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ORIGINAL ARTICLE

Effects of Environmental Waste Plastic Bottle Cover (EWPBC) on Physical and Mechanical Properties of Concrete

Wasiu John[1] and Osegbowa Enoguan Douglas[2]

[1]Department of Civil Engineering, Faculty of Engineering, Edo State Unversity Uzairue, Nigeria.
[2]Department of Civil Engineering, Faculty of Engineering, Edo State Unversity Uzairue, Nigeria.

ABSTRACT – The rapid industrialization and urbanization in many countries of the world are leading to great infrastructural development which, in turn results in problems like shortage of construction materials and increased productivity of wastes, which has caused environmental issues due to inadequate recycling and disposal facilities. The construction industry needs materials that can increase the strength of concrete structures with low cost and less environmental impact. This research aims to address such issues by investigating the effect of environmental waste plastic bottle cover (EWPBC) on the physical and mechanical properties of concrete. EWPBC samples was collected within the environs and used at different percentage (0%, 12.5%, 25%, 50% and 100%) replacement for coarse aggregate. The Physical properties of the materials were investigated and found to be in accordance with relevant specifications. The Mechanical properties such as compressive strength and flexural strength tests were also carried out according to relevant codes of practice. The compressive strength increases with days of curring and at 12.5% EWPBC, the strength is 4.7% higher than the conventional concrete. The flexural stress is also higher than that of the conventional beam sample at 12.5% EWPBC. The flexural strain is 0.00248-0.0036 and within the specified acceptable limit (0.002-0.0035) for concrete with a grade less than or equal to C50/C60. This shows promising properties at 12.5% EWPBC replacement and cost reduction. It was concluded that EWPBC can be used as a substitute for aggregates and a means of reducing environmental wastes and the cost of disposal of such waste.

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INTRODUCTION

Concrete is a composite material that is made up of cement (binder), coarse aggregates, fine aggregates, water, and sometimes admixtures are added to modify one or more of its properties [1],[2]. It is the most widely used construction material, due to its ease of application, strength and durability [3]. Concrete is an excellent material in compression but weak in tension. To counteract this weakness, the concrete is embedded with steel reinforcement [4]. There are different reinforced concrete (RC) members in a structure, such as beam, column and slab, etc.

Beam is a structural member which is acted upon by a system of external loads acting transversely to the axis [5] and just like other structural elements; beams are also frequently encountered in structures. It is a fact that traditional conventional materials such as concrete, and sandcrete blocks are all being produced from the existing natural resource [6]. Due to the high cost of obtaining aggregates for the production of concretes for different constructional purposes, inadequate recycling facilities of plastic waste in many developing countries and the problem associated with plastic waste disposal has become a great concern. The high increase in population has also contributed to the high usage of Polyethylene Terephthalate (PET) as a medium of packaging liquid products (like water, carbonated soft drinks, beverages, household sauces) [7]. The factors behind the growth of plastic bottles usage are not limited to low density, user-friendly designs, fabrication capabilities, long life, light weight, as well as low cost. This increase in the usage of PET has also increased the problem of environmental pollution.

Nevertheless it is a known fact that the protection and conservation of the enviroment for sustanability basis can be realised through the reduction, reuse, and recycling of waste materials [8] but the issue of inadequate recycling facilities in many countries has made these strategies(reuse and recycling) to be of great concerns[9]. It is therefore necessary to find an innovative method of making use of the waste platic PET bottle cover as construction materials – in the production of eco – friendly concrete, which will help to minimise enviromental pollution, cost of environmental waste disposal and the dependence on the conventional concrete materials.

Researchers have carried out different studies showing the effect of waste materials like plastic PET and metal cap materials in different forms on different properties of concrete. The studies conducted by [10],[11] concerning the application of PET waste in building construction showed that PET wastes can be used either partly as substitute for aggregates or wholly as aggregate in building construction.

The effectiveness of waste bottle caps as partial replacement(0%, 5%, 10%, 15% and 20%) for coarse aggregate in the production of concrete which act as solution strategy for waste disposal issues was examined by [12]. They observed

*CORRESPONDING AUTHOR | W. John | johnwasiu@yahoo.co.uk

from their study that there was increase in the compressive strength, split tensile strength and flexural strength of the concrete made with the waste bottle caps. They advised from their results that the 10% replacement of coarse aggregate with waste bottle caps be adopted for concrete production. Ishaya et al. [3] the compressive strength of concrete made with waste bottle caps(WBC) as partial replacement of coarse aggregate and orange leaves powder as plasticizer was examined. They revealed the optimum replacement to be between 5% and 15% with compressive strength of 35.85N/mm^2 and 27.02 N/mm^2.

The effects of shredded plastic PET wastes as a replacement of coarse aggregates(at 20%, 30%, 40% and 50% volumetric dosage) and 10% silica fume as a replacement by weight of cement content in concrete was done by[13]. They found out that concrete made with the plastic wastes exhibited reduction in weight and improved thermal insulating features. They also observed a decrease in the compressive strength with increase in the plastic wastes. They concluded that concrete made with high amount(40% and 50% of coarse aggregate replacement) with shredded plastic PET met the requirement for lightweight concrete as stipulated in American Concrete Institute(ACI 213 – 03) and can be used in appropriate construction purpose.

The research carried out by [14] revealed the effect of crushed waste plastic bottle caps as partial replacement of coarse aggregate in concrete which can be used in green constructions and also help to protect the environment through the reduction of solid waste disposal. They concluded from the result they obtained that the crushed plastic bottle caps enhanced both the compressive and flexural strength of the concrete, and also minimized cost when compared to the conventional concrete. They then advised that the coarse aggregate replacement with the crushed plastic bottle caps be done at 7.5%.

The study conducted by [15] investigated the effects of waste soft drink bottle cap fibers as partial replacement(0%, 5%, 10%, 15%, and 20%) of the entire weight of coarse aggregate in the production of M25 grade of concrete. They found out that there increase in the split tensile strength and a decrease in both compressive and flexural strengths as the soft drink bottle cap fibers dosage was increasing. They then concluded that the concrete made with the waste soft drink bottle cap fibers can be used in the construction of partition walls in buildings, with cost saving merit and also assisting in the reduction of environmental solid wastes.

The properties of concrete made with soft drink bottle metal cap fibers was studied by [16]. They used soft drink bottle metal cap fibers of rectangular size 10mm by 3mm at different dosage of 0.25%, 0.5%, and 1.0% of the total weight of concrete in their study. They discovered from their result that there was little increase in the compressive strength and appreciable increase in the split and flexural strength up to 1% addition when compared with the concrete without soft drink metal cap fibers. Divyabharathi and Pavithran [17] added metal caps and PET bottles fibers at the dosage of 0%, 0.5%, 1.0% and 1.5% by volume of total mixture in their study. They obtained optimum mechanical properties(compressive, split tensile, and flexural strengths) of concrete made with the waste materials at 0.5% of PET and 0.5% of bottle caps making a total of 1% dosage.

The study carried out by [18] examined the properties of concrete made with PET bottle scrap fine at distinct percentage replacement(15%, 20% and 25%) for fine aggregate. They recommended 25% for fine aggregate replacement with PET bottle scrap fine for concrete production due to the improvement they observed in the mechanical properties of concrete made with the 25% replacement. Ramadevi and Manju [19] investigated the effect of waste PET fibres at 1%, 2%, 4%, 6% replacement for fibre aggregate in concrete. They found out from their results that the concrete with PET fibers had lesser weight and there was increase in the mechanical properties(compressive strength and tensile strength) of the concrete at 2% replacement, while 4% and 6% replacements resulted into to decrease in the mechanical properties. They then recommended that 2% fine aggregate replacement with PET fibres be used for concrete production. Similarly [20] concluded from their study that concrete made with 1% PET bottle fibers as substitute for fine aggregate had better strength properties than other replacement level of 0%, 0.5%, and 1.5% respectively, while [21] recommended 3% as optimum substitution level for fine aggregate with shredded PET bottle waste material in concrete production.

Plastic fiber reinforced concrete with dosage 0.0% to 3.0% was examined by[22]. They revealed from their study that 1% fiber content gave maximum compressive strength and split strength when compared with 0% fiber concrete. It was revealed by [23] that PET bottle waste fiber at 0.5%, 1.0%, and 1.5% improved the mechanical properties of concrete.

The mechanical properties of concrete made with waste PET made into granules as replacement(1% to 8%) of sand was studied by [24]. They examined the engineering properties (slump, dry density, mechanical properties e.g compressive strength) of the concrete they made with and without granulated plastics. They discovered the optimum replacement of sand with the granulated plastics to be 2% due to the maximum compressive and split strength recorded for the 2% replacement.

Literatures have shown different studies which focused on using plastic waste bottle caps, other parts and other waste materials most especially in form of fibers for the replacement of concrete constituents in concrete, but one can rarely find the study which used waste plastic bottle cover as replacement of coarse aggregate in concrete. This studied is aimed at bridging the gap in literature by investigating the mechanical properties(compressive strength and flexural strength) of concrete made with Environmental Waste Plastic Bottle Cover (EWPBC) as partial replacement (0%, 12.5%, 25%, 50% and 100%) of coarse aggregates for different curing periods of 7, 14, 21, and 28days respectively.

MATERIALS AND METHODS

Materials

Environmental Waste Plastic Bottle Cover (EWPBC) were locally available environmental waste plastic covers (Figure 1) and were collected within Ado – Ekiti metropolis, Ekiti State, Nigeria. The cement used for this study was Ordinary Portland Cement(OPC), grade 42.5, Dangote Brand, conforming to standards stipulated in [25]. The cement was obtained from Ado – Ekiti in Ekiti State and physical properties from laboratory tests is shown in Table 1. The water used for this study was portable water obtained from the tap in Ado-Ekiti, Ekiti State. The water was clean and free from impurities and its conformed to the requirement in [26]. Fine and coarse aggregates were obtained from Ado-Ekiti metropolis and they are shown in Figure 2 and Figure 3 respectively. The fine aggregates conformed to requirements contained in [27]. The steel reinforcement bars (12mm high yield bars) were obtained from the commercial market in Ado - Ekiti metropolis. 10mm high yield bars were used as shear links as shown in Figure 4.

Figure 1. Environmental waste plastic bottle cover (EWPBC)

Figure 2. Fine aggregates

Figure 3. Coarse aggregate

Figure 4. Reinforcement bars with shear links

Determination of Specific Gravity of the fine and coarse aggregates

Specific gravity is the ratio of the mass of unit volume of soil at a stated temperature to the mass of the same volume of gas-free distilled water at a stated temperature. The specific gravity was determined with Standard Reference to [28]. The specific gravity was determined for the cement, fine and coarse aggregates and values computed using equation (1) and values tabulated in Tables 1, 2 and 3.

$$\text{Specific Gravity (Gs)} = \frac{W_2 - W_1}{(W_4 - W_1) - (W_3 - W_2)} \quad (1)$$

Where

W_1 = Weight of density bottles[g]
W_2 = Weight of sample and density bottle[g]
W_3 = Weight of sample, distilled water and density bottle[g]
W_4 = Weight of distilled water and density bottle[g]

Table 1. Properties of grade 42.5 Ordinary Portland Cement (OPC)

S/N	Physical test	Laboratory Values	References: [29],[30]
1	Fineness (retained on 90μm sieve) (%)	6.90	≤ 10
2	Specific gravity	3.15	-
3	Density (Kg/m^3)	1450	-
4	Vicat Setting time (minutes)	Initial setting time = 90 Final setting time = 256	≥ 45 ≤ 375

Table 2. Physical properties of fine aggregate

S/N	Physical test	Laboratory Values	Reference: [30]
1	Fineness modulus	2.85	2.3 – 3.0
2	Specific gravity	2.65	2.63 – 2.67
3	Apparent specific gravity	2.68	-
4	Water absorption (%)	0.55	-
5	Coefficient of uniformity (Cu)	2.18	≤ 4
6	Coefficient of curvature (Cc)	1.14	1 – 4

Table 3. Physical properties of coarse aggregate

S/N	Physical test	Laboratory Values	Reference: [30]
1	Aggregate impact value (AIV) (%)	14.3%	≤ 25%
2	Specific gravity	2.75	2.5 – 3.0
3	Apparent specific gravity	2.69	-
4	Water absorption (%)	0.61	-
5	Coefficient of uniformity (Cu)	1.57	≤ 4
6	Coefficient of curvature (Cc)	1.05	1– 4

Sieve Analysis

The sieve analysis was carried out by shaking the fine and coarse aggregates through a stack of screen with openings of known sizes. The equipment used for this analysis includes British sieve, mechanical shaker and a balance device for measuring the weight of the sample. The procedure was carried out in accordance to [31]. The coefficient of uniformity and curvature for the fine and coarse aggregates were estimated using equation (2) and (3) respectively as shown in Table 2 and 3.

$$C_c = \frac{(D_{30})^2}{D_{60}.D_{10}} \quad (2)$$

$$C_u = \frac{D_{60}}{D_{10}} \quad (3)$$

Concrete Mix Design/Concrete Mix Proportion

The Department of Environment Design (DOE) method [32] was used for the design mix and mix ratio obtained as 1:1.5:3.9 with characteristic strength of 30N/mm^2. Six different mix proportions were chosen for this study. Water - cement ratio of 0.5 was adopted for normal concrete (0% EWPBC) and in the mix containing EWPBC at 12.5%, 25%, 37.5%, 50%, and 100% percentage replacement with coarse aggregate. The mix proportions are shown in Table 4.

Table 4. Concrete mix proportion

Replacement	Cement (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	Plastic Bottle cover(EWPBC)	Water (Kg)
0% EWPBC	19.53	29.30	76.20	0.00	10.00
12.5% EWPBC	19.53	29.30	66.67	9.53	10.00
25% EWPBC	19.53	29.30	57.15	19.05	10.00
37.5%EW PBC	19.53	29.30	47.62	28.58	10.00
50% EWPBC	19.53	29.30	38.10	38.10	10.00
100%EW PBC	19.53	29.30	0.00	76.20	10.00

SlumpTest

The slump test was carried out on the concrete mix to determine the workability of the fresh concrete produced. A slump cone apparatus (with a height of 300 mm, bottom diameter 200 mm, and top diameter 100 mm), standard tamping rod, non-porous base plate, and measuring scale was used and slump test carried out in accordance with the procedures stated in [33].

Compressive test

The compressive strength test was carried out in accordance with BS EN 12390-3 specification [34]. A total of 12 cubes with size 150mm x 150mm x 150mm were cast for each mix design. A 2000kN capacity of Compression Testing Machine was used to determine strength at the curing age of 7, 14, 21 and 28 respectively. Figure 5 shows the testing of cube specimen using the compression testing machine.

Flexural Strength test of beams with and without EWPBC

The beam mould measuring (1000mm x100mm x100mm) were cleaned and lubricated. The mixing of the cement, fine aggregate was done on a water tight none-absorbent floor until the mixture was thoroughly blended. The coarse aggregates was added to the already mixed, cement and fine aggregate until the whole mass was uniformly distributed throughout the batch. Water was then added and mixed until the concrete appears to be the desired consistency in that specified batch. The concrete was poured in three layers into the mould with the reinforcement in place and tamping each layer of the concrete and the top of the mould levelled and smoothen with hand trowel. The cast beams were kept in moist air for 24hours prior to curing. These procedures was repeated for the different replacement of coarse aggregates with EWPBC (12.5%, 25%, 50% and 100%).

The flexural strength test is used for quality control of concrete delivered at site. The flexural strength is usually expressed as modulus of rupture (MoR). In this study, the flexural test was conducted using the centre - point loading system (ASTM-293C) with the beam samples in accordance with the standard procedures stipulated in [35], and the 100kN Electronic Universal testing machine used as shown in Figure 6. The flexural stress and flexural strain were computed using equations (4) and (5).

$$\text{Flexural stress, } \sigma_f = \frac{3FL}{2bd^2} \quad (4)$$

$$\text{Flexural strain, } \epsilon_f = \frac{6Dd}{l^2} \quad (5)$$

Where

F = Load applied
L = Distance between supports
b = width of beam
d = depth of beam
D = Deflection at mid-span.

Figure 5. Compression testing machine in action

Figure 6. Flexural testing of sample beam

RESULTS AND DISCUSSIONS

Specific Gravities and Sieve Analysis of the aggregates

The specific gravities of the fine and coarse aggregates were 2.65 and 2.75 respectively and within the relevant specifications and thus having a high strength and producing a durable concrete for the research work.

The concrete slump

Figure 7 shows the concrete slump test results of concrete made with and without EWPBC. The conventional concrete (0% replacement of EWPBC with coarse aggregates) revealed a slump values of 30mm (true slump) which showed proper workability of the concrete and 22mm slump value at 12.5% replacement. But the slump at other percentages of replacement (25, 50 and 100%) remains zero, i.e no slump, or stiff and almost no workability, which was due to the presence of the EWPBC in the concrete mix. Generally, the slump decreases with increase in the percentage of EWPBC replacement. Low or zero workability may be caused by the presence of EWPBC in the mix not able to absorb excess water thereby leading to a dry slump.

Compressive strength tests results

The compressive strength at different level of replacements (0, 12.5, 25, 50 and 100%) increases with curing days. The results of the compressive strength of the concrete mix measured at 7 days curing (for 0% EWPBC replacement) was 22 N/mm^2, while at 28 days, it attains a maximum compressive strength of 44 N/mm^2. At 12.5% replacement of coarse aggregates with EWPBC, the compressive strength at the 7 days curing obtained was 18 N/mm^2 and 45 N/mm^2 at 28 days. These values are 18.2% lower than that obtained from the conventional concrete (for 0% EWPBC at 7 days curing) and 2.3% higher (at 28 days curing) as shown in Figure 8. The increase in strength at 12.5% replacement may be due to the EWPBC having a proper bonding with the fine aggregates. This is evident that at 0% and 12.5% replacement of coarse aggregates with EWPBC, both mixes exhibits similar strength characteristics. On the other hand, the addition of EWPBC at 25%, 50% and 100% in the concrete mix yields a reduction in the compressive strength in the range 35.6-73.6% when compared with the conventional concrete. The reduction in the compressive strength beyond 25% replacement may be due to the decrease in adhesive strength between EWPBC and the cement paste.

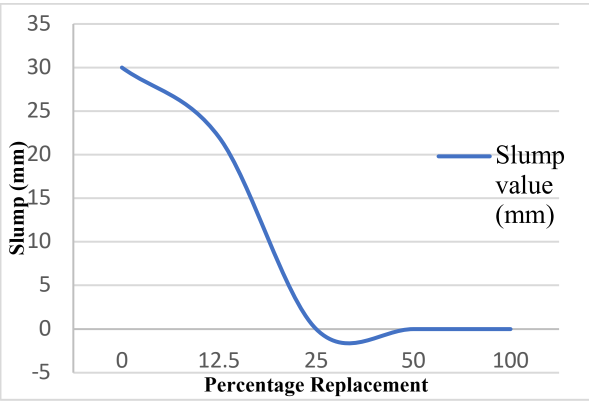

Figure 7. Slump Test values of concrete with and without EWPBC

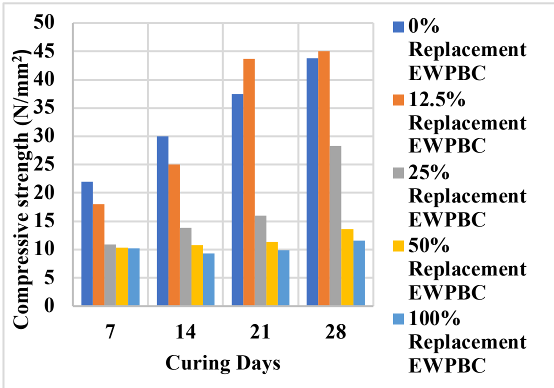

Figure 8. Compressive test values of concrete with and without EWPBC

Flexural Strength results of the beams

The results for the flexural strength test at different percentage of replacement (0%, 12.5%, 25%, 50% and 100%) with EWPBC is shown in figures 9 to 14. Table 5 also gives the summary of the computed flexural stress and flexural strain at different percentage of replacement. The force-deflection curves in Figures 9-13 reveal an initial linear line progression upon loading before beam failure. At 0% replacement and 28 days curing (conventional beam specimen), the maximum load was 16.4kN; at 12.5% EWPBC, 19.4kN; at 25% EWPBC, 20.1kN; at 50% EWPCB, 8.2kN; and at 100% EWPBC, maximum load was 10.6kN. The maximum bearing load for the replacement of aggregate with EWPBC at 12.5-25% is about 18.3-22.6% higher than that of the conventional beam (0% replacement with EWPBC). The slight increase in strength was due to the fact that the EWPBC acted as an elastic material within the concrete beam upon the application of load thereby increasing the force causing failure. Figure 14 shows the stress-strain curve at the different level of replacements. At 12.5% replacement of aggregate with EWPB, the flexural stress is 18.3% higher than that of the conventional concrete and strain value in the range of 0.00248-0.0036. This is within the acceptable range value for concrete classes ≤C50/60 (0.002-0.0035) [36]. At 25% replacement, the ultimate flexural strain (0.00498) is higher than the conventional concrete. At 50-100% replacement, the beam cannot withstand higher force and the flexural strain are much lower compared to the conventional concrete.

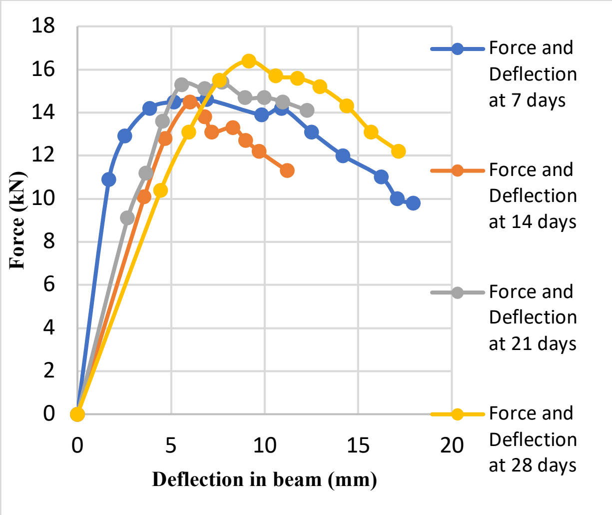

Figure 9. Force-Deflection curve at 0% replacement of EWPBC

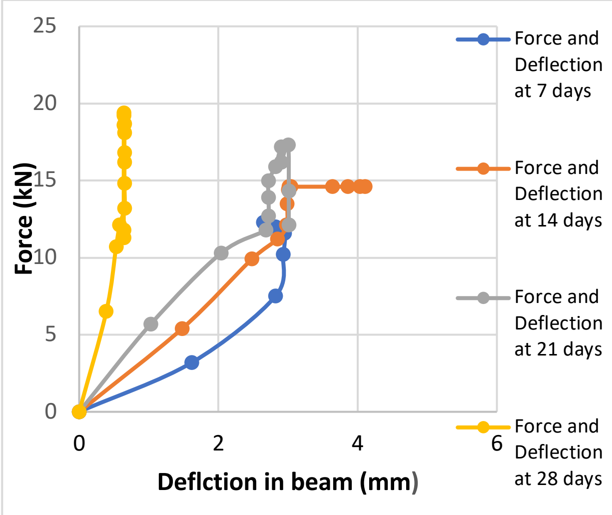

Figure 10. Force-Deflection curve at 12.5% replacement of EWPBC

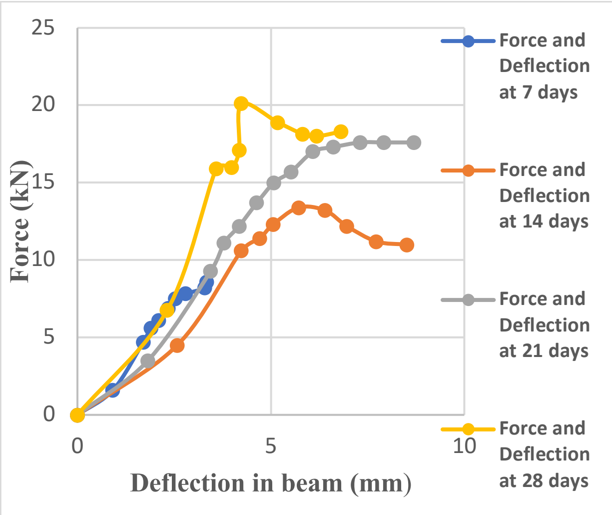

Figure 11. Force-Deflection curve at 25% replacement of EWPBC

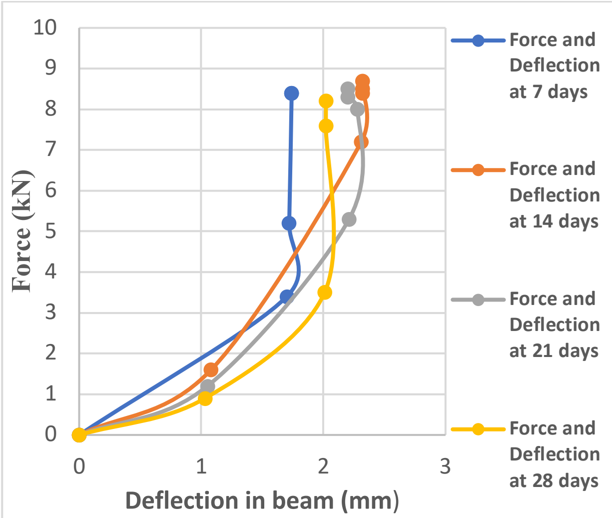

Figure 12. Force-Deflection curve at 50% replacement of EWPBC

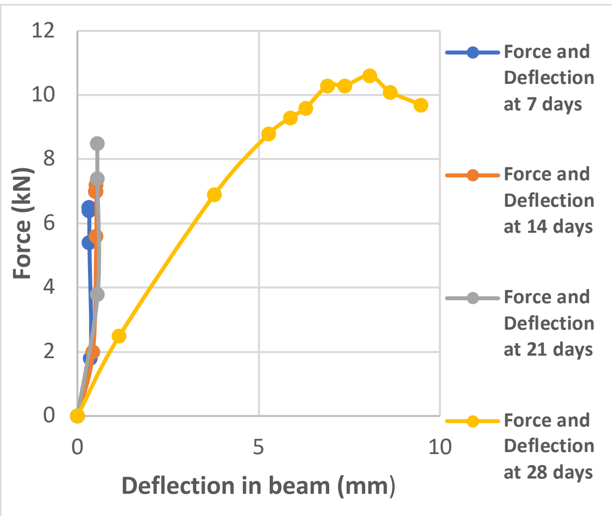

Figure 13. Force-Deflection curve at 100% replacement of EWPBC

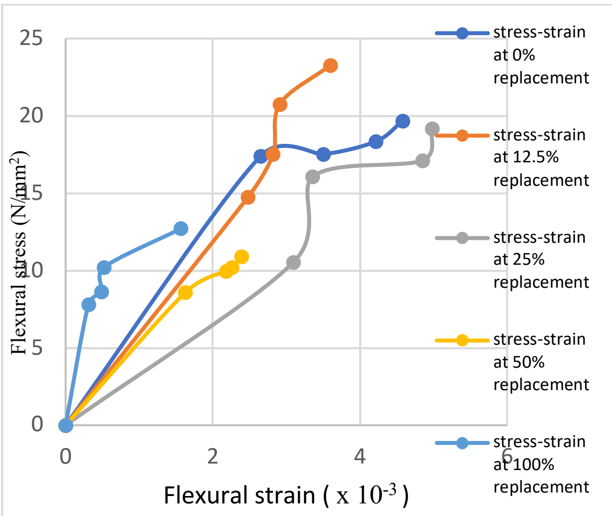

Figure 14. Flexural stress-strain curve at different % replacement of EWPBC

Table 5. Flexural stress and strain at different percentages of EWPBC

Days	Flexural stress and Flexural strain values (N/mm^2)									
	0%		12.5%		25%		50%		100%	
	σ_f	$\epsilon_f \times 10^{-3}$	σ_f	$\epsilon_f \times 10^{-3}$	σ_f	$\epsilon_f \times 10^{-3}$	σ_f	$\epsilon_f \times 10^{-3}$	σ_f	$\epsilon_f \times 10^{-3}$
	0	0	0	0	0	0	0	0	0	0
7	17.40	2.65	14.76	2.48	10.56	3.10	8.60	1.63	7.80	0.31
14	17.52	3.50	17.52	2.82	16.08	3.36	9.96	2.18	8.64	0.49
21	18.36	4.22	20.76	2.91	17.12	4.85	10.21	2.26	10.20	0.52
28	19.68	4.58	23.28	3.60	19.19	4.98	10.90	2.39	12.72	1.57

CONCLUSIONS

The physical properties of materials used in this research were found to conform with relevant specifications. The compressive strength generally increases with increase in the days of curing. At 12.5% EWPBC replacement, the compressive strength is 4.7% higher than that of conventional concrete. At other percentage replacements, the compressive strength decreases with increase in the days of curing. The flexural stress is higher with 12.5% EWPBC replacement with strain within the acceptable range and at 25% EWPBC, there is a promising stress value but higher strain. 50-100% replacement can be applied as light weight concrete. With 12.5% EWPBC replacement, there will be an appreciable economy in terms of volume of concrete. The results from the study revealed that EWPBC can be used in the production of eco – friendly concrete which serves as solution strategy in solid waste disposal issues. It was then recommended that optimum replacement level of coarse aggregates with EWPBC be 12.5%, in concrete production due to its strength performance and cost effectiveness.

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