Physical and Mechanical Experimental Investigation of Concrete incorporated with Polyethylene Terephthalate (PET) Fibers

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Abstract

Concrete plays an inherent role in the construction industry one of the most widely used manmade material because of its advantageous properties like good compressive strength, though it also has some undesirable properties like low ductility and brittleness. On the other hand, waste management and disposal is still a major challenge in most third world countries. Wastes like Polyethylene Terephthalate (PET) bottles which are used in packaging of carbonated and non- carbonated drinks and are non-biodegradable in nature constitute about 11% of the landfill content. These wastes have so many hazardous challenges associated with them especially damaging the environment. The aim of this study was to investigate the effect of PET fibers on the Physical and Mechanical properties of concrete. In this study, an experimental analysis with a mix ratio of 1:2:3 for cement: fine aggregates: coarse aggregates with a constant water to cement ratio of 0.57. The PET fibers were obtained by shredding the PET bottles that were collected from nearby restaurants and dustbins, into rectangular strips of 35mm length and 5mm width, Aspect ratio of7, they were incorporated in to the mix at percentages of 1%, 2% and 3% of the weight of cement. Physical properties including workability using slump test was carried out on each fresh mix of concrete and water absorption carried out on concrete cubes at 28 days of curing. Mechanical properties including Compressive strength, Splitting Tensile Strength and Density were carried out on hardened concrete at 7days and 28 days of curing period. From the study, it was concluded that PET fibers can be used to improve the ductility properties of concrete up to 2% PET though 1%PET gave the best results in terms of splitting tensile strength but cannot be used to enhance compressive strength and water absorption.

Key words: Polyethylene Terephalate (PET); Plastic Fiber Reinforced concrete (PFRC); Aspect Ratio (AR); Workability; Water absorption; Compressive Strength; Splitting Tensile Strength; Density

1. INTRODUCTION

Construction industry is one of the rapidly growing industries across the world due to the increase in population. Concrete plays an inherent role in the construction industry as it the most widely used manmade construction material due to its versatile advantageous properties such as good compressive strength, impermeability, fire resistant and durability (Mishra &Deodhar, 2015). However, concrete has some undesirable properties like being weak in tension, brittleness, less resistance to cracking, low impact resistance and heavy weight hence there is need to improve on such properties (Chavan& Rao, 2016). On the other hand, solid waste management and recycling has become a great challenge especially in third world countries as they are associated with various problems like diseases, flooding, ugly scenery and pollution. Plastics is one of the most disposable material rapidly filling up landfills and chocking water bodies and yet they are non- biodegradable in nature as they take approximately 300 years to decompose, and are therefore considered a sustainable waste and environmental pollutant (Webb et al; 2013). Polyethylene Terephthalate (PET) bottles, which are mainly used for packaging both carbonated and non-carbonated drinks, make up approximately 11% of the landfill content, that cause serious environmental consequences due to chemicals used in their manufacture, improper use and disposal. Global consumption of PET packaging was forecasted to reach 19.1 million tonnes by 2017 with a 5.2% increase per annum (Van de Berg, 2014). Many investigators are utilizing such wastes to enhance the properties of the conventional construction materials or as alternatives and at the same time preserving the environment.

The PET fibers have been used by some researchers to enhance some of the weak properties of concrete by incorporating them into the cementitious matrix to improve the mechanical response producing concrete commonly known as PET fiber reinforced concrete (PFRC). Maqbool and Sood (2016) reported that the effect of the PET fibers greatly depends on the amount, size and shape of the fibers in the mix as they impact on the physical and mechanical properties of concrete differently. Chanko and Sunilaa (2017) also reported that lower aspect ratios of PET fibers like AR 2.5 and 7.5 had a significant increase in compressive strength of concrete as compared to those with higher aspect ratio like AR 10. Nibudey et al (2013), reported that 1% PET fiber content for AR 50 gave the best strength properties for both compressive and splitting tensile while Ramadevi et al (2012) reported up to 2% replacement for aggregates increased the compressive strength for M25 grade of concrete. Though some researchers have reported that the fibers have no impact on the compressive strength of concrete like Shamskia (2012), who reported a slight decrease in compressive strength at all levels of incorporation of PET fibers for sizes of 40, 50 and 60 mm with 3mm width at 0.5%, 1%, 1.5% and 2% by weight of cement mix. While for splitting tensile strength, most researchers have reported an improvement with the incorporation of the PET fibers for various dimensions and amount like Kandasamy&Marugesan (2011) obtained an improvement in tensile strength up to 2% PET fiber replacement of fine aggregates and therefore PET fibers may be used in enhancing the ductility properties of concrete.

2. MATERIALS AND METHODS

The materials used in this study were PET fibers, coarse aggregates, fine aggregates, OPC and water. The PET fibers were obtained by collecting plastic bottles from the nearby hostels and restaurants, labels removed, cleaned, dried and then shredded into rectangular strips manually using a pair of scissors and a knife. The dimensions of the fibers were 35mm length by 5mm width hence AR-7. The fibers were characterized in terms of color, texture, tensile strength and density. OPC of grade 42.5N conforming to East African Standard KS EAS 18.1 was used in the study. Coarse aggregates were obtained locally and those conforming to BS 882: 1992 specification and limited to a maximum size of 15mm were used. They were first washed to remove the dust and dirt, and then dried to surface dry condition before use in the mix. They were characterized in terms of specific gravity, density, particle size distribution, water absorption, AIV and ACV. The fine aggregates used was river sand obtained locally from Meru, in Kenya and was then sieved through a 5.0mm BS 410 sieve to remove any coarse particle before use. PSD, fineness modulus, specific gravity, density and water absorption were the tests carried out on the sand. Portable water conforming to BS 1348-2(1980) was used for mixing and curing of the concrete samples and was obtained from the general supply water system of JKUAT university.

The materials were batched by weight at ratio of 1:2:3 with respect to OPC: fine aggregates: coarse aggregates with a constant water/cement ratio of 0.57, they were then mixed and after PET fibers were added to the mix at percentages of 1%, 2% and 3% of cement weight and finally water added to form a paste. On each fresh mix of concrete workability was determined using the slump test in accordance with BS 1881-102(1983). The mixture was then cast into greased cubes of 150X150X150mm and cylinders of 100mm diameter and 200mm height and then compacted using a poker vibrator after which was left to set for twenty four (24) hours and then demoulded and placed in curing tanks for 7days and 28days of curing.

The concrete cubes and the cylinders were tested for compressive strength and splitting tensile strength using the universal testing machine at 7days and 28days in accordance with BS 1881-116(1983) and BS 1881-117(1983) respectively. Water absorption at 28days (BS 1881-122(1983)) and Density at 7days and 28days were the other tests performed on the concrete cubes.

3. RESULTS AND DISCUSSIONS

3.1 Material Characterization

3.1.1 Coarse and fine aggregates

The fine aggregates used in the study was river sand sieved on a 5mm BS sieve to remove any coarser particles. The coarse aggregates used were crushed angular shaped rocks ranging from 5mm- 15mm. Table 1 shows the physical properties of both coarse and fine aggregates that were carried out. From these results, conclusion was made that the aggregates satisfied the standards and therefore could be used in production of Normal weight concrete.

Table 1: Physical properties of coarse and fine aggregates

Property	Coarse Aggregates	Fine Aggregates
Density	Bulk-1365.33kg/m^3 Loose-1254.58kg/m^3	Bulk-1661.3kg/m^3 Loose-1522.06kg/m^3
Specific gravity	2.58	2.44
Particle size	5mm- 15mm	0.15mm- 15mm
Water Absorption	2.916	6.534
Shape	Angular	-
Surface texture	Rough	-
Fineness Modulus	-	2.68
AIV	7.61	Less than 45
ACV	17.40	Less than 30

3.1.2 Ordinary Portland cement (OPC)

OPC CEM 1 42.5N conforming to EN 197-1 was the cement used in this study. Table 2 shows the physical properties of the cement used in the study as compared to the requirement as per EN 197-1.

Table 2: Physical Properties of Ordinary Portland cement CEM I 42.5

Property	Description	Requirement as per EN 197-1
Specific surface	3197cm^2/g	-
Specific gravity	3.11	-
Water Demand	25.65%	-
Soundness	0.3mm	Not more than 10mm
Compressive Strength @2days	19.30MPa	Not less than 10MPa
Compressive Strength @ 28days	48.94MPa	Not less than 42.5MPa
Setting Time	Initial - 160minutes Final - 252minutes	Not less than 60 minutes Not more than 600 minutes
Density	Bulk- 1396.1kg/m^3 Loose- 1162.8kg/m^3	-
Color	Grey	-

3.1.3 PET Fibers

The PET fibers were shredded into rectangular strips as portrayed in figure 1, the tensile strength was obtained using a tensometer machine shown in figure 2 with the ultimate tensile strength of 254MPa. The properties of the PET fibers are summarized in Table 3.

Table 3: Properties of the PET fibers

Property	Description
Length	35mm
Width	5mm
Thickness	0.2mm
Aspect ratio	7
Tensile Strength	254MPa
Surface Texture	Smooth
Shape	Rectangular
Color	Colorless and opaque

Figure 1: PET fibers

Figure 2: Tensometer machine for testing Tensile Strength of the PETfibers

3.1.4 Water

Ordinary portable water conforming to BS 1348-2(1980) available in the laboratory with a pH of 8.1 was used in the study for mixing and curing of concrete mixes.

3.2 Workability of concrete with PET fibers

Determination of workability in this study was done by the slump test which was carried out twice on every mix that was made and an average value obtained. Results of the slump test are presented in figure 3showing the average slump for each mix versus the percentage addition of PET fibers in the mix.

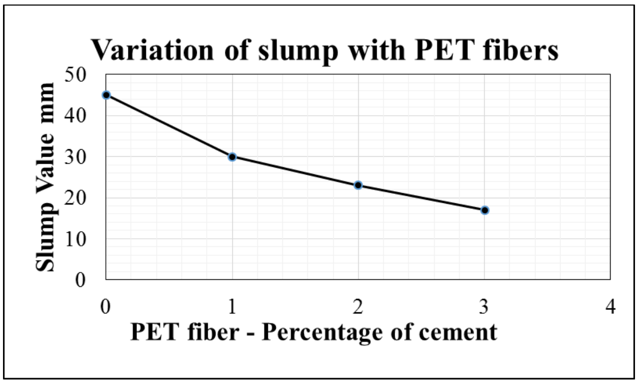

Figure 3: Variation of slump with PET fibers

Considering a constant water/cement ratio of 0.57 which was used in the mix design, as seen from figure 3, as the content of PET fibers were increased in the mix, there was a reduction in the workability levels as reported by a reduction in the slump values from 45 for normal concrete at percentage reductions of33%, 48.9% and 62.2% for 1%, 2% and 3% PET fiber addition respectively as compared to the control. As there was a reduction in the slump with addition of PET fibers in the mix, the concrete remained workable in nature. This reduction in slump of concrete was attributed to the presence of fibers in the mix as they lump on each other reducing the slump while the mixture is still workable. Also a reduction in the workability of fresh concrete may be caused by an adhesion within the concrete and holding the other ingredients of concrete together impeding easy flow as was reported by Nibudey et al (2014). Therefore the mix required more compacting effort to achieve proper compaction as this would directly affect the density, strength, water absorption and hence the durability of the hardened concrete.

3.3 Water Absorption of concrete with PET fibers

As portrayed in figure 4, PET fibers incorporation in the concrete mix increased the water absorption of the mixes as the control had the least water absorption whereas there was a subsequent increment as the PET fibers were increased in the mix. PET fibers added at percentages of 1%, 2% and 3% had a percentage increase in the water absorption of 6.7%, 16.5% and 23.5% respectively as compared to the control mix (0% PET).The increment in water absorption as the PET fibers are increased could be as a result of the poor compaction leading to poor bonding as a result of the smooth texture of the fibers and this increased the number of pores in the concrete specimen causing it to absorb more water. As a result, this makes the concrete more susceptible to damage when exposed to corrosive environment and hence making the concrete less durable.

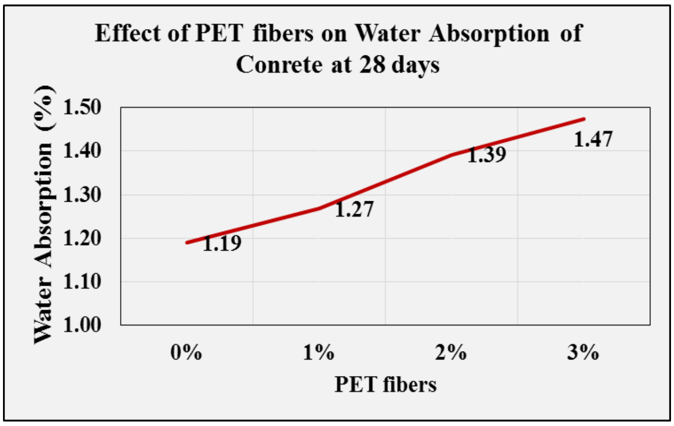

Figure 4: Effect of PET fibers on the water absorption of concrete at 28 days.

3.4 Compressive Strength of concrete with PET fibers

As shown in figure 5, a reduction in compressive strength was recorded for both the 7 days and 28 days though there was an increase in compressive strength with curing time as 28 days compressive strength values were greater than those at 7days curing. Percentage reductions of 4.2%, 9.5% and 17.0% at 1%, 2% and 3% PET fiber additions respectively were obtained as compared to the control mix at 7days testing where as 2.2%, 5.8% and 14.3% percentage reductions at 1%, 2% and 3% PET fiber additions respectively as compared to the control mix were obtained at 28 days curing time. From these results, it can be seen that 1% PET fiber addition had the less percentage reduction in compressive strength compared to normal weight concrete and therefore it offers better compressive strength properties as compared to other percentages of 2% and 3% PET fibers.

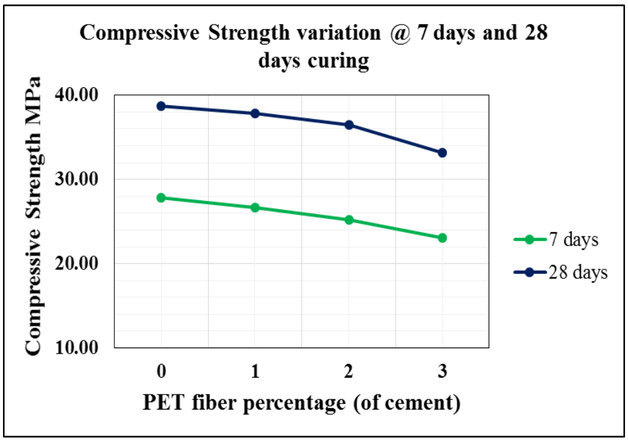

Figure 5: Effect of PET fibers on the Compressive Strength of concrete at 7 and 28 days.

From these results, conclusion can be made that addition of PET fibers in normal weight concrete reduces its compressive strength. This could be attributed to the adhesion properties due to the smooth texture of the PET fibers in the mix which reduce the bonding properties of the concrete mix and hence more compacting energy is required to achieve the desired compressive strength of the concrete. Therefore rectangular PET fibers of 35mm length and 5mm width cannot be used to enhance the compressive strength properties of normal weight concrete.

3.5 Splitting Tensile Strength of concrete with PET fibers

As depicted in figure 6, the PET fibers can enhance the splitting tensile strength of concrete. The Splitting Tensile Strength at all percentages of PET fiber addition increased with curing time as 28 days at each percentage had a larger Splitting Tensile Strength value than those at 7 days curing. Figure 6 shows that there was an improvement in the tensile splitting values at 1% PET fibers for both 7days and 28 days curing times. At 7 days curing time, a percentage increment of 7.1% as compared to normal weight concrete (control) was obtained at 1% PET fiber incorporation in the mix while on further addition of PET fibers of 2% and 3% PET fibers a percentage reduction of 3% and 11.2% respectively was realized in the splitting tensile strength of the concrete. While at 28 days, figure 6 also portrays an improvement in the splitting tensile strength at both 1% and 2% PET fiber incorporation with a percentage increment of 10% and 5.2% compared with the control whereas a percentage reduction of 8.9% was realized at 3% PET fiber incorporation in the concrete mix.

From these results, it can be seen that the addition of PET fibers in the concrete mix improves the splitting tensile strength up to 2% PET fiber incorporation though 1% PET fibers portrayed the optimal strength values of splitting tensile for both 7days and 28days. This affirms to the results obtained by previous researchers like Kaothara et al (2015); Asha and Resmi (2015); Nibudey et al (2014) and Prabhu et al (2014).The reason for the improvement in the splitting tensile strength of concrete with PET fiber addition would be that the fibers bridge across the cracks and impart more ductility of the concrete as the specimens take more time to break down into pieces than normal concrete specimens as shown in figure 7 therefore incorporation of fibers in the concrete can also improve first crack strength and ultimate ductility index.

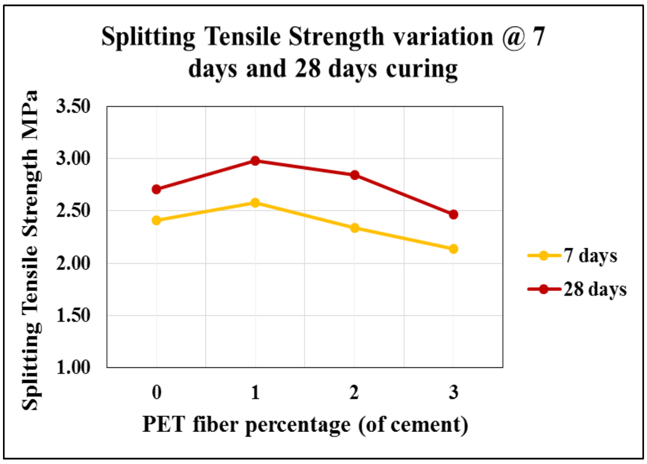

Figure 6: Effect of PET fibers on the Splitting Tensile Strength of concrete at 7 and 28 days.

Figure 7: Concrete cylinder with PET fibers after splitting tensile strength test

3.6 Density of concrete with PET fibers

There was a general reduction in the density of concrete as PET fibers were added to the control mix and as there percentage was increased as portrayed in figure 8. The density of the concrete reduced for both 7 days and 28 days though the one at 28 days was less than that of 7 days at the different percentages of PET fiber incorporation. The density of the concrete was reduced at percentages of 0.53%, 1.9% and 2.4% at 1%, 2% and 3% PET fiber addition respectively as compared with the control mix (0% PET fibers) for 7 days curing. While at 28 days curing, the percentage reductions in the density were 0.61%, 2.0% and 2.7% at 1%, 2% and 3% PET fiber addition respectively. Taherkhani (2014) also reported a reduction in density of concrete with the incorporation of PET fibers during his research. This reduction in density of concrete may be attributed to the incorporation of light weight PET fibers as compared to other concrete constituents in the concrete mix occupying a fixed volume that would be occupied by heavier constituents of concrete.

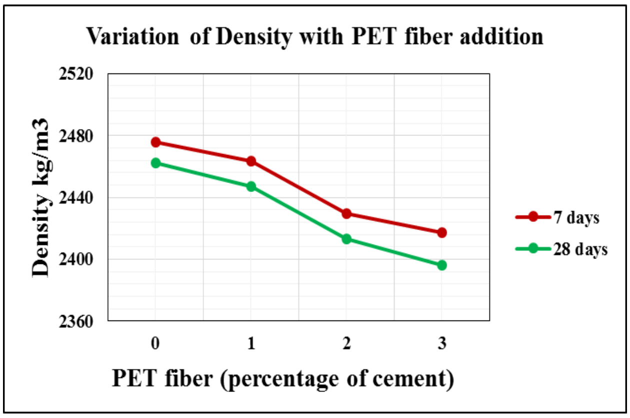

Figure 8: Effect of PET fibers on the Density of concrete at 7 and 28 days.

4. CONCLUSIONS

From this experimental investigation, the following conclusions can be made:

1) The workability of fresh concrete mixed with PET fibers reduces due to clumping of the materials on one another though the material remained workable in nature.
2) The Compressive Strength and density of concrete decreased with increase in PET fibers due to poor bonding resulting from the smooth texture of the fibers which made it hard to compact the mix to achieve the desired strength. Therefore PET fibers cannot be used to enhance compressive strength of concrete.

3) The Splitting Tensile Strength of concrete improves up to 1% PET fiber addition and reduces on further addition of the fibers. Therefore 1% PET fiber addition can be used to impart ductility and crack control as the fibers bridge across the cracks.
4) Water absorption of the concrete increased as PET fibers increased in the mix due to increase in pores in the mix. Therefore PET fiber concrete should not be used in corrosive environment as this will affect the durability of concrete.
5) The optimum mix in the study was 1%PET fiber addition which gave 70.52MPa Compressive strength and 2.98MPa Splitting Tensile strength at 28days of curing, therefore 1% PET fibers can be used in production of PFRC.
6) Utilization of PET fibers up to 1% can be used to improve concrete ductility properties and also reduce the amount of PET bottles disposed of in the landfills and hence preserve the environment.

5. RECOMMENDATIONS

From this experimental study the following recommendations were made:

For Possible Applications:

- PFRC with PET fibers of 35mm by 5mm width can be utilized up to 1% of the weight of cement in the production of structural concrete especially where crack control is a concern especially in water retaining structures.

For Further Studies:

- Investigations should be made on how to improve the bonding properties of the PET fibers either by coating them with some materials that can roughen their texture.
- A machine or equipment should be designed to help in the shredding of the PET fibers in order to obtain large volumes in a short period of time.
- Further studies and documentation should be made on the effect of the various aspect ratios of the PET fibers on the properties of concrete.
- The durability aspect of PFRC should also be studied.

REFERENCES

Asha S, & Resmi P.R. (2015). Experimental research on concrete with straight and crimped waste plastic fibres, International Journal of Engineering Sciences & Emerging Technologies, Volume 8, Issue 2, pp: 55-71.

BS 882 (1992), Specification for aggregates from natural sources for concrete. British Standards Institution, London, UK.

BS 1348-2, (1980), Test of Water for making Concrete, British Standards Institution, London, UK.

BS 1881 Part 116 (1983). Testing concrete. Method for determination of compressive strength of concrete cubes. British Standards Institution, London, UK.

BS 1881 Part 117 (1983). Testing concrete. Method for determination of tensile splitting strength. British Standards Institution, London, UK.

BS 1881 Part 122 (1983). Testing concrete. Method for determination of water absorption. British Standards Institution, London, UK.

BS EN 197-1, (2000), Cement - Part 1: Composition, specifications and conformity criteria for common cements, British Standard Institution, London, UK.

Chanko, B & Sunilaa, G. (2017). Performance of Concrete with PET fibers, International Journal of Engineering Science Invetion Research & Development, Vol III, Issue XI, May 2017, pp 725-728.

Chavan, S., & Rao, P. (2016). Utilization of Waste PET Bottle Fibers in Concrete as an Innovation in Building Materials - [A Review Paper], 6890(5), 304–307.

Hasan Taherkhani. (2014), An Investigation on the Properties of the Concrete Containing Waste PET Fibers, International Journal of Science and Engineering Investigations, vol. 3, issue 27, April 2014 pp 37-43 .

Kandasamy,R & Murugesan, R. (2011). Fibre Reinforced Concrete Using Domestic Waste Plastics as Fibres, ARPN Journal of Engineering and Applied Sciences, Volume 6, No.3, ISSN 1819-6608. Retrieved from www.arpnjournals.com

Kaothara, O.I.; Babajide, O.S.; & Mustapha I.A, (2015). Structural Behaviour of Fibre Reinforced Concrete Using PET Bottles, ARPN Journal of Science and Technology Vol. 5, NO. 3, March 2015, pp 125- 129

Maqbool, S & Sood, H. (2016). Effect of PET fibers on the Performance of concrete. International Journal of Scientific Research and Education. Volume 4. Issue 12 December-2016. Pages-6085-6089. ISSN(e):2321-7545.

Mishra, S., & Deodhar, S. V. (2015). Effect of Rice Husk Ash on Concrete. Nbmcw, 87(November), 33–39. https://doi.org/10.6088/ijcser.6003

Nibudey, R. N., Nagarnaik, P. B., Parbat, D. K., Pande, A. M., & Polytechnic, G. (2014). Compressive Strength And Sorptivity Properties of PET Fiber Reinforced Concrete, 7(4), 1206–1216.

Nibudey, R. N., Nagarnaik, P. B., Parbat, D. K., Pande, A. M. (2013) Strength of Waste Plastic (PET) Fiber Reinforced Concrete e-ISSN :2349-9745 p-ISSN : 2393-8161

Prabhu,G.P.; Kumar, A.C.; Pandiyaraj, R.; Rajsh, P.;& Sasikumar, L. (2014) Study on utilization of waste PET bottles fiber in concrete, International Journal of Research in Engineering & Technology. 2(5). 233-240. May 2014.

Ramadevi, M. K., & Manju, M. R. (June 2012). Experimental Investigation on the Properties of Concrete With Plastic PET (Bottle) Fibres as Fine Aggregates, 2(6), 42–46.

Shamskia N. (2012) The influence of pet fibers on the properties of fresh and hardened concrete, Journal of Structural Engineering and Geotechnics, Vol. 2, No. 1, pp.13-17.

Van den Berg, S. (2014). Integration of the informal sector in PET bottle collection and recycling: South Africa, Ecuador, and Columbia, (June). Retrieved from http://www.waste.nl

Webb, H. K., Arnott, J., Crawford, R. J., & Ivanova, E. P. (2013). Plastic Degradation and Its Environmental Implications with Special Reference to Poly(ethylene terephthalate), 1–18. https://doi.org/10.3390/polym5010001