Environmental Technology & Science Journal
Vol. 10 Issue 1 December 2019

Flexural Strength Characteristics of Concrete Modified with Pulverised High Density Polyethylene

[1]Anum, I. [2]Job, O. F. & [2]Dakas, A. I. I.
[1]Department of Building, Modibbo Adama University of Technology, Yola
[2]Department of Building, University of Jos, Jos
ioranum@gmail.com

Reuse of waste plastics as filler materials in concrete matrices as an environmentally friendly construction material has drawn attention of researchers in recent times. These research efforts have potentials for improving on the inherent weaknesses of concrete such as its poor flexural behaviour. This research work studied the flexural strength characteristics of grades M25 and M50 concretes prepared using the BRE mix design method. The concrete mix was modified with pulverised high density polyethylene at (0, 0.25, 0.5, 0.75 and 1%) by weight of cement. Hydroplast-500, a high range water reducing agent was used throughout the study in order of 1000litres/ 50kg by weight of cement. A constant water/cement ratio of 0.4 and 0.36 was adopted for requisite workability for grades 25 and 50 concretes respectively. After 28 days of curing in water, the concrete beams prepared using 100 X 100 X 500 mm steel moulds were removed from water, dried and tested for their flexural strengths. The modulus of rapture of the various concrete beams was then computed. Results obtained shows that 0.5% HDPE dosage improved concrete brittleness and increased flexural strength of the modified concrete up to 8.0% and 11.7% for grades 25 and 50 concretes respectively. It was concluded that there will be significant reduction of reinforcements in tension of structural members subjected to bending with the modified concrete, especially where light weight is desired.

Keywords: Flexural strength, Modified Concrete, Pulverisation, Chemical treatment, High Density Polyethylene

Introduction

Concrete is the dominant material used for building and civil engineering infrastructures, however, ordinary concrete experiences inherent shortcomings such as brittleness, low resistant to crack and low tensile strength (Chung, 2004). These shortcomings according to Vajje and Krishna-murthy (2013) are as a result of micro-cracks propagation which eventually lead to brittle fractions in concrete, which is a major setback since it can cause sudden and catastrophic failure, especially in structures which are susceptible to tensile loads, earthquake, blast, or suddenly applied loads (Kandasamy & Murugesan, 2011). The weakness in tension can be overcome by the use of conventional steel bars reinforcement and to some extent by the mixing of a sufficient volume of certain fibers (Nataraja & Dhang, 1999).

Naik *et al.* (1996) investigated the effects of post-consumer plastics in concrete and found out that crack growth and propagation characteristics of concrete are improved by inclusion of flexible filler such as plastic materials which causes relaxation of stresses due to deformation that occurs during loading. A study by Siddique *et al.* (2007) revealed that the use of waste plastics in concrete production, not only improved the properties of concrete but also made concrete economical and helped in reducing disposal problems. The improvement in concrete properties is due to their light weight, high strength to density ratio, improved heat resistance and corrosion resistance, increased resistance to permeability and very low moisture absorption that makes it a material of choice in building and civil engineering fields (Dorigato *et al.*, 2012).

United Nations Environment Report ([UNER], 2018) estimated that only 9% of plastic waste ever produced has been recycled, 12% is been incinerated and the remaining 79% is accumulated in landfills, dumps or the natural environment. The plastic wastes generated blemish rural and urban scenery, causing damage to ground water, air and soil, flooding, choking of livestock and fish, entangle birds and threaten animals in general. In Nigeria, over 2.5 million tons out of 32 million tons of solid waste generated annually are of plastic origin (Bakare, 2019). According to Plastic Insight Report (2019), polyethylene is one of the most used polymer globally with 103 million tons produced globally in 2016 and high density polyethylene accounting for 47.5 million tons representing 46% in total polyethylene production globally.

High density polyethylene is defined by density of greater or equal to 0.941g/cm^3 (Tasie, 2010). Pulverised HDPE that have been reclaimed and reduced to smaller particles by grinding to create a new material with smaller particle sizes and improved surface area (Plastic Waste Management Institute, 2009). Although there are several types of concrete with different materials and purposes, pulverised high density polyethylene concrete is a composite material consisting of cement based matrix with ordered or randomly distributed particles of high density polyethylene material as admixtures.

The flexural strength of concretes made with plastic replacing coarse aggregate recorded 5% increase in flexural strength over the normal concrete according to Patil *et al.*, (2014). Similarly, the highest value of 6N/mm^2 was recorded at 0.8% inclusion of plastic pieces over 4N/mm^2 of normal concrete at 28 days of curing in water (Raghatate, 2012). A separate study by Anum and Job (2011) recorded a 16% increase in flexural strength over control specimens with the additon of 0.5% fractions by weight of polyethylene shreds to concrete. Unfortunately, all previous research attempts by Naik *et al.* (1996); Anum & Job (2011); Patil *et al.* (2014) and Ragghatate (2012) made use of plastics which presented wider surface areas (which may have inhibited hydration of cement) or were not treated (which may have affected their bonding to cementing materials).

Separate studies by Marzouk *et al.* (2007) and Corodaba *et al*. (2013) further revealed that the surface texture, sizes, shape, quantity and morphology of the filler materials substantially influences the physical and mechanical properties of plastic concrete. Therefore, this research is premised on improving the effectiveness of plastic filler materials in concrete through pulverisation and chemical treatment of the surfaces to improve its bonding to cementitious materials. To achieve this, the present study characterised the properties of pulverised and chemically treated high density polyethylene. The study further evaluated their effects on flexural strength characteristics of concrete injected with superplasticizer with a view to producing a sustainable and environmentally friendly concrete for building and civil engineering applications.

Materials and Methods

Materials

The materials used in this research are: 'BUA' (42.5R grade) brand of ordinary Portland cement conforming to ASTM C 150 (2004). Pulverised high density polyethylene which were sourced from landfills in Jimeta, Yola North local government Area of Adamawa State, Nigeria. The high density polyethylene (HDPE) were first sorted, cleaned and mechanical pulverized into smaller particles passing 2mm BS sieve and chemically treated with 20% hydrogen peroxide to make the particles hydrophilic. Sieve analysis was then performed on the pulverised high density polyethylene after taking the samples to approximately saturated surface dry (SSD) condition as shown in figure 1.

Figure 1: Pulverised and Sieved High Density Polyethylene

Hydroplast - 500 conforming to ASTM C 494 (2005) was procured at Armosil West Africa Garki, Abuja. Good quality zone I river sand passing through 4.75mm BS sieve sourced from Jere town in Kagarko Local Government Area of Kaduna State was used. The suitability of the sand for the intended use was ascertained in the laboratory in accordance with the provisions of BS EN 12620 (2013). 20mm nominal sizes natural machined crushed rock sourced at Dutse Alhaji, Abuja and Potable water obtained from Nigerian Building and Road Research institute laboratory, supplied by the Federal Capital Territory Water Board was used. This water was used throughout this research work both for mixing as well as curing of the concrete and in accordance with the provisions of ASTM C1602/C1602M (2018). The properties of the materials are presented in Table 1.

Determination of Specific gravity of HDPE

The specific gravity of a material is regarded as the ratio of the weight of a given volume of that material to the weight of an equal volume of water displaced. The specific gravity of the pulverised HDPE was determined by pyknometer procedure in accordance to the provisions of BS EN1097-7 (2008) after the samples were oven-dried for 24 hours at a temperature of 50ºC. The specific gravity bottle (SPG)/pyknometer was dried completely and weighed with its cap tightly screwed (M_1). The cap was marked initially, so that the cap was screwed by the same amount each time. The cap was unscrewed and dried pulverised HDPE from the oven were placed in it and weighed against (M_2). The SPG bottle having the pulverised HDPE in it was filled with water completely up to the specified mark and weighed again by wiping the outer surface of the bottle with cotton cloth (M_3). The SPG bottle was completely filled with kerosene up to the mark without the HDPE and weighed (M_4). The weighing was done using electronic balance and the specific gravity of the pulverised HDPE was determined using the expression as shown in equation (1)

$$specific\ gravity = \frac{M_2 - M_1}{(M_3 - M_2) - M_4 - M_1} \times 1 \quad \ldots\ldots\ldots\ldots (1)$$

This test was repeated for three samples and the average value determined and taken as the representative value of specific gravity of the pulverised High Density Polyethylene.

Workability Studies

Slump and compaction factor tests were adopted for this research work as a measure of the workability in accordance to the provisions of BS EN 12350-2 (2009) and BS EN 12350-4 (2009). The results obtained indicated that increase in HDPE content initially was generally similar to that of the control mix up to a maximum of 0.5% dosage before a gradual decline in slump/compaction factor as shown in Table 2. This trend could be attributed to the fact that the HDPE had a closed cellular structure with a negligible water absorption capacity (approximately zero), hence could not significantly affect the slump of the concrete containing HDPE. The further decrease in slump beyond 0.5% HDPE content could be as a result of the non-uniform shapes of the HDPE which results to low fluidity.

Table 1: Properties of Materials Used

Properties	Cement	HDPE	Fine Aggregate	Coarse Aggregate	Hydroplast-500
Specific Gravity	3.15	1.03	2.66	2.62	1.175
Standard Consistency	30%	-	-	-	-
Initial Setting Time (min)	60	-	-	-	-
Final Setting Time (min)	320	-	-	-	-
Bulk Density(Kg/m^3)	1440	-	-	-	-
Compressive Strength at 3 Days (N/mm^2)	11.3	-	-	-	-
Compressive Strength at 7 Days(N/mm^2)	25	-	-	-	-
Compressive Strength at 28 Days(N/mm^2)	46	-	-	-	-
Moisture Content (%)	-	0.55	0.13	0.2	-
Water Absorption (%)	-	0.067	0.38	0.29	-
Appearance	Grey	Ash-grey	-	-	Dark brown

Table 2: Workability of Fresh Concrete

Grade of Concrete	Admixture Dosage (%)	Slump (mm)	Compacting Factor	Degree of workability
M_{25}	0	110	0.96	High
	0.25	110	0.95	High
	0.5	100	0.94	Medium
	0.75	100	0.93	Medium
	1.0	85	0.92	Medium
M_{50}	0	125	0.98	High
	0.25	125	0.96	High
	0.5	120	0.95	High
	0.75	120	0.95	High
	1.0	115	0.95	High

Density of Concrete

The densities of the concrete specimens under study ranged between 2390 to 2700 kg/m.^{3} This lies within the range of 2200 to 2600 kg/m^3 specified as the density for normal weight concrete (Neville, 2000). It was further observed that the densities increased with the curing age and decreased with an increase in the HDPE content. The above findings were consistent with the findings of Silva *et al* (2013) and Anum and Job (2011) that the density of concrete incorporating plastic materials decreased with increased substitution level of the plastic materials. This phenomenon could be attributed to the lower density of the HDPE compared to that of the aggregates leading to reduction in overall density of the concrete.

For Grade M25 concrete beams, the highest decrease of 8.75% was recorded with 1% HDPE content at 28 days of curing in water compared to the control mix. Also, for Grades M50 concretes, the highest decrease of 5.2% was recorded with 1% HDPE at 28 days of curing in water respectively compared to the control mix.

Preparation of Specimen

The concrete specimens were prepared at the Materials and Concrete laboratory, Nigerian Building and Road Research Institute (NIBRRI) headquarters Abuja, Nigeria using 100 x 100 x 500 mm steel

moulds. The beams were prepared in accordance with the provisions of BS EN 12390-5(2009). Concrete mixes were prepared using the BRE method of mix design. Table 3 shows the quantity of materials required per cubic metre of concrete as computed by the mix design. Investigation was carried out on Grade 25 and grade 50 concretes representing medium strength concretes (grade 25) and high strengths (grade 50) concretes respectively.
The samples were prepared with pulverized HDPE of fine consistency, precisely those passing through 2.00mm BS sieve and added in percentages of (0, 0.25, 0.5, 0.75 and 1) by weight of cement. Dosages of *hydroplast-500* in order of 1000litres/ 50kg by weight of cement was used throughout the study as recommended by the manufacturers to enhance the workability of the matrix. A constant water/cement ratio of 0.4 and 0.36 for requisite workability was adopted for grades 25 and grades 50 concretes respectively after trial mixes.

The fresh concrete was cast into the appropriate moulds (figure 2) and vibrated for at least 25 seconds in accordance with ASTM C 192/ C192M (2018) using an electrically operated small size poker vibrator.

Table 3: Quantity of Ingredients Required (kg) Per Cubic Metre of Concrete

		Concrete Grades	
Ingredient (Kg)		**C25**	**C50**
Cement		360	430
Fine Aggregate		630	570
Coarse Aggregate		1330	1330
Water		145	155
Hydroplast-500		7.2	8.6
Pulverized HDPE			
	0.0%	*0*	*0*
	0.25%	*0.90*	*1.08*
	0.50%	*1.80*	*2.15*
	0.75%	*2.70*	*3.25*
	1.0%	*3.60*	*4.30*

Figure 2: Concrete Beams cast with 100 X 100 X 500 Steel Moulds

Flexural Test

After 24 hours of casting, the concrete beams were demoulded, weighed and completely cured in water tanks. At the end of 28 days of curing in water, the concrete beams were brought out of water and allowed to dry before testing for their flexural strength using four point loading system on a universal testing machine. The modulus of rupture (f_{bl}) was then computed based on the formula stated in equation (2) at 28 days of curing.

$$M_{max} = \frac{PL}{6}$$

$$Z = \frac{bd_2}{6}$$

$$(f_{bl}) = \frac{M}{Z} = \frac{PL}{bd2} \quad \ldots\ldots\ldots\ldots (2)$$

Where: P = maximum total load in KN;
L = length of the specimen
b = breadth of the specimen;
d= depth of the specimen.
M_{max} = maximum moment and Z = section modulus

Results and Discussion

Figures 3 (a) and (b) show the relationship between beam flexural strength of the hardened concrete beams and the curing periods up to 28 days for Grades M25 and M50 concretes respectively. It was observed during the test that all beam specimens failed by rapture and all the failures occurred within the middle third span of the beam as shown in Figure 4.

The results further indicated that for all the concretes investigated, the flexural strength in each case increased progressively with curing age. The results also showed that the HDPE content in the mixes tended to increase the flexural strength of the concretes up to a maximum of 0.5% HDPE dosage, beyond which the flexural strength began to decrease.

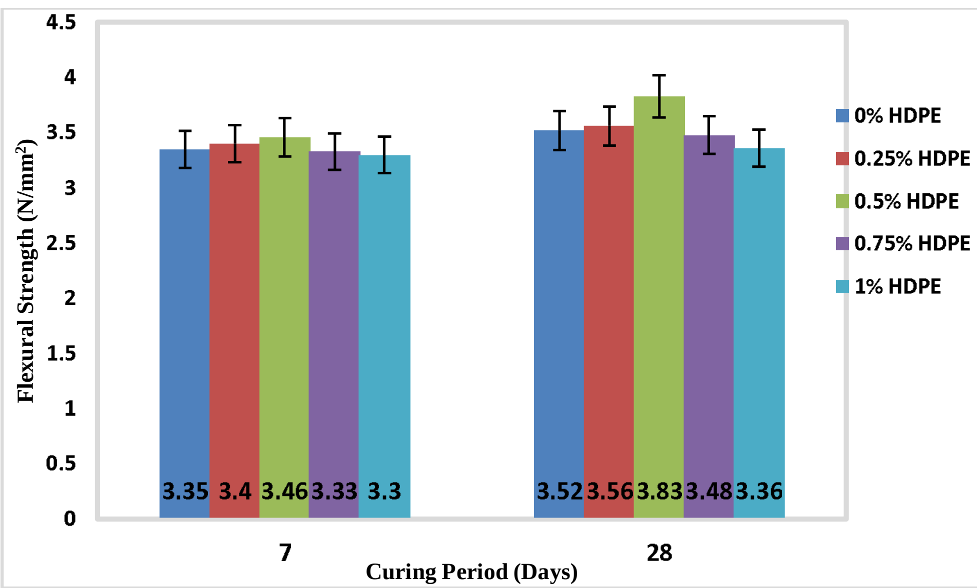

Figure 3 (a): Flexural Strength with curing period for M25 Concrete

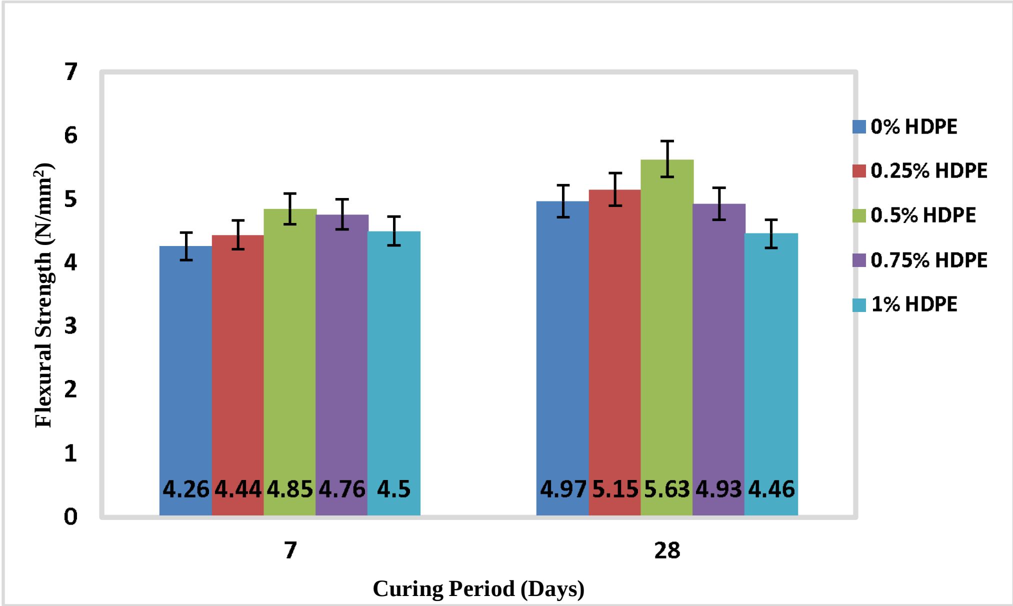

Figure 3 (b): Flexural Strength with curing period for M50 Concrete

Figure 4: Beam Specimen Tested in Flexure showing Failure at the Middle Third-Span

This phenomenon could be interpreted to mean that restrained cement hydration reaction near the surfaces of the plastic becomes more beyond 0.5% dosage of the pulverized HDPE accounting for this decrease in strength.

For Grades M25 concretes, a maximum flexural strength increase of 8.0% over control samples was obtained with 0.5% HDPE dosage, also a maximum flexural strength increase of 11.7% was obtained with same 0.5% HDPE dosage for Grades M50 concretes. This trend in flexural strength increase was observed to be consistent with the findings of Patil *et al*. (2014) using concrete made by replacing coarse aggregate with shredded post -

consumer plastics and Anum and Job (2011) using shredded polyethylene as admixtures in concrete. The increase in flexural strength could be as a result of the high values of flexural modulus of the HDPE and the stress transfer that occur when the treated HDPE particles fill up the split portions of the matrix and thus supporting the load.

Conclusion

The following conclusions were drawn from the investigation of flexural strength characteristics of concrete modified with pulverised high density polyethylene;

It was observed that the M50 grade beams recorded higher flexural strength compared to the grade M25 beams. This development was not unexpected since the grade M50 beams have a higher water to cement ratio hence a denser microstructure resulting to more resistance to failure. It was further observed that the inclusion of pulverised HDPE improved concretes' brittleness and the failure pattern. Hence, concrete modified with pulverised HDPE at failure may likely allow ample time for evacuation of occupants before complete failure. The addition of pulverised HDPE increased the flexural strength of the modified concrete up to 8.0% and 11.7% for grades 25 and 50 concretes respectively both at 0.5% HDPE dosage. This informs that there could be significant reduction of reinforcements in tension of structural members subjected to bending with the modified concrete, especially where light weight is desired.

References

Anum, I. & Job, O.F. (2011). Performance of Concrete Reinforced with Polythene. *Nigerian Journal of Construction Technology and Management*, 12 (1&2), 16 – 20.

ASTM C 150 (2004). *Standard Specification for Portland cement*, Philadelphia, U.S.A.: American Standards of Testing Materials.

ASTM C 1602/ C1602M (2018). *Standard Specification for Mixing Water Used in the Production of Hydraulic Cement Concrete*, American Standards of Testing Material International 1916 Race Street, Philadelphia, Pa 19103, USA.

ASTM C 192/ C192M (2018*). Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*, American Standards of Testing Material International 1916 Race Street, Philadelphia, Pa 19103, USA.

ASTM C 494/494M (2005). *Standard Specification for Chemical Admixtures for Concrete*, Philadelphia, U.S.A.: American Standards of Testing Materials.

Bakare, W. (2019). Solid Waste Management in Nigeria https://www.bioenergyconsult.com/solid-waste-nigeria/ [Retrieved: November, 2019]

British Standard Institution (2002).BS EN 1008; Mixing *Water for concrete*. 389 Cheswick High Road, London: British Standard Institution.

British Standard Institution (2008). BS EN 1097*: Tests for Mechanical and Physical Properties of Aggregates. Determination of the particle density of filler. Pyknometer method.* 389 Cheswick High Road, London: British Standard Institution.

British Standard Institution (2009) BS EN 12350-2: *Method for Determination of slump*. 389 Cheswick High Road, London: British Standard Institution.

British Standard Institution (2009) BS EN 12390 –5; *Method of Determination of Flexural Strength of Concrete Beams*. 389 Cheswick High Road, London: British Standard Institution.

British Standard Institution (2009).BS EN 12350 – 4; *Method of Determining Compaction Factor*. 389 Cheswick High Road, London: British Standard Institution.

British Standard Institution (2013). BS EN 12620*: Aggregates for concrete, Sands and Fillers.* 389 Cheswick High Road, London: British Standards Institution.

Chung, D. D. L. (2004). Use of Polymers for Cement – based structural Materials *Journal of Material Sciences*, 39 (9), 2973 – 2978.

Corodoba, L.A., Martinez-Barrera, G., Diaz, C.B., Nunez, F.U. & Yanez, A.L. (2013). Effects of Mechanical Properties of Recycled PET on Cement Based Composites. *International Journal of Polymer Science*, 2013, 1 – 6 [Retrieved: July 2016].

de Oliveria, L. A. P. & Castro-Gomes, J. P. (2011). Physical and Mechanical Behaviour of Recycled PET fibre Reinforced Mortar. *Construction and Building Materials*, 25, 172 – 1717.

Dorigato, A., D'Amato, M. & Peggoretti, A. (2012). Thermo-Mechanical Properties of High Density Polyethylene-fumed Silica Nanocomposites: Effect of filler surface area and treatment. *Journal of Polymer Research*, 19 (6), 9889 – 9899.

Kandasamy, R. & Murugesan, R. (2011). Properties of Fibre Reinforced Concrete Using Plastic Waste. *APRN Journal of Engineering and Applied Sciences*, 6 (3), 75 – 82.

Marzouk, O.Y., Dheilly, R. & Queneudec, M. (2007). Valorization of Post-consumer Waste Plastic in Cementitious Concrete Composites. *Waste management*, 27, 310 – 318.

Naik, T. R., Singh, S. S., Huber, C. O. & Brodersen, B.S. (1996). Use of Post-Consumer Waste Plastics in Cement-Based Composites. *Cement and Concrete Research*, 26 (10), 1489 - 1492.

Nataraja M. C., Dhang, N. & Gupta, A. P (1999), Stress - Strain Curve for Steel Fiber Reinforced Concrete in Compression. Cement and Concrete composites, 21(5/6), 383 – 390.

Neville A.M. (2000). *Properties of Concrete* (4thed.). Edinburgh: Pearson Education limited.

Patil, P. S., Mali, J. R., Tapkire, G.V., & Kumavat, H.R. (2014). Innovative Techniques of Waste Plastic used in Concrete Mixture. *International Journal of Research in Engineering and Technology, 3 (9),* 29 – 32.

Plastic Insight Report (2019). High Density Polyethylene (HDPE): Production, Market, Price and its Properties. [Retrieved: February, 2019] from www.plasticsinsight.com/resin-intelligence/resin-prices/hdpe/

Plastic Waste Management Institute (2009). An Introduction to Plastic Recycling. https://www.pwmi.or.jp/ei/plastic_recycling_2009.pdf [Retrieved: July, 2016].

Raghatate, A. M. (2012). Use of Plastic in Concrete to improve its Properties. *International Journal of Advanced Engineering Research and Studies*, I (3): 46 – 59. [Retrieved March, 2015] from www.technicaljournalsonline.com/ijaers/VOL%20I/.../137.pdf

Siddique, R., Khatib, J. & Kaur, I. (2007). Use of Recycled Plastic in Concrete: A Review. *Journal of Waste Management, 28 (10), 1835 – 1852.*

Song, P., Hwang, S. & Shehu, B. (2005). Strength Properties of Nylon and Polypropylene Fibres – Reinforced concrete. *Cement and Concrete Research*, 35, 1546 – 1550.

Suji, D. Natesan, S. & Murugesan, R. (2007). Experimental study of on behavior of Polypropylene Fibrous Concrete Beams. J. Zhejiang University of Science A.8 1101- 1109.

Tasie, A. O. (2010). *Basic Plastics Materials and Technology* Owerri: Adyudo press.

United Nations Environment Report (2018). Banning Single Use Plastics: Lessons and Experiences from Countries. www.unenvironment.org/interactive/beat-plastic-pollution/ [Retrieved: May, 2019].

Vajje, S. & Krishna-murthy, N. R. (2013). Study on Addition of the Natural Fibres into Concrete. *International Journal of Science and Technology Research*, 2(11), 213 – 218.