1 Cu. Feet	80
Shredded Plastic Bottles	-	0

The cost of PET bottle waste varies with the season. In the peak season the cost goes up to 1 Rs/bottle whereas during off season it costs 2 Rs/ kg. The waste bottles for this project have been provided free of cost by the disposable unit of Municipal Corporation of the city. This is so because most municipal corporations use bottles for landfill purposes and they would give away the bottles readily.

TABLE V: Cost of materials per m^3

Materials	Quantity	Price (Rupee)
Water	1 m^3	400
Cement	1 m^3	21420
Sand	1 m^3	1942.30667
Coarse Aggregate	1 m^3	2825.1733
Overall Concrete	1 m^3	4773.12

Hence overall cost of 1 m^3 of concrete = Rs 4773.12

Since we are not bringing about any changes in the rest of the materials except for the fine aggregate, we will be studying the cost saving only in terms of the fine aggregate.

TABLE VI: Cost savings in sand per m^3

Cost savings for	Reduction in sand volume per m^3	Cost saving per m^3 (Rupee)
1% replacement	0.00243248	4.7246
2% replacement	0.00486496	9.449
3% replacement	0.00729744	14.1738

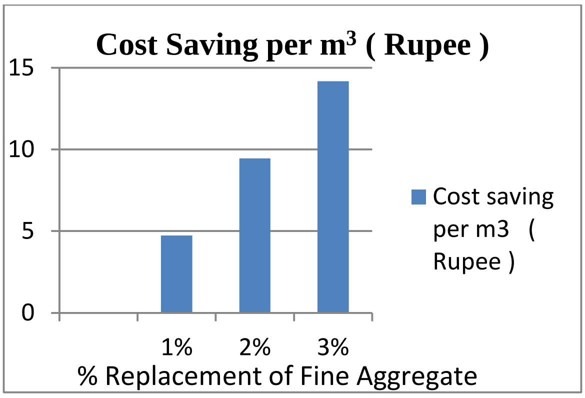

Fig. IV: Cost savings for different proportions

Considering the cost savings and strength reduction, we have decided on an optimum percentage of replacement of fine aggregate by shredded plastic flakes. We came to a conclusion that a 2% replacement of fine aggregate gives lesser reduction in strength and gives adequate cost savings of Rs 9.5 per cubic meter of concrete.

For a project like the Hoover Dam in which about 3.4 million m^3 of concrete is used, the cost savings could be phenomenal.

C. *Waste Reduction*

PET (poly ethylene terephthalate) has a very low density and thus occupies large volume for a given weight. Hence it is a very polluting substance as it is non-biodegradable and covers a large volume and a large surface area. If large quantities of plastic are utilized in building construction, it would be exceedingly beneficial as the plastic waste openly exposed to the environment will be greatly reduced.

Shredded plastic obtained from 1 PET bottle (500 ml) = 10 grams

No of bottles required to make 1 kg of Shredded plastic material = 100

TABLE VI: Waste reduction in PET bottles per m^3

PET bottles replacement	Mass of plastic per m^3 (Kg)	No of bottles required per m^3
1%	6.6649	6.6649 X 100 = 666.49
2%	13.32	13.32 X 100 = 1332
3%	19.9947	19.9947 X 100 = 1999.47

Thus even at such small percentage of replacement the No. of waste plastic bottles being utilized is considerably large. If this technique is employed practically even in small projects, it would have the capacity to successfully utilize the daily production of waste plastic bottles of a city.

Larger projects like dams would have the ability to utilize the wastes from several metropolitan cities, for a considerable duration.

CONCLUSION

It was noted that the compressive strength decreased up to 2% replacement of the fine aggregate with PET bottle flakes and it drastically decreased for 3% replacement. Hence replacement of fine aggregate with 2% replacement will be reasonable. It was noted that the flexural strength decreased up to 2% replacement of the fine aggregate with PET bottle fibres and it gradually decreased for 3% replacement. Hence replacement of fine aggregate with 2% replacement will be reasonable. It was noted that the split tensile strength decreased up to 2% replacement of the fine aggregate with PET bottle flakes and it drastically decreased for 3% replacement. Hence, the replacement of the fine aggregate with 2% replacement will be reasonable with high split tensile strength compared to the other specimens casted and tested. Hence, the replacement of the fine aggregate with 2% of PET bottle flakes will be much more reasonable than other replacement percentages like 1% and 3% as the compression, flexural and split tensile strength reduces drastically. It is concluded that a 2% replacement of fine aggregate gives lesser reduction in strength and gives adequate cost savings of Rs 9.5 per cubic meter of concrete. The concrete with PET fibres reduced the weight of concrete and thus if mortar with plastic fibres can be made into light weight concrete based on unit weight.

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