Environmental Waste Management through the Utilization of Waste Plastics Polyethylene Terephthalate (PET) and Low Density Polyethylene (LDPE) as Partial Replacement of Sand in the Production of Concrete Blocks

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ABSTRACT

M30 concrete grade was produced using ACI mix design proportioning method in the ratio 1:1.5:2.6 (cement: sand: coarse aggregate) and a water-cement ratio (W/C) of 0.40. WPET and WLDPE were utilized in the production of plast-crete, by percentage replacement by volume of 10%, 20%, 30%, 40%, and 50% of sand with waste plastic. The following samples were produced 110 cubes of 100mm×100mm×100mm for compressive tests, 110 cylinders of 100mm×200mm for split tensile tests, 110 prisms of 100mm×100mm×500mm for flexural tests and discs of 100mm×50mm are used for water absorption tests.

The influence of introducing waste PET and LDPE on the compression, tensile, flexural and absorption on the plast-crete, was investigated and compared with that of the convectional concrete (CC). The WPET filled concrete (CP) at 10% replacement, showed a slight decrease of 7%, 8.52% and 8.12% for compressive, split tensile and flexural strength respectively for a period of 28 day cure period compared to that of the CC. In addition, the CP at 10% replacement, showed a slight increase in the water absorption of 4.48% for 28 day cure period compared to that of the CC. The WLDPE filled concrete (CL) at 10% replacement, showed a slight decrease of 10.65%, 10.16%, and 12.52% for compressive, split tensile and flexural strength, respectively, for a period of 28 day cure period compared to that of the CC. However, the CL at 10% replacement showed a slight increase in the water absorption of 9.70% for 28 day cure period compared to that of the CC. Overall the compressive, tensile and flexural strength of the CP was slightly higher than that of the CL. Despite the slight decrease in the compressive, tensile and flexural strength of CP and CL, both concrete mixes showed good workability, and compressive strength of between 20 to 40N/mm^2 which is still very good for the production of fancy blocks for pedestrian walk ways, slabs, partition walls, fences, low-cost housing and light traffic structures, and this was achieved when 5 to 50% WPET and 5 to 40% WLDPE were utilized. In conclusion, CP and CL offer high potential in cost reduction, good cost desirability factors in strength and can be effectively utilized as a tool for disposing our waste plastics and in the process achieve a cleaner environment, create a better and more effective waste management system, create jobs, and help to expand the waste to wealth initiative proposed by the Federal Government of Nigeria.

(Keywords: waste plastics, environmental waste management, concrete blocks, compressive strength)

INTRODUCTION

Waste plastic is a menace in a developing country like Nigeria, where the government is suffering from limited funds and poor waste management system, coupled with high level of illiteracy and lack of proper orientation of the populace which has also made source sorting and separation of plastic wastes difficult and almost impossible Adekunle *et al.* (2012). The effects of plastic wastes include blocked drainages, flooding, destruction of aquatic life and water pollution. Thus, the need to provide a very robust, ingenious and cost-effective ways of disposing of our plastic wastes rather than the conventional method of dumping in landfill sites with its detrimental effects to the environment is very important if the country is to fit into the committee of nations in this twenty-first century, considering her rapid population growth which is estimated to reach a whopping 420 million in 2050, United Nations WPP (2015).

Some of the most abundantly used plastics in Nigeria are Polyethylene Terephthalate (PET) and Low Density Polyethylene (LDPE). These plastics are used for tubing, bottles, and flexible packaging, but after usage; no plan is made to collect these waste plastics and dispose of them efficiently without any detrimental impact on the environment. The author(s) are interested in using these waste plastics as fillers to partially replace sand in concrete blocks and producing light weight concrete for non-structural application(s) for the construction industries. Many authors have studied the effect of waste plastics used as fillers in concrete. Some of the properties studied include compressive, split tensile and flexural strengths, density, water absorption, void and cost implications.

Choei, *et al.* (2005), Marzouk, *et al.* (2007), and Manasear and Dalal (1917), in their studies, reported that the densities of plastic filled concrete reduced as the plastic content in the concrete increased.

Batayneh, *et al.* (2006), in his study reported that when up to 20% of plastic and crushed concrete was used in concrete, the compressive and splitting tensile strengths reduced compared to the conventional concrete (CC).

Kahademzadeh, *et al.* (2008), in his study showed that the introduction of recycled powdered High Impact Polystyrene (HIPS) with a polymer-cement ratio of 10, 15, and 20 wt %, showed a gradual decrease in compressive strength.

The compressive strength of the plastic filled concrete showed a decrease in compressive and split tensile strength as the quantities of waste plastics increased, (Zainab, *et al.,* 2008).

Vanitha, *et al.* (2015) used waste plastics to replace coarse aggregate from 0-10% and the study showed that there was a gradual reduction in compressive strength as the quantity of waste plastic increased.

The study of Rahman, *et al.* (2012), showed that an increase in Poly urethaneformaldehyde (PUF) in the concrete increased the water absorption of the concrete.

Hossian, *et al.* (2016) showed that water absorption increased as the quantity of waste plastics used to replace the coarse aggregate increased, the highest being at 20% volume of plastics at 28 day cure in water.

Zainab, *et al.* (2008), reported in her study that the introduction of waste plastics as fillers for partial replacement of aggregates saves energy and reduces the cost of concrete.

Jo, *et al.* (2006), investigated the compressive and flexural strengths of polymer concrete using an unsaturated polyester resin based on the recycled PET, and showed that this reduces the cost of material and saves energy. The author(s) in this work are keen on keying into the "waste to wealth" initiative of the Federal Government of Nigeria and chart a course where prudent and effective waste management of plastics wastes would be adopted for a more productive and cleaner environment.

MATERIALS AND METHODS

Materials

Cement: Dangote 42.5 grade Ordinary Portland Cement (OPC) was used for the work. The specification(s) used to characterize the cement was ASTM C 150 and shown in Table(s) 1 and 2, respectively.

Fine Aggregate (Sand), Coarse Aggregate (Gravel), Portable Water, WPET and WLDPE: Sand obtained from Ahmadu Bello University (ABU) Dam was utilized in the work. The Gravel was obtained from a quarry site opposite Nigerian College of Aviation Technology (NCAT) along Sokoto Road Zaria in Kaduna State Nigeria. The WPET and WLDPE were obtained from ABU dump site, Nigeria Institute of Leather and Science Technology (NILEST) dump site and Sabon Gari market in Zaria. Kaduna State Nigeria. Samples were kept and collected in accordance with ASTM D 75-03 as standard procedures for handling concrete aggregates for production of concrete blocks.

Table 1: Chemical Constituents of OPC Utilized.

Constituents	% Weight
Lime (CaO)	60.20
Silicate (SiO_2)	20.40
Iron Oxide(Fe_2O_3)	3.48
Loss on Ignition	0.75
Aluminium Oxide	7.89
Chemical Constituent of Cement	
Tricalcium Silicate	50.20
Dicalcium Silicate	21.50
Tricalcium Aluminate	9.22
Tetra Calcium Alumino Ferrite	10.89

Table 2: Physical Properties of OPC Utilized in the Study.

Properties		OPC
Specific gravity		3.15
Bulk Density		1452Kg/m^3
Initial Setting Time		35mins
Final Setting Time		300mins
Soundness (%)		0.18
% Fineness	75µm	90%
	45µm	91%
3 days Compressive Strength (MPa)		25.00
7 days Compressive Strength (MPa)		33.00
14days Compressive Strength (MPa)		38.80
21 days Compressive Strength (MPa)		42.00
28Days Compressive Strength (MPa)		45.00

Table 3: Physical Properties of Sand, Gravel, WPET and WLDPE.

Properties	Sand	Gravel	WPET	WLDPE
Shape	Rounded	Angular	Angular	Angular
Maximum Size	5.00mm	20.00mm	4.36	5.00
Nominal Maximum size	4.75mm	19.5mm	4.75	3.56
Fineness Modulus	3.14	6.95	3.59	4.17
Specific Gravity	2.65	2.52	1.38	0.92
Water Absorption	1.10	1.20	0.01	0.05
Loose Bulk Density	1630Kg/m^3	1542Kg/m^3	520.34	237.82
Compacted Bulk Density	1750Kg/m^3	1647Kg/m^3	638.98	291.16
Compaction Factor	0.931	0.936	0.814	0.864
% Void	38	43.9	62.29	74.15
% Moisture Content	2.0	1.10	Nil	Nil

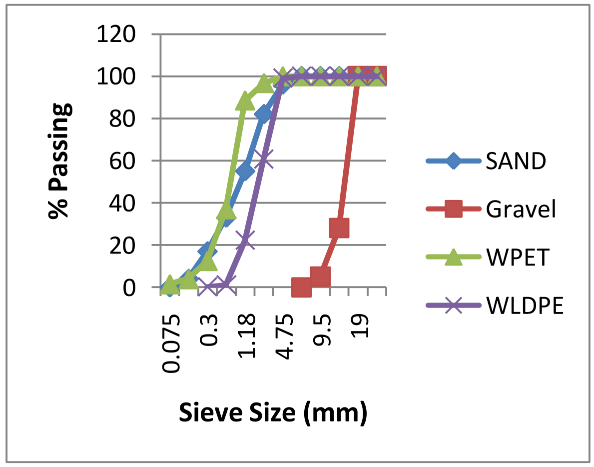

Figure 1: Particle Size Analysis of Sand, Gravel, WPET and WLDP.

METHOD

Mix Design Formula

The mix design proportioning method for the M30 grade concrete produced was 1: 0.39: 1.50: 2.59, CMT, water, sand and gravel, respectively, with water-cement (W/C) ratio of 0.39. The waste plastics were crushed. Sand, Gravel, WPET and WLDPE were all utilized in their saturated surface dry (SSD) conditions (ASTM C 127). The gravel was also utilized in its SSD condition (ASTM C 128) in the production of the concrete blocks. Portable water (ASTM C 114) was utilized for hydration of cement in the concrete and also for curing of the samples (ASTM C192/C192M- 16a).

The samples were cured for 7, 14, 21 and 28days to achieve maximum strength. Waste Plastics was used to replace sand from 0%, 5%, 10%, 15%, 20%, 25%, 30%, 40%, and 50%. The concrete with 0% waste plastics was utilized as the control sample. The following tests were carried out on the control sample and plast-crete and results were compared. Flexural Strength (ASTM C), Compressive Strength (ASTM C 109 - 99), Split Tensile Strength (ASTM C 496-85), Water absorption (ASTM C 140), Percent Void (ASTM C 642-06) and Cost Evaluation.

Table 4: Mix Design Proportion for CP.

S/N	% Plas-tics	Kg/m³				
		CMT	Water	Sand	PET	Gravel
1	0	420	163.54	627.93	0.00	1085.80
2	5	420	163.54	616.53	11.30	1085.80
3	10	420	163.54	565.14	22.60	1085.80
4	15	420	163.54	533.73	33.91	1085.80
5	20	420	163.54	502.34	45.21	1085.80
6	25	420	163.54	471.18	56.43	1085.80
7	30	420	163.54	439.55	67.82	1085.80
8	35	420	163.54	408.15	79.10	1085.80
9	40	420	163.54	376.73	90.42	1085.80
10	45	420	163.54	345.36	101.72	1085.80
11	50	420	163.54	313.97	113.02	1085.80

Compacted bulk density WPET=638.98Kg/m^3,
Compacted bulk density sand=1750kg/m^3,
Conversion factor=638.98/1750=0.365

Table 5: Mix Design Proportion for CL.

S/N	% Plas-tics	Kg/m³				
		CMT	Water	Sand	LDPE	Gravel
1	0	420	163.54	627.93	0.00	1085.80
2	5	420	163.54	616.53	5.24	1085.80
3	10	420	163.54	565.14	10.48	1085.80
4	15	420	163.54	533.73	15.73	1085.80
5	20	420	163.54	502.34	20.97	1085.80
6	25	420	163.54	471.18	27.20	1085.80
7	30	420	163.54	439.55	31.45	1085.80
8	35	420	163.54	408.15	36.70	1085.80
9	40	420	163.54	376.73	41.95	1085.80
10	45	420	163.54	345.36	47.19	1085.80
11	50	420	163.54	313.97	52.43	1085.80

Compacted bulk density WLDPE=291.6Kg/m^3,
Compacted bulk density sand=1750kg/m^3,
Conversion factor=291.6/1750=0.167

Compressive Strength

$f_c = P_{max} / A$ **(1)**,

where f_c= compressive strength, P_{max}= fracture Load applied on cube, A= area of cube.

Split Tensile Strength

$f_{sp} = f_t = 2P/\pi dL$, **(2)**,

where f_{sp}= Split Tensile Strength, P = Fracture Load, d and L= Diameter and Length of specimen.

Flexural Strength

$F_b = PL/bd^2$, **(3)**,

where P = fracture load, L= Supporting roller distance, b= width of beam, d= Depth of beam.

RESULTS AND DISCUSSIONS

Effect of the Quantity of Waste Plastics and Number of Cure Days on the Compressive, Split Tensile and Flexural Strength on CP and CL

Figure 2 and Figure 3 showed the Compressive Strength for various cure days for various percentages of waste plastics replacement for CP and CL. The figures showed a gradual reduction in compressive strength as various quantities of waste plastics was used to replace sand increased for 7, 14, 21, and 28 day cure in water. For CP at 28 day cure the compressive strength decreased by 3.51%, 7.01%, 10.52%, 14.03%, 17.53%, 20.91%, 24.55%, 25.45%, 31.56%, and 35.06%, respectively, compared to the CC as WPET was used to replace sand from 5% to 50%.

For CL at 28 day cure, the compressive strength decreased by 5.32%, 10.65%, 15.97%, 21.30%, 26.62%, 31.95%, 37.27%, 42.60%, 47.92%, and 53.75% respectively compared to the CC as WLDPE was used to replace sand from 5% to 50%. Figure 4 and Figure 5 showed the Split Tensile Strength for various cure days for various percentages of waste plastics replacement for CP and CL. The figures also showed a gradual reduction in Split Tensile Strength as various quantities of waste plastics was used to replace sand increased for 7, 14, 21 and 28 day cure in water. For CP at 28 day cure the Split Tensile Strength decreased by 4.47%, 8.94%, 15.42%, 17.89%, 22.37%, 26.84%, 31.32%, 35.79%, 40.26%, and 44.74%, respectively, compared to the CC as WPET was used to replace sand from 5% to 50%.

For CL at 28 day cure there was a decrease of 5.26%, 10.53%, 15.79%, 21.05%, 26.32%, 31.58%, 36.84%, 42.11%, 47.37% and 52.63%, respectively, compared to the CC as WLDPE was used to replace sand from 5% to 50%. Similarly, Figure 6 and Figure 7 showed the flexural Strength for various cure days for various percentages of waste plastics replacement for CP and CL. The figures showed a gradual reduction in Flexural Strength as increased quantities of waste plastics was used to replace sand increased for 7, 14, 21, and 28 day cure in water.

For CP at 28 day cure the Flexural Strength decreased by 3.90%, 7.80%, 11.71%, 15.61%, 19.51%, 23.41%, 27.31%, 31.22%, 35.12%, and 39.02%, respectively, compared to the CC as WPET was used to replace sand from 5% to 50%. For CL at 28 day cure the flexural Strength decreased by 5.12%, 10.24%, 15.37%, 21.71%, 25.61%, 30.73%, 35.85%, 40.98%, 46.10%, and 51.22%, respectively, compared to the CC as WLDPE was used to replace sand from 5% to 50% .

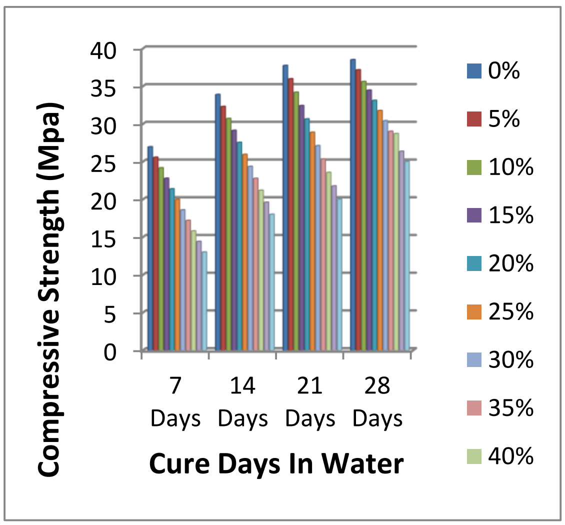

Figure 2: Compressive Strength of CP.

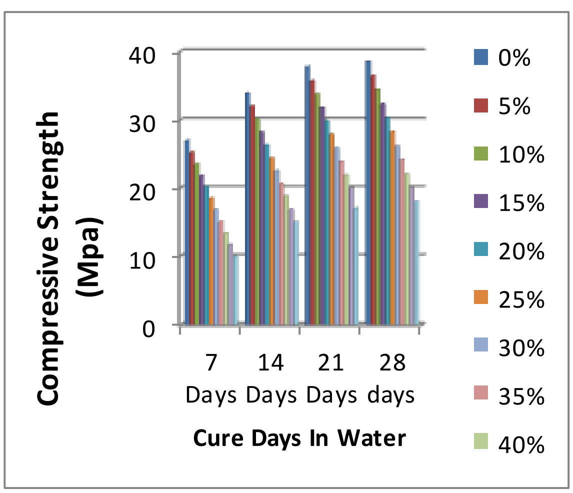

Figure 3: Compressive Strength of CL.

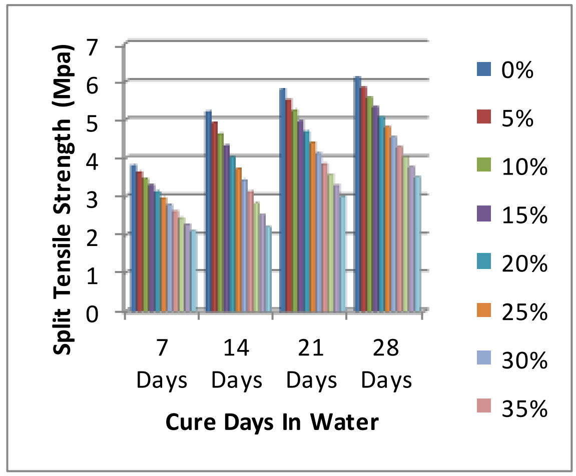

Figure 4: Split Tensile Strength of CP.

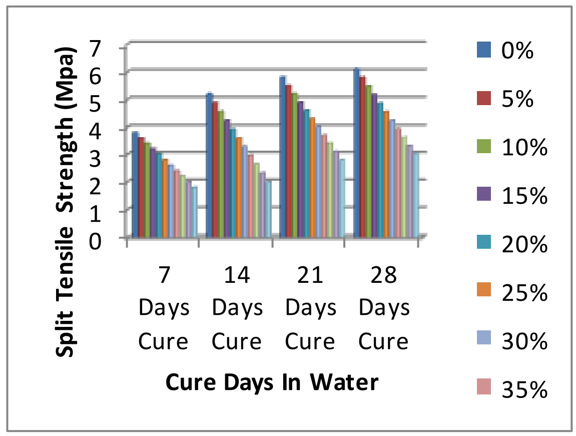

Figure 5: Split Tensile Strength of CL.

The reduced compressive, split tensile and flexural Strength(s) in the CP and CL was as a result of the reduced interfacial bonding between cement paste and waste plastics aggregate and this becomes more pronounced as the waste plastic content increases. The reduced strengths is also as a result of lower compaction of plastic compared to that of sand, the lower compaction of waste plastics is as a result of lower Specific gravity (SG) of the waste plastics compared to sand, thus, this reduces compaction and bulk, at the same time increasing the voids in the concrete which reduces the compressive, split tensile and flexural strength of the concrete. This agreed with the study of Batayneh, *et al.* (2006), whose study showed a gradual decrease in compressive, flexural and split tensile strength in the concrete as the waste plastics content used to replace the fine aggregate increased.

The slightly higher compressive, split tensile and flexural strength(s) experienced by the CP over the CL was because the particle size analysis showed that the WPET had better gradation (ZONE 2) than the WLDPE, this indicated that the WPET had better compaction, consolidation and packing density than the WLDPE thus, CP had higher strength(s) than the CL. Another reason for the lower strength(s) experienced in the CL was because the WLPE was gap graded in the 1.18mm sieve size with over 45% particle retained and did not conform to the standard for the gradation of the aggregate under Zone 1, 2, 3 or 4. This introduced more voids and porosity in the CL compared to that of the CP and caused higher strength reduction in the CL than in the CP. This agrees with the study of Lafarge (2017), which showed that gap grading in aggregates have a negative effect on the strength of concrete.

At 5% replacement of waste plastics at 28 day cure in water, the CL showed a reduction of 1.18%, 0.79% and 1.22% in the compressive, split Tensile and Flexural Strength(s), respectively, compared to the CP. Generally, at 50% replacement of sand by waste plastics at 28 day cure in water, the percentage reduction in strength for CP was below 50% while that for CL was over 50% for the compressive, tensile and flexural strength(s), respectively.

Effects of Quantity of Waste Plastics and Number of Cure Days on the Water Absorption and Percent Void of CP and CL

Figure 8 and Figure 9 showed the water absorption for various cure days for various percentages of waste plastics replacement for CP and CL after 24hrs. The figures showed a gradual increase in absorption as various quantities of waste plastics used to replace sand increased for 7, 14, 21 and 28 day cure in water. For CP at 28 day cure the compressive strength increased by 1.49%, 4.48%., 6.72%, 8.21%, 14.93%, 16.42%, 17.91%, 19.40%, 20.90%, and 23.13% respectively compared to the CC as WPET was used to replace sand from 5% to 50%. For CL at 28 day cure, the compressive strength decreased by 5.22%, 9.70%, 14.93%, 19.40%, 24.63%, 29.85%, 34.33%, 39.55%, 44.03, 49.25%, and 47.92%, respectively compared to the CC as WLDPE was used to replace sand from 5% to 50%.

The increase in water absorption in CP and CL was as a result of increased voids as a result of poor interfacial bonding between the cement paste and waste plastics used to replace sand, the pores/ voids increased as more waste plastics was introduced into the concrete in place of sand. This behavior agreed with the study of Omeheng, *et al.* (2014). The lower absorption of CP over CL was as a result of higher compaction of WPET over WLDPE, this introduced more consolidation, compaction and fewer voids. Thus, at 5% replacement of waste plastics at 28 day cure in water, CL had a higher water absorption of 235.12 % compared to CP.

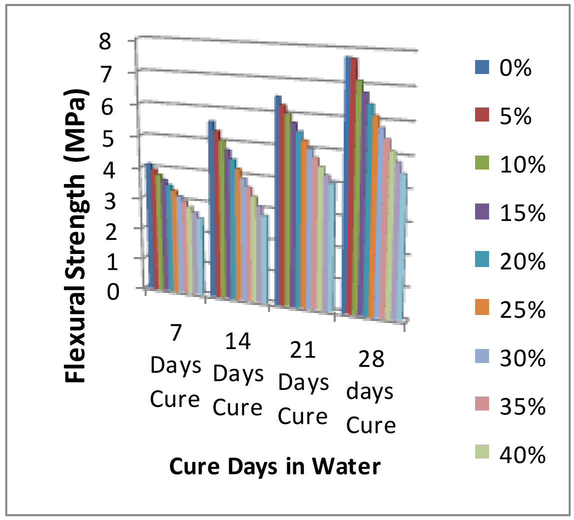

Figure 6: Flexural Strength of CP.

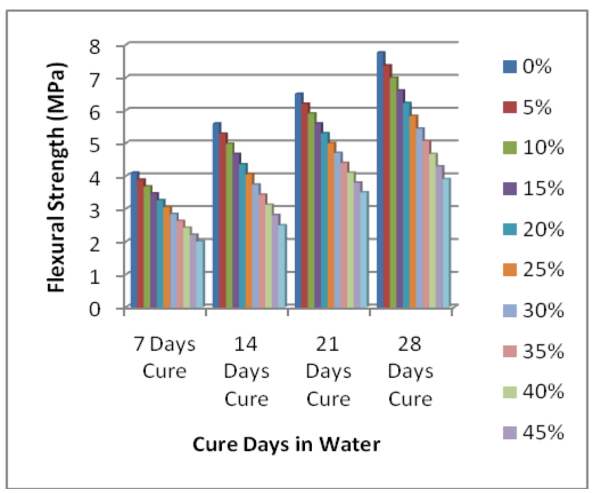

Figure 7: Flexural Strength.

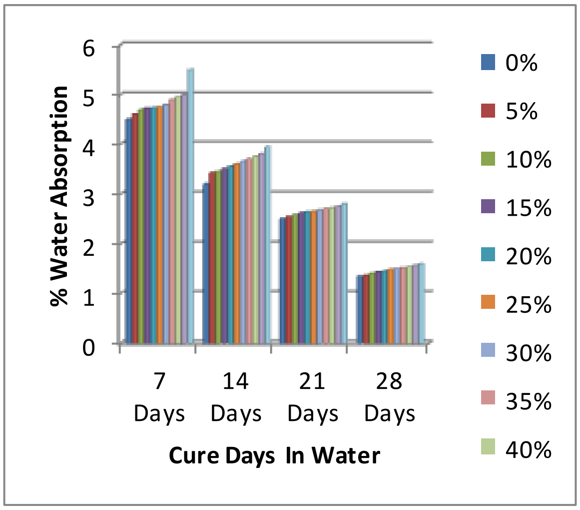

Figure 8: Water Absorption for CP in 24hrs.

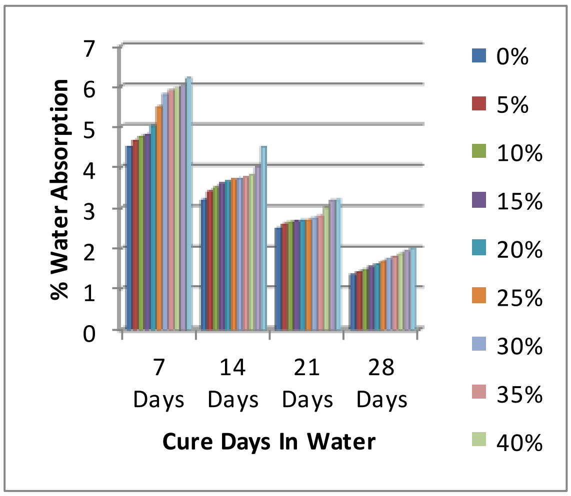

Figure 9: Water Absorption for CL in 24hrs.

Cost Analysis for CP and CL

Figure 12, showed the material cost analysis of CP and CL compared to CC. The results showed that the cost of producing CP and CL concrete reduced significantly as the percentage of waste plastics utilized to replace sand increased. This was because WPET and WLDPE are relatively cheap and abundant in the environment. They are readilly collected and are easily and cheaply processed. WPET and WLDPE are relatively cheaper than sand. The cost of 1kg of sand was about 36.80% and 71.00% higher than WPET and WLDPE, respectively.

Figure 11, showed a gradual reduction in cost as the quantity of waste plastics introduced into the concrete increased. For CP there was a reduction in cost of 0.021%, 0.629%, 0.637%, 0.849%, 1.100%, 1.270%, 1.490%, 1.700%, 1.900%, and 2.607% as WPET was used to replace sand from 5% to 50% compared to CC. For CL there was a reduction in cost of 0.077%, 0.0536%, 0.804%, 1.070%, 1.331%, 1.607%, 1.875%, 2.143%, 2.411%, and 2.752% as WLDPE was used to replace sand from 5% to 50% compared to the CC. The slightly higher cost of CP over CL can be attributed to the fact that WPET is more difficult to crush due to its higher Specific Gravity (S.G).

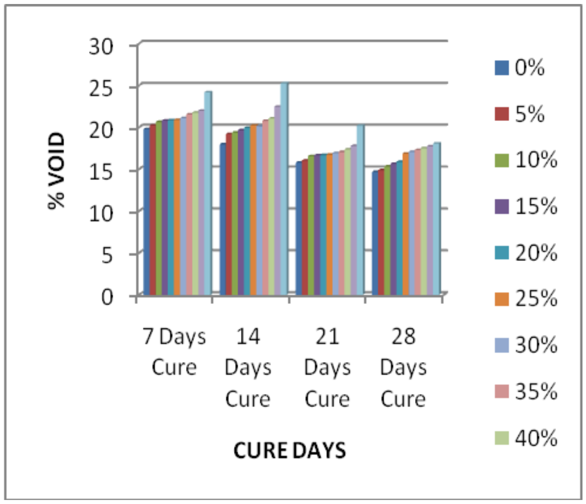

Figure 10: Percent Void for CP.

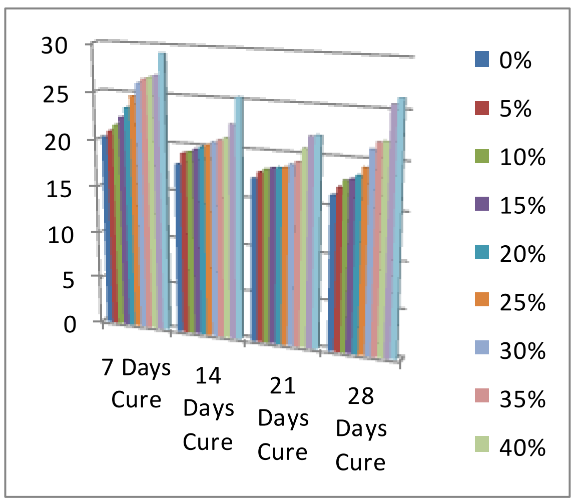

Figure 11: Percent Voids for CL.

The S.G of PET is about 32.26% higher than that of LDPE. In addition WPET had a higher bulk density than WLDPE, which implies that more WPET can be used to replace Sand compared to WLDPE for each percent replacement, which means a slightly higher cost for CP; however, this is compensated for as CP has better mechanical properties than CL.

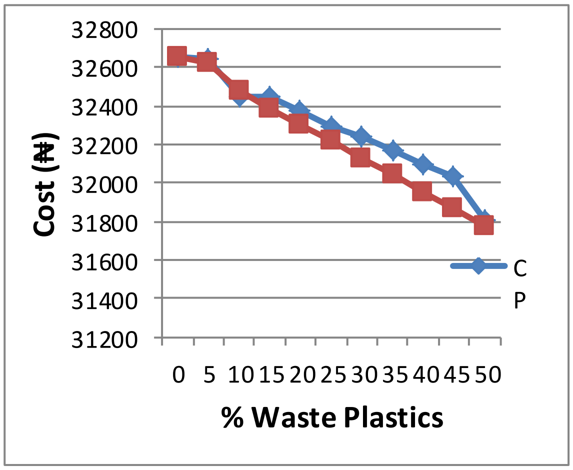

Figure 12: Cost Evaluation for CP and CL.

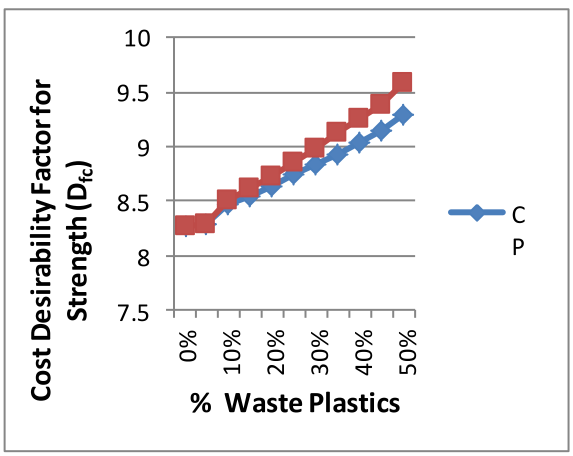

Figure 13: Cost Desirability Factor for CP and CL.

Figure 13, showed the cost desirability factor for CP and CL in terms of their compressive strength. The results showed that the desire to use CL and CP for specific end use applications increased as a result of the advantage inherent in utilizing waste plastics because it is very cheap to obtain, process and apply. The strength to cost-benefit is enormous and looks very promising for industrial applications. This shows the potentials in the utilization of CP and CL in the industry. The potentials in terms of cost-benefit are enormous in the industry. This is a major drive for the industry to cash into this opportunity.

CONCLUSION

The effect of WPET and WLDPE on the properties of CP and CL have been effectively carried out and results recorded. The properties of concrete that was tested include; compressive, tensile, flexural, water absorption, percent void content, and cost analysis of the CP and CL compared to CC.

The results showed that there was a gradual reduction in compressive, split tensile and flexural strength(s) as the quantity of waste plastics used to replace sand increased. However, water absorption, voids, and cost reduced as the quantity of waste plastics used to replace sand increased. Despite the reduction in strength(s) due to increase in waste plastic content, yet CP at 28 day cure exceeded the targeted mean compressive strength (TMCS) for M30 grade concrete produced of 30Mpa from 5-30% waste plastics content, and CL at 28 day cure exceeded the TMCS at 0-20% waste plastics content. In addition compressive strength of 20Mpa are also suitable for applications in pedestrian walk ways, fancy blocks, concrete wall partitions, fences, slabs, and low cost building could all be achieved for CP at 5-40% waste plastics replacement and CL 5-45% waste plastics replacement at 28 day cure days, this means enormous amounts of waste plastics can be utilized without compromising the integrity of the concrete block. The significant material cost reduction achieved by utilizing CP and CL make these categories of light weight concrete an attractive alternative for CC in the areas of applications mentioned above.

Though the water absorption and void increased as the quantity of waste plastics content increased, CP and CL still met the ASTM C 140 standard specifications for water absorption at 28 day cure in water of less than 7%, showing that CP and CL have relatively low permeability and resists ingress of water, thus; they are not susceptible to freezing and thawing, which are desirable properties of durable concrete. The inherent properties mentioned makes these concrete filled plastics attractive to the construction companies, creating a very significant avenue for disposing of/recycling the PET and LDPE plastic wastes in Nigeria.

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