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Utilization of Waste PET Bottle Fibers in Concrete as an Innovation in Building Materials - [A Review Paper]

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Abstract : PET (polyethylene terephthalate) bottles have increasingly become an indispensable part of a common man's life. With the phenomenal increase in plastic consumption the problems with plastic waste disposal have also aggravated. Our voracious appetite for PET bottles coupled with the undeniable behavioral propensity of increasingly over consuming, discarding, littering and thereby polluting the natural environment makes it a lethal combination. Hence the need arises to route the waste plastic bottles to their optimum usage. That is why utilization of waste PET bottles has become an attractive alternative for disposal. This review paper reports the properties of concrete when waste PET bottles are used in fiber form as aggregates in reinforced plain concrete. The aim of the paper is to analyze and study the different experiments, case studies based on researches and experimental works and scientific reports to determine the improvement in selected properties of PET fiber reinforced concrete. Also to convey that the use of PET fibers as reinforcement of cement composites is a promising technique for developing sustainable materials to be applied in the civil construction industry. And hence concrete with waste PET bottle fiber can be used not only as an effective plastic waste management practice but also as a strategy to produce more economic and sustainable building materials in the future.

Keywords: Polyethylene Terephthalate (PET), PET fiber reinforced concrete (PFRC), modified concrete, mechanical properties

Introduction

The quantity of plastics of all types consumed annually all over the world has increased substantially. The manufacturing processes, municipal solid wastes (MSW) and service industries generate a large amount of waste plastic materials. With a continuous growth for over 50 years , the global production of plastics rose from 204 million tons in 2002 to 299 million tons in 2013 (Plastics the Facts -2014) and is ever increasing. The worldwide production of PET exceeds 6.7 million tons/year and shows a dramatic increase in the Asian region due to recent increasing demands in China and India (M. L. Anoop Kumar et. al. 2014). In India approximately 40 million tons of solid waste is produced every year. This is increasing at a rate of 1.5 to 2% annually. Plastics comprise 12.3% of total waste produced most of which is from discarded PET water bottles (Ms. K. Ramadevi et. al. 2012). PET bottles are extensively used as containers for beverage, water, household cleaners and oil and are thrown away after single usage. Disposed PET bottles are treated by landfill and burning, which creates serious environmental problems and hence creates waste disposal and management issues.

Recycling is one of the ways to reduce the environmental impact of the waste PET bottles. But the biggest problem with plastic recycling is that it is difficult to automate the sorting of plastic waste and so is labor intensive. Statistics show that only about 25% of the plastic produced in the US is recycled. This means that the Americans alone, throw away 35 billion plastic bottles every year (Plastics the Facts -2014). It is clear that the plastics are not harming our natural environment and health all by themselves; it is our use of them that has catastrophic consequences. A material that lasts hundreds of years in the environment should never be used for applications that last seconds, minutes, hours, or even days. Plastic pollution is alarmingly increasing and the major reasons for that are improper disposal, irresponsible design and unsustainable throwaway habits. Hence the need arises to route the waste plastic bottles to their optimum usage.

Communities around the world rely on concrete as a safe strong and simple building material. Concrete is used on a large scale worldwide due to its many advantageous properties like good compressive strength, structural stability, high mould ability, strength, durability, impermeability, specific gravity and fire resistance. Although already pilloried through its use in countless architectural eyesores, from tower blocks to car parks, concrete's defects are also now coming under scrutiny. The material used so widely has its own flaws like lower tensile strength, heavy weight, brittleness, lower crack resistance and lower impact resistance.

All over the world, many researchers are inventing materials which can be suitably added into concrete for enhancing its properties. The incorporation of materials like waste PET bottle fibers in cementitious matrix improves the mechanical response of the resulting product; commonly known as PET fiber reinforced concrete (PFRCs), have the potential of exhibiting higher flexural strength and ductility in comparison to unreinforced mortar or concrete, which fail in tension immediately after the formation of a single crack (Margareth da Silva Magalhães et. al. 2015) Hence this review paper addresses to reuse PET bottles in their fiber form as aggregates in concrete to obtain improved mechanical properties over traditional concrete and thereby solve the problems of disposal and management of waste PET bottles.

1. Polyethylene Terephthalate

Polyethylene Terephthalate (PET) is the most commonly used thermoplastic polyester. PET is used predominantly in the form of bottles for storing carbonated and non carbonated drinks. It is a transparent polymer that has good mechanical properties and good dimensional stability under variable load. Semi crystalline thermoplastic polyester, durable, low gas permeability, chemically and thermally stable, easily processed and handled, wear and tear resistant and non biodegradable are the common characteristics of PET. Based on its versatility, it is also used in textiles, films, utility ware, sportswear etc. Food processing industries prefer PET as it is hygienic, strong, lightweight (Pet resin, 2013) (M. Sulyman et. al. 2016, Arulmalar Ramaraj et. al. 2014). This shows that it has a wide range of applications.

PET belongs to the thermoplastics with excellent physical properties. It constitutes around 18% of the total polymers produced worldwide and over 60% of its production is used for synthetic fibers and bottles. Which consume about 30% of the global PET demand (M. Sulyman et. al. 2016).

2. Utilization of waste pet fiber in concrete

Concrete is characterized by a number of defects such as low tensile strength, low ductility, heavy weight and low energy absorption. These disadvantages have triggered the civil engineers to make use of the conventional reinforcement in order to increase the tensile strength and ductility. The concept of using fibers as reinforcement is not a new one. Addition of fibers to concrete would act as crack inhibitors and substantially increase the tensile strength, cracking resistance, impact strength, wear and tear, fatigue resistance and ductility of concrete (M. Sulyman et. al. 2016, Bon-Min Koo et. al. 1996-1944). In addition to the advantage of recycling of the MSW, the incorporation of plastics such as PET wastes in concretes is essential as a light weight aggregate. The reduction of unit weight of concrete is one of the goals of production of earthquake resistant structures (A. A. Abdel-Azim 1996). PET fiber reinforced concrete has experimentally been proven to perform better (R. N. Nibudey et. al. 2013, Ms. K. Ramadevi et. al. 2012, R. N. Nibudey et. al. 2014, Margareth da Silva Magalhães et. al. 2015). PET fibers or synthetic fibers show most success in practical applications and experiments as they have qualities that are unique compared to the ordinary fibers such as

i) They are chemically inert.

ii) They do not corrode.

iii) They allow easy jetting of concrete.

iv) They are lighter than steel fibers of the same number.

v) They allow a better control of the plastic shrinkage cracking (Dora Foti 2011)

Hence reusing of PET wastes in the building industry is an effective approach in both, preventing environmental pollution and designing economical buildings.

3. Mechanical behavior of modified concrete

A compressive review of study of researchers on the different mechanical properties of modified concrete is discussed in this section.

i. Compressive Strength

R.N. Nibudey et. al.2013 reported that fibers made from waste PET bottles were appropriate for concrete reinforcement. The experimental compressive strength of PET fiber reinforced concrete (PFRC) was found to increase by 7.35% compared to normal concrete for M_{20} grade of aspect ratio 50 for 1% fiber volume fraction thereafter the strength decreased at higher percentage volumes of fraction, as they noted a 27% fall in compressive strength for 3% fiber volume fraction for the same grade and aspect ratio. The rise in compressive strength for M_{30} grade concrete is very little and the fall in strength on increasing the fiber volume fraction was low. For higher aspect ratio increase in compressive strength of PFRC was higher. In the analysis of tests done by Ms. K. Ramadevi et. al. 2012 for a mix design of M_{25} grade concrete an appreciable increase in compressive strength is observed till 2% replacement of fine aggregate by PET bottle fibers and then the compressive strength gradually decreases (R. Kandasamy et. al.2011) . For conventional concrete (M_{25} grade concrete) the replacement of fine aggregates by 2% increases the compressive strength by 12% (Sahil Verma et. al. 2015) Hence 2% replacement of fine aggregate is found to be reasonable.

ii. Flexural Strength

The flexural strength of specimens with replacement of the fine aggregate with PET bottle fibers increases gradually with increase in the replacement percentage (R.Kandasamy and R.Murugesan 2011). Ms. K. Ramadevi et. al. 2012 stated from her analysis that the flexural strength of the modified M_{25} grade concrete increased at 2% replacement of fine aggregates with PET bottle fiber, gradually decreased for 4% and remains same for 6% replacement.

iii. Split tensile strength

The experiments by J. M. Irwan et. al. 2013 shows that PET fiber can enhance the tensile splitting strength of concrete cylinder. Strength of concrete containing PET fibers increase by 0.5% -1.5% compared to normal concrete at all ages. At 28 days the increment of splitting tensile strength of concrete containing PET fibers at 0.5%, 1.0% and 1.5% was by 9.1%, 15.5% and 23.6% respectively. Results of bending tests done by Dora Foti et. al. 2010 showed that the tensile strength increased with the addition of PET fiber reinforcement at 8.19KN compared to ordinary concrete specimen at 7.88KN tensile strength. The split tensile strength is seen to be increasing till the 2% replacement of fine aggregates with PET bottle fibers and then decreases gradually with increase in replacement (R.Kandasamy and R.Murugesan 2011). As the role of adding PET fiber in concrete is bringing across the crack and improving the bonding of its element in concrete, we can conclude that the PET fiber added will improve the bending strength as well as the splitting tensile strength.

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iv. Sorptivity

From the tests done by R. N. Nibudey et. al. 2014 it is clear that the sorptivity of PET fiber reinforced concrete (PFRC) at 1% fiber volume fraction and thereafter increased for higher volumes of fraction for both grades M_{20} and M_{30} and both aspect ratios 35 and 50.

v. Shear strength

The shear strength and the comparative percentage increase or decrease in the shear strengths of normal concrete (NC) and PET fiber reinforced concrete (PFRC) has been tested and reported by R. N. Nibudey et. al. 2014. The shear strength of PFRC mix increases at 1.0% volume fraction of plastic fibers and reduces with the increase in volume fraction of fibers thereafter. The maximum increase in shear strength is 27.25% at 1.0%volume fraction of PET fibers with the concrete of grade M20 and aspect ratio 50.

vi. Modulus of elasticity

The Modulus of Elasticity or MOE test conducted by J. M. Irwan et. al. 2013 on ordinary Portland cement shows a definite rise in the modulus of elasticity of concrete on addition of PET fibers. The MOE for 0.5% PET FRC specimens increase by 8.3% compared to normal concrete. But the values of MOE reduced on the consequent increase in PET fiber content. For 1.0% and 1.5% PET FRC there was decrease in MOE by 8.3% and 20.8% respectively. Studies by Kim et al. 2010 followed the same trend. The value of modulus of elasticity decreased with increase in PET fiber aggregate content. Also, the rise in w/c ratio reduces the modulus of elasticity (Swaptik Chowdhury et. al. 2013).

vii. Bulk Density

PET fibers have low unit weight compared to the steel fibers. Hence using PET fibers in concrete reduces the weight (density).The reduction in bulk density was found to be directly proportional to the PET fiber aggregate replacement and was attributed to the low unit weight of the plastic.

viii. Energy Consumption

There is a need for high energy absorbing materials that will mitigate the hazards for structures subjected to dynamic loads such as blast, seismic and impact. Margareth da Silva Magalhaes 2015 illustrated the energy absorption capacity of concrete according to its fiber volume content using toughness values. The data collection indicates an increase of up to 76% in the energy absorption capacity of PFRC with 2.0% PET fiber content. Also it has been shown that the inclusion of recycled concrete is advantageous from energy point of view as it keeps the interior temperature cooler when the outside is raised, as compared to the conventional concrete.

4. Scope of Future Work

Based on established properties determined in this study, mix designs could be researched to achieve increased compressive strength. 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. The effect of decrease in the plastic aggregates size and the use of admixtures, among other alterations should also be studied for increasing strength. In addition a complete cost analysis can be done to determine the cost effectiveness of producing 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 fibers 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

5. Conclusion

Case studies based on researches and experimental works and scientific reports have proved that waste PET may be applied for the modification of concretes. The incorporation of PET bottle fibers as reinforcement in concrete has shown, on the basis of different tests on its mechanical properties, that there is a significant improvement in the modified concrete. The use of PET fibers as reinforcement of cement composites is a promising technique for developing sustainable materials to be applied in the civil construction industry. And hence concrete with waste PET bottle fiber can be used not only as an effective plastic waste management practice but also as a strategy to produce more economic and sustainable building materials in the future.

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