International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 9 (2019), pp. 1435-1440
© International Research Publication House. http://www.irphouse.com

Flexural Performance Evaluation of Polyethylene Terephthalate Fibre Reinforced Concrete with Fly Ash as a Partial Cement Replacement

Rebecca Belay Kassa*
Research Student
Department of Civil Engineering
Pan African University Institute for Basic Sciences, Technology and Innovation (PAUSTI), Nairobi, Kenya

Christopher Kanali
Professor Department of Agricultural and Biosystems Engineering Jomo Kenyatta University of Agriculture & Technology (JKUAT), Nairobi, Kenya

Nathaniel Ambassah
Lecturer (PhD)
Department of Civil Engineering
Jomo Kenyatta University of Agriculture & Technology (JKUAT), Nairobi, Kenya

**Corresponding Author*
ORCID: (0000-0002-9573-8547)

Abstract

Waste disposal is becoming both economically and environmentally daunting in most African countries. Plastic wastes like Polyethylene Terephthalate (PET) bottles and powdered wastes like fly ash degrade the environment at an alarming rate. Using PET bottles and fly ash to improve concrete quality is a move in the right direction as it helps deal with the environmental issue and concurrently contributes to the construction industry's improvement. This paper is an outcome of a study that assessed the effects of using PET fibres and fly ash (as a partial cement replacement) on the structural performance of concrete. PET fibres with an aspect ratio of 50 (100mm length and 2mm width) were incorporated in the concrete mix at a percentage of 1.5% and fly ash at 27.5% by weight of cement. The flexural tests result show that the ductility and load carrying capacity at failure improved by 27.3 and 44.16%, respectively. There was delay in appearance of cracks and energy absorption increased by 60.55%. Flexural capacity also increased by 43.91% for the modified concrete mix as compared to the control. These results indicate that PET and fly ash wastes can effectively be utilized for the improvement of flexural performance of concrete in the construction industry.

Keywords: Concrete; polyethylene terephthalate; fly ash; flexural strength, bending, deflection, control, modified

I. INTRODUCTION

Waste disposal is becoming both economically and environmentally daunting in most African countries. Plastic wastes like Polyethylene Terephthalate (PET) bottles and powdered wastes like fly ash degrade the environment at an alarming rate. PET bottles used for packaging of drinking water and other beverages are seen disposed all over places risking human, animal and plant lives. The worldwide consumption of PET bottles was predicted to reach 19.1 million tons by 2017 with an increase of 5.2% per annum. However, out of all these only 18-20% is recycled. The remaining 15.5 million tons of un-decomposable PET bottles are left out exposed to the environment [1]. Kenya PET Recycling Company Limited stated that in Kenya about 20,000 tons of PET are generated annually and only 1,000 tons (5%) is recycled [2]. Waste PET bottles take more than a hundred years to degrade in nature [3]. In recent years, the construction industry has been working towards solving environmental problems like improperly disposed solid wastes. Using PET bottles and fly ash to improve concrete quality is a move in the right direction as it helps deal with the environmental issue and at the same time positively contributes to the construction industry.

This article is an outcome of a study that assessed the effects of using PET fibres and fly ash (as a partial cement replacement) on the structural performance of concrete. The study showed that PET fibres with an aspect ratio of 50 (100mm length and 2mm width) were incorporated in the concrete mix at percentages of 0.5, 1.0 and 1.5% by weight of cement. Fly ash on the other hand, was introduced as a cement replacement at percentages of 20, 22.5, 25, 27.5 and 30% by weight of cement. The first part of the study evaluated the performance of the modified concrete based on workability, compressive strength, and splitting tensile strength [4]. The combination of 1.5% PET fibres and 27.5% fly ash resulted in 33.45% tensile strength improvements, while keeping the workability and compressive strength unaffected [4]. This article presents the evaluation of the flexural performance of the PET fibre (1.5% by cement plus fly ash weight) reinforced concrete with fly ash (27.5% by cement weight) as a partial cement replacement.

Flexural strength also known as the bending strength of concrete is the ability of a concrete beam or a slab to resist failure in bending. It is measured by flexural strength test in the laboratory. The maximum stress in a structure before it yields in a flexural test is its flexural strength. Various researchers have studied the effects of PET fibre addition on the flexural strength of concrete and concluded that it improves performance. For instance, according to [5] and [6], the addition of PET fibres to a concrete mix improved the bending strength of concrete. [5] depicted that the bending strength of PET fibre reinforced concrete increased by 3.9% compared to the control concrete. [6] also showed that the PET fibre reinforced concrete had a bending strength increase from 7.8% up to 25.7% compared to the control concrete. They both concluded that the addition of PET fibres plays a role of sewing of the elements of the concrete, which improves the bending strength of the concrete. [7] is another study that reported the flexural strength of PET fibre reinforced concrete had a marginal enhancement compared to the control concrete. In addition, according to [8], the calculated flexural strength from the test data showed that PET reinforced concrete with fibre volume fractions of 0.5, 0.75 and 1.0% had maximum flexural strength increases of 25, 31 and 32%, respectively, compared to the concrete without fibre reinforcement.

The effects of partial cement replacement by fly ash on flexural performance of concrete has also been studied by researchers. [9] studied the flexural strength of concrete made from portland pozzolana cement partially replaced by fly ash. The replacement levels were from 10 to 60% and the results showed that up to 30% replacement, the flexural strength improved. [10] studied the effects of fly ash on flexural strength of concrete and concluded that the flexural strength of concrete increased by 11.08% with 20% partial replacement of cement by fly ash compared to the control concrete. This article presents the results of experimental works carried out to study the combined effects of PET fibres and fly ash on flexural performance of concrete.

II. MATERIALS AND METHODS

A. *Materials and Concrete Mix*

Materials used for this study were; ordinary Portland cement (42.5 MPa) of density 3.09 g/cm3 accompanied by 27.5% class F fly ash replacement by weight; coarse aggregate with aggregate size between 5 and 20mm; fine aggregate (river sand) with aggregate size between 0.15 and 5mm; clean drinking water; and PET fibres added to the concrete mix at 1.5% by weight of binder (cement and fly ash). Reinforcement bars used to make the beams were 8 and 12 mm diameters and had a tensile strength of 460 kN/m2. The mix design for the control mix of 25 MPa ordinary Portland cement concrete was prepared as per [11] and [12] provisions. A mix ratio of 1:1.63:3.13 was taken for cement, fine and coarse aggregates, respectively. The water to binder ratio was 0.6. The mix proportions used to produce both modified and control C25 concrete mixes are given in Table I. The physical and chemical properties of cement and fly ash, studied in the material characterization section of [4], are given in Table II and III, respectively.

Table I: Material proportions

Material	Modified Mix (kg/m3)	Control Mix (kg/m3)
Cement	266.15	367.11
Fly ash	100.95	-
Coarse aggregate	1150	1150
Fine aggregate	583	583
Water	221.26	221.26
PET fibres	5.51	-

Table II: Physical properties of cement and fly ash

Tests	Ordinary Portland cement	Fly ash
Consistency (%)	31.25	23.75
Initial setting time (min)	133	199
Final setting time (min)	270	278
Specific gravity	3.09	2.12

Table III: Chemical composition of cement and fly ash

Major Component (% by mass)	Chemical composition (% by mass)	
	Ordinary Portland cement	Fly ash
CaO	61.48	6.36
SiO2	25.79	54.57
Al2O3	5.60	23.14
Fe	2.34	5.89
S	2.60	0.39
K2O	1.00	1.92
P2O5	0.52	0.33
Cl	0.23	-
Ti	0.21	0.62
Sr	0.14	-
MgO	-	6.24
Ba	-	0.16

The PET fibre strips were rectangular and had an aspect ratio of 50 (100mm length and 2mm width). PET bottles were collected from the surrounding environment; they were cleaned, dried and cut in to rectangular fibre strips (Fig. 1). The fibres were 0.21mm thick and had an average tensile strength of 84.123 MPa.

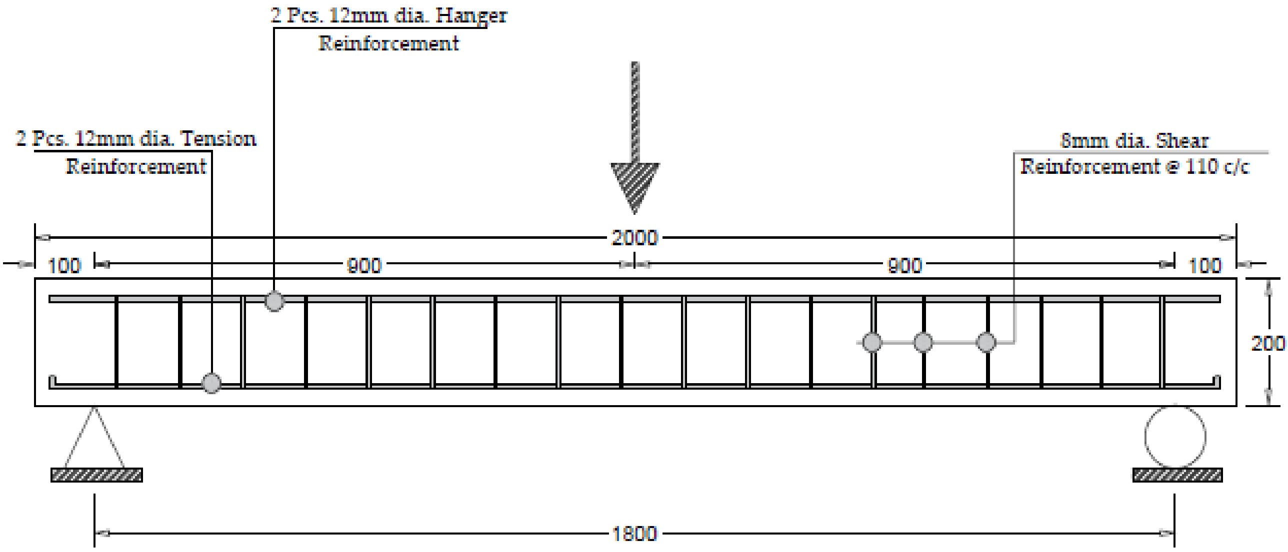
Fig. 1: PET fibres

B. *Methods*

To mimic the true stress conditions in structures, a simply supported reinforced concrete beam of span 2m and cross-section 150mm by 200mm was designed according to [13]. It was used to study the flexural performance of the fibre reinforced concrete with fly ash as a partial cement replacement. A concrete cover of 25mm was introduced while casting the beams. It had evenly dispersed shear reinforcements of 8mm diameters at 110 mm centre to centre spacing and two (2) 12 mm diameter tensile reinforcements. Fig. 2 shows the experimental setup of the test beam design.

The flexural strength test was performed according to [14] by analysing flexural test results of specimens at 28 days of age. Experimental tests were run on six (6) beams; three (3) beams made of the control concrete mix and three (3) others made of the modified concrete mixture (containing 27.5% fly ash replacing the cement weight and 1.5% of PET fibres by binder weight). A universal testing machine was used to test the specimens. Flexure testing was carried out using a three-point bending test by which the simply supported beam was monolithically loaded until failure took place. To accurately measure the applied load, a load cell was used. Strain gauges were attached to the reinforcement in the tension zone and the bottom mid-section of the concrete surface to measure the strain due to bending. A Linear Variable Differential Transducer (LVDT) was also placed at the expected point of maximum deflection (mid span of the bottom face of the beam) in order to measure the deflection. The initiation and propagation of cracks were studied using visual inspection.

Beam Layout



Beam Cross Section

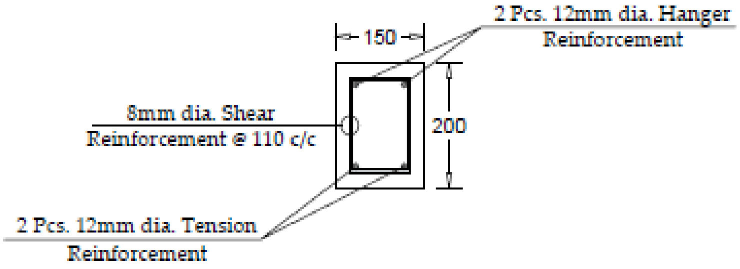


Fig. 2: Beam experiment setup

III. RESULTS AND DISCUSSIONS

A. Load Carrying Capacity

The load carrying capacity of control and modified beams is shown in Fig. 3. The loads at initial cracking and at failure are taken in order to discuss the capacities of the beams and run a comparison.

The results show that, for the control beam, the first crack appeared at 20 kN whereas for the modified beam it was delayed until the loading reached 41 kN. Similarly, the failure load for the control beam was 43 kN while the modified beam failed at 77 kN. The increment of the load carrying capacity of the concrete beam (51.2% at initial crack and 44.16% at failure load) that is modified by the combination of PET fibres and fly ash might be due to the combination of the following two reasons. First, the addition of PET fibres plays a role of sewing micro cracks in concrete structures which might be why higher loads were required for the first crack to appear as well as for the structure to entirely fail [5] and [6]. Second, the addition of fly ash has an effect of a continued hydration reaction with more C-S-H present in the concrete even at a latter age. This gives the modified concrete beams more strength to resist the applied load better as compared to the control concrete beams.

B. Load versus Deflection Behaviour

The flexural test results indicated the control and modified beams had similar deflection behaviour, in their elastic state towards the applied load, but the peak load-deflection of the modified beams was fairly larger than the control beams (Fig. 4). This shows that the deformation capacity or ductility of the beams improved with the addition of PET fibres and fly ash.

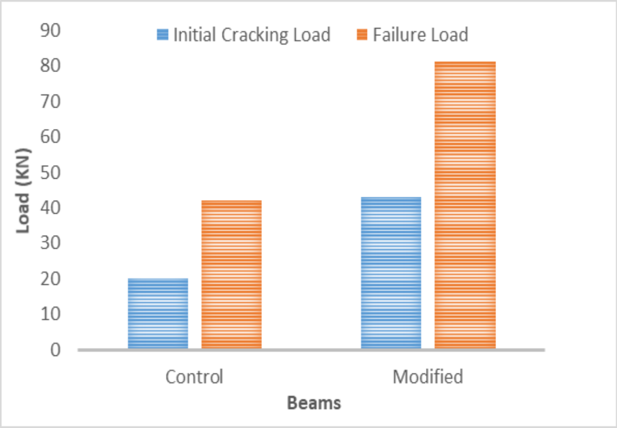


Fig. 3: Load carrying capacity chart

C. Ductiity Charactersitcs

Ductility is a major parameter that is used to quantify the load-deflection capacity of a specimen being loaded. The ductility of the flexural members can be calculated from their load deflection curves. The ductility index (μ) can be defined as the ratio of ultimate deflection (Δu) to deflection at first yield (Δy) as presented in (1). Table IV provides the readings from the tests as well as the ductility indices for both control and modified beam.

$$\mu = \frac{\Delta_u}{\Delta_y} \qquad (1)$$

Table IV: Summarized test results

Parameters	Control	Modified
Pcr (KN)	20	41
Δcr (mm)	5	9
Py (KN)	39	58
Δy (mm)	12	14
Pu (KN)	43	77
Δu (mm)	39	58
μ	3.25	4.14

The relative ductility index of modified concrete beams improved by 27.39% as compared to the control concrete beams. It might be due to the micro crack interlocking nature of PET fibres, giving the specimen strength to absorb stress, and strength increment of concrete due to addition of fly ash that the deformation increases and ductility is enhanced.

D. Stiffness Behaviour of Concrete Beams

Stiffness is the load required for a unit deflection. The load deflection curve shows the modified concrete has a slightly steeper slope than the control concrete. This indicates that the modified beams required more load than the control beams to undergo the same amount of deflection. Which means they were able to resist deformation and this shows that stiffness has increased with the addition of PET fibres and fly ash.

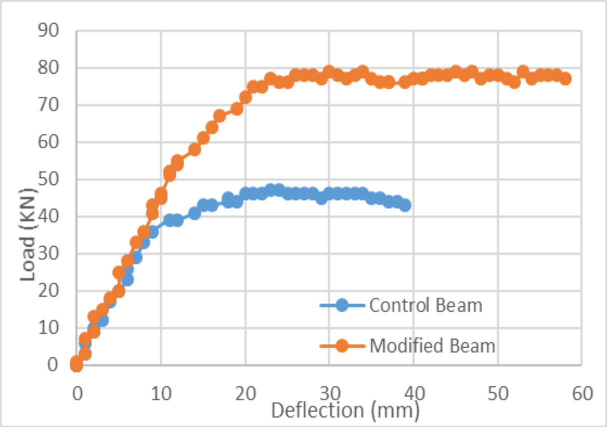


Fig. 4: Load deflection curves

E. Energy Absorption Capacity

The energy absorption capacity of the reinforced concrete beams is the area under the load-deflection curves of each beam. It can be deducted from the results that since the area under the load-deflection curve is larger for the modified concrete beams, the energy absorbing capacity or toughness is improved. From the area under the load-deflection curve, calculated using numerical integration using Microsoft excel, the energy absorbing capacity of the modified concrete beams increased by 60.55% compared to the control concrete beams. This might be due to the part that the PET fibre strips play towards preventing micro cracks from propagating by means of stitching them [8]. The strength development of the beam from the addition of fly ash might also have played a role in enduring more load as large deflections take place.

F. Cracking Mode and Failure Pattern of Beams

The results also show that cracks formed in the mid third section both for the control and modified beams (Fig. 5). Initially the cracks occurred at the bottom section of the beam and progressed to the top section getting wider as loading increased up to failure. The first crack appeared at 16 seconds for the control beams and at 25 seconds for the modified beam.

It was clearly seen, from the crack distribution, the control beam had a typical flexural failure by yielding of the tensile reinforcement. The cracks distribution of the modified concrete on the other hand, indicated that the specimens failed both by compression of concrete and yielding of tensile reinforcements. Although both concrete mixes had the same compressive strength values and both beams had the same tensile reinforcement arrangements, the modified beam failed by compression and yielding of the reinforcement. It is possible that the compression failure might have occurred due to increased deflection in the modified concrete beams. From the load deflection diagram it is seen that the ultimate mid-span deflection for the modified concrete beams is 32.76% larger than the control concrete beams (Fig. 4). Fig. 5 presents an illustration of the crack distribution of the beams after experimental tests.

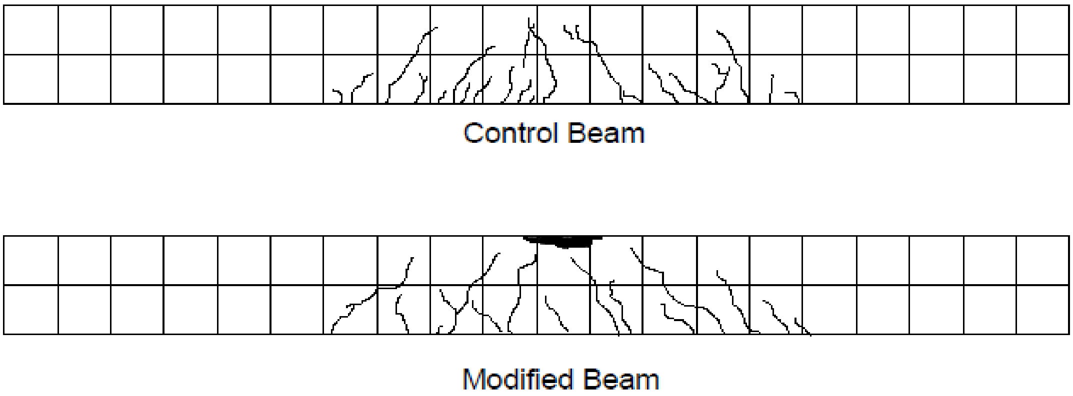


Figure 5: Crack distributions at failure

G. *Flexural Strength of Beams*

The maximum load sustained by the specimen was recorded and the flexural strength was calculated for both modified and control concrete beams using (2). In the equation, fcf is the flexural strength, in MPa (N/mm²); F is the maximum load, in N; I is the distance between the supporting rollers, in mm; b is the thickness of the specimen, in mm and d is the depth of the specimen, in mm.

$$f_{cf} = \frac{3FI}{2b(d)^2} \qquad (2)$$

Using the maximum load recorded for both the control and modified concrete beams, the flexural capacity is calculated to be 19.35 and 34.65 MPa, respectively. This shows that the flexural strength has increased by 43.91%. The most possible reason for the increment of the ability of modified concrete beams to withstand failure in bending would be one of following. First, the role PET fibres play as reinforcements in prevention of the fine micro cracks that are formed at the initial stages of loading from propagating. Second, the role fly ash plays in increment of the effective load resisting cross-section due to better bonding between the modified concrete and reinforcement bars. This leads to higher strength development of the paste as fly ash contributes in continuing hydration reaction even as time passes.

IV. CONCLUSIONS

This study investigated the effect of using PET fibres and fly ash on the engineering properties and flexural performance of concrete. The results show that:

- There was improved ductility and load carrying capacity for beams made from the modified concrete mix. The relative ductility index of the modified concrete beams improved by 27.39% as compared to the control. On the other hand, the load carrying

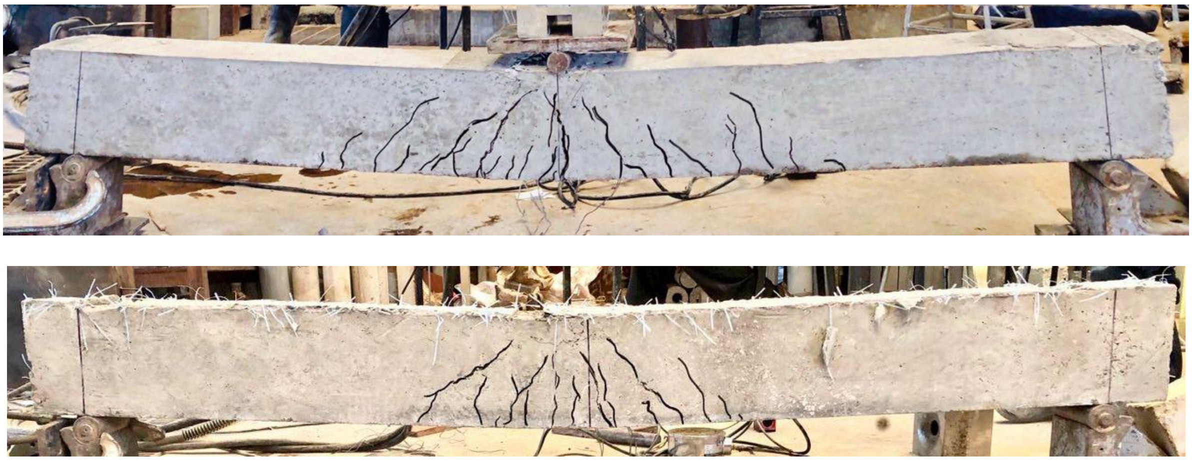


Figure 6: Control Beam (top) and Modified Beam (bottom) after testing

capacity of the concrete beam increased by 51.2% at initial crack and 44.16% at failure load.

- The energy absorption capacity and stiffness behaviour of concrete beams increased with addition of PET fibres and fly ash by 60.55%.
- The cracks for both the control and modified concrete beams occurred in their mid-third section. The initial crack for the control concrete beam appeared at 16 seconds for a load of 20 kN; it was delayed to 25 seconds for a load of 41 kN for the modified concrete beam.
- The flexural capacity or modulus of rapture of the concrete also increased by 43.91% as PET fibres and fly ash were incorporated in the mix.
- PET fibres do not react chemically but act as bridging reinforcements to arrest micro cracks.

REFERENCES

[1] Van den Berg, S. Integration of the informal sector in PET bottle collection and recycling: South Africa, Ecuador, and Columbia, Waste. (2014), Available online: http://www.waste.nl

[2] Kenya targets to recycle 14,000 tonnes of plastic bottles. Available online: https://www.google.com/amp/s/www.standardmedia.co.ke/mobile/amp/article/2001305050/kenya-targets-to-recycle-14-000-tonnes-of-plastic-bottles (accessed on 18th June 2019)

[3] Akçaözoğlu, S., Atiş, C. D., & Akçaözoğlu, K. An Investigation on the Use of Shredded Waste PET Bottles as Aggregate in Lightweight Concrete. Wst. Mngm. (2010), 30, 285–290.

[4] Kassa, R.B., Kanali, C., Ambassah, N. Engineering Properties of Polyethylene Terephthalate Fibre Reinforced Concrete with Fly Ash as a Partial Cement Replacement. J. Civ. Env. Res. (2019), 11, 25-34.

[5] Foti, D. Preliminary Analysis of Concrete Reinforced with Waste Bottles PET Fibres. Constr. Build. Mat. (2011), 25, 1906-1915.

[6] Ochi, T., Okubo, S., & Fukui, K., Development of Recycled PET Fiber and its Application as Concrete-Reinforcing Fiber. Cem. Conc. Comp. (2007), 29, 448–455.

[7] Marthong, C., Effects of PET Fiber Arrangement and Dimensions on Mechanical Properties of Concrete. IES. J.Part A: Civ. Struc. Eng. (2015), 8, 111–120.

[8] Kim, S.B., Yi, N.H., Kim, H. Y., Kim, H. J., Song, Y.C. Material and Structural Performance Evaluation of Recycled PET Fiber in Reinforced Concrete, Cem. Conc. Comp. (2010), 32, 232-240

[9] Upadhyay, R., Srivastava, V., Herbert, A., & Mehta, P. K. Effect of fly ash on flexural strength of portland pozzolona cement concrete. J.Acad. Ind. Res. (2014), 3, 218-220.

[10] Solanki, J. V., & Pitroda, J. Flexural strength of beams by partial replacement of cement with fly ash and hypo sludge in concrete. Int. J. Eng. Sci. Innov Tech. (2013), 2, 173-179.

[11] BS EN 206. Concrete Specification, Performance, Production and Conformity; British Standards Institution: London, UK, 2014.

[12] BS 8500-2. Concrete Complementary British Standard to BS EN 206: Constituent Materials and Concrete; BSI Standards Ltd.: London, UK, 2012.

[13] BS EN 1992, Eurocode 2, Design of concrete structures. EUROPEAN COMMITIEE FOR STANDARDIZATION, Belgium, 2004

[14] BS EN 12390-5. Testing Hardened Concrete, Flexural Strength of Test Specimens; British Standards Institution: London, UK, 2009.