Polyethylene Terephthalate (PET) Waste as Building Solution

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***Abstract*—T**his paper presents the work on synthetic fiber Polyethene terephthalate (PET) as alternative construction entity. As plastic is non biodegradable, its disposal has been a problem. Recently, PET fibers were proposed to be used as either reinforcement in concretes or being casted as blocks. And recent studies show that they can be accepted as successful building materials. Although PET fiber reinforced concrete offer less compression strength and flexural rigidity than conventional concrete but it offers high ductility thereby increasing deforming capability of the concrete. Also, it reduces the density of the reinforced concrete thus aiding in light weight materials production. This paper also presents the study on some other innovative ideas like PET panels and mattress or direct use of PET bottles for construction of non load bearing walls with suitable fillers. The solution offered in the paper is one of the answers to long standing menace of waste disposal.

***Keywords*— Waste** PET aggregate, light weight concrete, structural properties, Bottle house , PET panels

I. Introduction

THE problem of recycling waste materials will remain one of the problems which will continue to plague the society in the near future. Therefore it is necessary find practical and imaginative solutions to the reuse of the waste. With the less available of space for land filling and due to ever increasing price, the focus is towards reuse of waste rather than its disposal .Plastics are widely used due to their characteristics like versatility, lightness, hardness, chemical resistance etc and therefore contribute most to ever increasing solid volume waste. The growth of the world plastic industry has been tremendous, from a little over 3 million tons in 1955 to 30 million tons presently (Jain et al., 1977). Among plastic, Polyethene forms the largest portion followed by Polyethylene terephthalate (PET) .The last is obtained in massive quantity from bottles most commonly used for packaging of beverages and drinking water. . India approximately produces 40 million tons of solid waste of which 12.3% is plastic which is discarded mainly in form of water bottles.PET is basically is a thermo plastic resin composed of phthalates[2].

In Table I most common uses of PET is given. But unfortunately recycling of PET is much lower than its usage and this gap is dramatically increasing forcing to innovate a method for high recycling of this material.

A possible application is to use PET fibres as short fiber reinforcement in structural [8] concrete .It can improve its tensile strength as concrete is good in compressive strength but lack tensile strength. The reduced strength is mainly due to presence of micro and macro cracks due to shrinkage of concrete[1]. PET comes in the category of low modulus synthetic fibres along with fibres of polyethene, nylon, polyester which are effective in controlling shrinkage cracking but is not so effective in increasing tensile strength[2]. Also, PET bottles are being experimented to act as non load bearing and partition walls in many parts of world. The present paper attempts to bring out various methods by which PET can be used as a successful building material alternative (As in concrete reinforcement or non load bearing and facade walls). The solution proposed solves the problem of its disposal and in the process, render new properties to the construction element itself (by reducing its weight).

TABLE I
USES OF VIRGIN AND RECYCLED PET

Name of plastic	Description	Use of virgin plastic	Use of recycled plastic
Polyethylene Terephthalate (PET)	Clear tough plastic, may be used as fiber, chemically inert, versatile	Soft drinks and water bottles, textile fibers, packaging	Soft drinks bottles, clear film for packing, carpet fibers, fleecy jackets, bottles for detergents and soaps

Basic Properties Of Recycled Pet: Density: 1380 kg/m^3 [8] Elastic Modulus: 3100 N/mm^2[2] Tensile strength: Around 450 MPa[10] Ultimate elongation: 11.2%

II. PET Fibres As Aggregate In Concrete

A. Literature Review

Yesilata et al. reported improved thermal insulation in concrete with shredded PET bottle and automobile tire waste. The adiabatic hot box technique was used for comparing thermal transmittance[11]. Choi et al. [6] researched the effects of Waste PET bottles on properties of concrete and it was observed that waste plastic can decrease the weight of

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conventional concrete by 2-6 %. But compressive strength was reduced by 33 % to that of normal concrete. Similarly the observations of Batayneh et al.[6] showed a decrease of compressive strength with an increase proportion of plastic content. With plastic proportion of 20% of sand, the compressive strength was reduced upto 70 % compared to that of normal concrete .Marzouk et al.[6] studied the effects of plastic wastes on the density and compressive strength of concrete. The study clearly showed that shredded PET fibres may be successfully used as sand substitution aggregate in concrete mortar. But it was also noticed that if PET aggregate exceeded 50% by volume of sand .The density and compressive strength of concrete were between 1000-2000kg/m3 and 5-60 MPa respectively. Studies have also shown that it is possible to use plastic fibers in mortars and concrete as binder thus substituting cements with various types of glycols and metal acetates to be used as catalysts. Saradhi et al.[3] show that fresh concrete with expanded plastic mixes show better flow values compared to normal concrete for similar water- cement ratio and also no segregation was observed in any mix even without additives. In a study done by Ghaly and Gills[3], coarse aggregates were partially replaced by plastic chips to observe the effect on density, water cement ratio and plastic content. And the result showed that introducing plastic fibres reduces density and gives superior deformational qualities making it use ful in harsh weather. Ismail and Al Hassani[3] used waste plastic as a partial replacement of sand and it gives good approach in reducing cost. So, the idea of using PET fibres is increasingly being researched due to the environmental problems it proposes and several studies are now based on using plastic as lightweight aggregate.

B. Case Study

In the study conducted; 0.5%, 1%, 2%, 4% & 6% of traditional fine aggregate was replaced for M25 grade concrete by the PET fibres. The materials used for the concrete are:-[5]

Cement: Ordinary Portland cement 53 grade.

Fine aggregate: River sand. Coarse aggregate: 20 mm - 60% and 12.5 mm - 40%. Plastic fibres: PET bottles. All the cast specimens were de-moulded after 24 hours and were cured in curing tank for a period of 7 to 28 days. They were taken for test such as compression test, split tensile strength test and flexure test and results were duly noted. It was observed that:

1. Bulk Density

The concrete with PET fibres reduces the weight (density) of concrete substantially and thus, mortar with plastic fibres can be made into light weight concrete based on unit weight. These can find application in non load bearing construction such as panels in façade. The reduction in bulk density was found to be directly proportional to plastic aggregate replacement and was attributed to low unit weight of plastic.

2. Compressive Strength

It was noticed that the compressive strength increased up to 2% replacement of the fine aggregate with PET bottle fibres and then decreased for 4% and 6% replacements as in figure a. Hence replacement of fine aggregate with 2% replacement will be reasonable [5]. So, in general for given w\c ratio, the use of plastics reduces compressive strength. But for a particular PET aggregate content, compressive strength decreased with w/c ratio. The effect of w/c ratio in strength development is not important in this case as plastic aggregate reduce the bond strength of concrete and sometime becomes the reason of its failure.

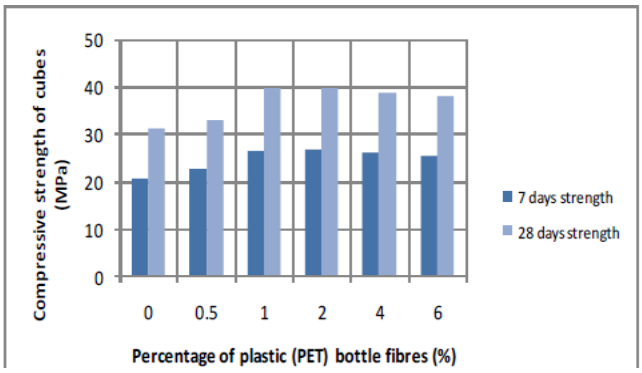

Fig. 1 Compressive strength vs Plastic fibers (%) [5]

3. Split Tensile Strength

It was observed that the split tensile strength gradually increased up to 2% replacement of the fine aggregate with PET bottle fibres and it decreased for 4% and 6% replacements as in figure b. 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.[5]

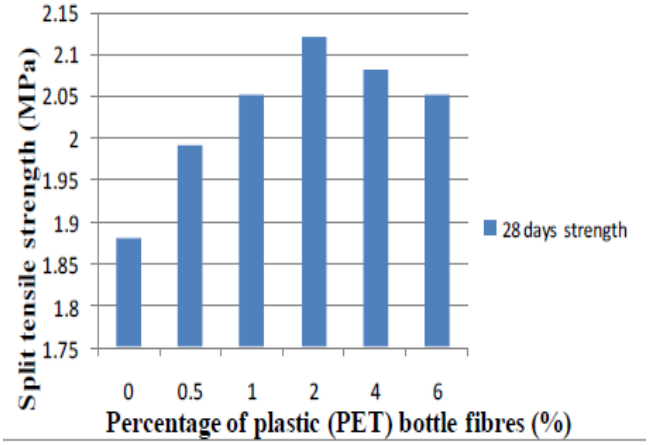

Fig.2 Split tensile strength vs Plastic fibres (%) [5]

So, in general for given w\c ratio, the use of plastics reduces tensile strength. Also for a given plastic aggregate content, splitting tensile was found to get reduced with increasing w\c ratio.

4. Flexural Strength

The flexural strength of samples with PET bottle fiber as fine aggregate increases gradually with the increase in the replacement percentage but it may decrease for further replacement percentage as it is somewhat same for the 4% and 6%[5] as represented in fig c.

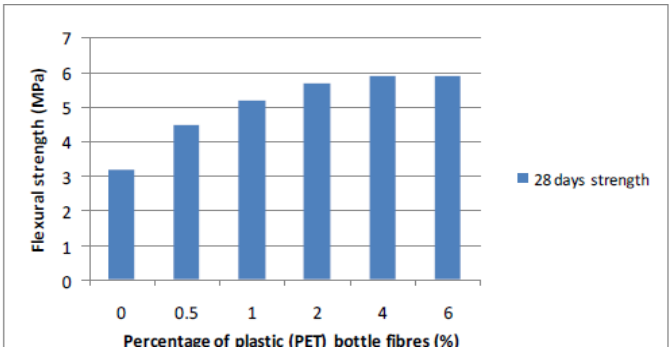

Fig.3 Flexural strength vs. plastic fibers (%)[5]

5. *Deformation Capacity*

Introducing PET makes concrete ductile thus increasing its ability to deform before failure [5]. So it makes it makes it useful in situation where it is subjected to harsh condition like expansion and contraction and regular wear and tear.

6. *Energy Consumption*

It has been shown that inclusion of recycled concrete is advantageous from energy point of view as it keep interior temperature cooler when outside is raised as compared to conventional concrete.

7. *Modulus Of Elasticity*

The value of modulus of elasticity decreased with raise in plastic aggregate content [5]. Also, increasing w/c ratio reduces modulus of elasticity.

Also plastics act as freeze thaw resistant aggregates increasing the concrete entities life. Toughness and Impact resistance was also increased [3] as compared to conventional concrete mixtures.

Also an amazing aspect was observed in the thermal conductivity of the reinforced concrete and an increase in thermal insulation was registered of the concrete [1].It was also found that it has comparable alkali resistant when used in normal concrete [3].Cracking due to drying shrinkage was delayed indicating bridging properties of PET fibers and delayed macro crack formation [9].

PET fibres can be used as partial or complete substitutes for sand in concrete. Various volume fractions of sand varying from 2% to 100% were substituted by the same volume for granulated plastic and various sizes of PET aggregates. They observed that if sand is substituted at a level below 50%[3] by volume with granulated PET whose upper granular limit is 5mm, then they can successfully act as sand-substitution aggregates. Although a small decrease in compressive strength was registered. Thus, they offer an attractive low cost material with comparable properties.

III. Application Of Pet Reinforced Concrete

A. *Application to mine construction*

As PET fiber had good mix ability and has satisfactory reinforcing quality, concrete (shotcrete) mixed with the PET fiber was installed at Hishikari Mine, Japan, operated by Sumitomo Metal Mining Co. Ltd.[10] Hishikari Mine is a gold mine located in Kagoshima Prefecture, which is one of Japan's leading gold-producing areas. It was sprayed on a gateway which was not giving satisfactory result with steel reinforcement.

B. *Pavement of narrow areas*

Passages in tunnels under construction, passages through underground structures, urban alleyways, and
bush roads are mostly narrow, winding, and steeply. It is important to apply fiber-reinforced concrete to the pavement of such narrow sections of road; however, steel fiber if used can puncture tires, and conventional fiber has workability concerns. Thus, it has not been used previously to pave narrow sections of road in Japan. So, PET-fiber-reinforced concrete to pave bush roads was used keeping in mind its easy workability. PET-fiber-reinforced concrete was applied to a bush road between Hayatogawa and Kanazawa, Kanagawa Prefecture, Japan[10].

IV. Pet Fibres In Concrete Block Production

Shredded PET were used as aggregate to produce concrete building blocks and with the alteration of mix ratios, compressive strengths varying from 6.89 N/mm^2 to 26.05N/mm^2 were[4] achieved for the blocks, which were moist cured for 7, 14 and 28 days. These values indicated that the blocks are useful for moderate (6.89-8.27 N/mm2) and structural light weight concrete (>17.23 N/mm2)[4] usage such as floors in high–rise buildings (to reduce support load requirements), and as thermal and sound insulation in walls and roof panels (Kosmatka/PCA).

The blocks were produced utilizing stones, shredded Polyethylene terephthalate (PET), sand and Portland cement and of course water. During the research, the unit weight and durability of the lightweight aggregate blocks were compared against that of the normal aggregate blocks containing gravel. The 101.6cm (four inch) thick specimens were moist cured for 7, 14 and 28 days. The unit weight and failure load measured for each block, were used to calculate density and compressive strength, respectively. And following results were drawn:-

1) The plastic aggregate blocks have average lower compressive strengths and are lighter than the normal aggregate blocks. This is due to the relatively higher density of stones (2.3 – 2.4 g/cm^3) to that of plastic, (0.94 – 0.97 g/cm^3)[4]which causes the blocks to be harder and stronger. Further, stones have rougher surfaces than the plastic aggregates; this facilitates good mechanical interlocking between the aggregate surface and the surrounding cement paste which result in a stronger chemical bond formation whereas bond formation between the plastic aggregates and the cement paste is initiated by chemisorption (adsorption in which a single layer of molecules is held with high strength to a surface by a chemical bond) which is weaker than chemical bond.
2) In addition, the water absorption capacity of stone (1%) is greater than that of plastic (0%)[4]. This factor also contributed to the higher strength in the control specimens. These all factors combine makes

the blocks lighter and imparts less compressive strength.

3) It was also observed that there was a gradual increase in compressive strengths as the cure age increased. The continuous supply of water over a longer period led to an increase in the formation of calcium silicate hydrate bonds and calcium hydroxide crystals thereby increasing hardness, and thereby strength[4].

So to sum up, Blocks with PET replacement have following features as compared to conventional blocks:

1. Greater weather resistant due to chemically inert PET and HDPE;
2. Less stress or load on foundation (due to lighter blocks);
3. Economical foundation (since the stress on foundation is less)
4. Less manual labour in making blocks (mixture is lighter);
5. Less cost of transportation (due to lighter blocks);
6. Good sound insulation;
7. Variable strengths (dependent on size and nature of plastic aggregate);
8. Better shock absorption; and
9. Deduction in the dead load of concrete structure which allows the contractor to reduce the dimension of columns, footings and other load bearing elements.

V. PET BOTTLE HOUSE

The idea of building house with pet bottle was successfully applied in Tonopha, Nevada where first bottle house was constructed by William F. Peck in 1902. Simplified, the construction method includes turning the plastic bottles into bricks, placing them on their sides in their desired positions, binding the bottles together with string and applying the plaster. The making of the bricks, can take as quick as 2 minutes. The important thing, though, is that the soil mixture placed inside the bottle to make the brick must be sufficiently compacted. The plaster used is a mud mixture consisting mainly of sand, soil and only enough cement to bind everything together. This method is currently being researched by Andreas Froese in Honduras, Nigeria.

VI. PET NON LOAD BEARING CONSTRUCTION FIGURES AND TABLES

Construction elements such as reinforced concrete plates (monolithically cast) can be made from packages and depending on the type of packaging used, there can be plates with circular, rectangular or circular gaps. They are of 2 types: [7]

a) Floor with circular gaps on two directions

b) "Boxed" floor with flat underside

As convention, monolithic reinforced concrete plates have a full and consistent section on their entire surface. This has the disadvantage of imposing extra weight as compared to the actual load it has to support , which leads to the need of an additional amount of reinforcement for balancing the force of its own weight. In some of the precast floors, the intrinsic weight has been successfully reduced by making gaps (e.g. precast strips with circular gaps) or by executing frames which have led to easy forms (caissons, π- shaped roof elements etc.)[7]. Because of the above solution being uneconomical, it was proposed that, using a series of plastic bottles as lost shuttering, gapped plates can be executed whose weight is smaller, and so the concrete steel consumption is reduced. The connection of the bottles can be made using adhesive tape or joints can be made of plastic bottles again, by sectioning their body. In addition, coupons made of steel, wood or other even cheaper materials can be applied for joining the bottles' thinner parts.

Another construction element which can use this waste is used in ceiling, porch or boarded floor insulation. For making insulations, it was proposed to have mattresses obtained by joining bottles coated in a thermo-contractile film[7]. Thus, a thicker or thinner air layer will be entrapped according to the bottle shape, which is a known thermal insulator. The mattresses above could provide a solution for obtaining walls and roofs meant for temporary settlements to be used on camping sites or post disaster relief. The PET bottles can also be used for making transparent / semitransparent walls and roofs for agricultural production greenhouses, as they make sure of both appropriate illumination and thermal protection, successfully replacing glass or plastic films which are currently implemented. Another possible implementation of PET bottles is in the solar panels for warming up water.

VII. DISADVANTAGES OF PLASTICS

1. Plastics have low bonding properties which results in reduction in compressive, tensile and flexural strength. So to improve the bonding strength the PET fibers can be modified into one of the several patterns like crimped, twist or cramped patterns.[9]
2. Its melting point is low so that it can't be used in furnaces because it melts in high temperature.
3. Plastic production involves use of potentially harmful chemicals which were used as stabilizers or colorants. So, they may need environment risk assessment and need certain results. For eg. Phthalates used in PVC is released when in contact with saliva in case of toy.[3]

VIII. CONCLUTION

In this study, recycled PET fibres were considered as reinforcement for concrete as a means for studying and analyzing thereby improving its performance. Also the ecological benefit of successfully using a waste material give added benefit and had been a prime motivation for the work. So from the study it was concluded that PET aggregate concrete have less compression strength, flexural rigidity and tensile strength which can be attributed to the decreased bonding tendency of PET with cement matrix. But as the density of PET fiber is lower than the conventional aggregate, it is very useful in producing light weight construction entities. Also an improvement was registered in freeze thaw resistance and impact resistance and toughness. Also deforming capability of concrete was increased as PET fibers are ductile. It was shown that PET bottles or Panels and mattresses

developed from it can be directly used for quick and temporary structure and can be used during post war or disaster rehabilitation and reconstruction. The economic part was also taken care of as solution shown clearly helps in disposing the waste. One of the advantage of PET reinforced concrete is that wastes do not need to be purified including removal of colours[6].

IX. Scope Of Future Work

Based on established properties (compressive strength, density) determined in this study, mix designs could be researched with to achieve increased compressive strength. The effect of decrease in the plastic aggregates size and the use of admixtures, among other alterations should be also studied for increasing strength. In addition a complete cost analysis can be done to determine the cost effectiveness of production and operating with the plastic aggregate blocks. With the availability of specific instruments, further mechanical tests and a microscopic analysis can be carried out to improvise the process and develop a superior quality product. Also use of PET fibres with industrial wastes like Blast furnace slag, fly ash, foundry slag etc as aggregate replacement can be researched and analyzed upon. Possible application of continuous PET strips in mono or bi directional reinforcements for concrete slabs and pavements can also be studied. Research could be conducted to analyze and increase the bonding strength between PET Fibers and concrete matrix.

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