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Research Article

Potentials of increasing levels of recycled waste plastic on the physical characteristics of concrete

Abstract

This research focused on the integration of waste plastic into concrete in a bid to restrain water ingress when exposed to water. Polyethylene water sachet (PWS) was the source of waste plastic used. Waste plastic concrete treatments were designed and cast successfully with percentage waste plastic contents of 0, 0.25, 0.50, 0.75 and 1.00. It also involved a constant water/cement ratio of 0.45, a mix design of 1:2:4 and 2% by 342.85kg cement weight of superplasticizer. Twenty cubes, 20 beams and 45 cylindrical specimens were cast for compressive, flexural, split tensile and water absorption tests respectively at 28 days of curing. Waste plastic treatments of 0.5% and 0.75% contents had the highest compressive strength. Water absorption characteristics of waste plastic concrete dropped with increasing plastic waste content to 0.75% after which further increase gave undesirable effects. Optimum water absorption (impermeability) were observed between 0.50% and 0.75% waste plastic content. Waste plastic concrete of 0.75% content with compressive strength and water absorption values of 21.19MPa and 0.22% respectively met the requirements of ASTM C55-11, ASTM C139-11 and CP 102. Waste plastic concrete showed desirable characteristics for potential use in the built environment.

Introduction

Plastic is used in a wide range of product and industrial application due to favorable properties such as low density, high strength-to-weight ratio, high durability, resistance to chemicals, water and impact, ease of use and low cost [1,2]. To this end, there has been considerable plastic in municipal waste stream. Unfortunately, the drastic growth in waste generation has not been adequately managed especially in Africa. In some countries, laws have been enacted for a total ban on use of plastics while in Nigeria, the National Orientation Agency advocates a ban on selected plastic packaging materials [3]. The largest component of plastic waste is polyethylene [4]. Water sachet polyethylene are the most widely used polyethylene especially in Nigeria. Idita and Iyasele [5], observed that the area of sachet water generated in Nigeria is greater than the total land mass of the country. Plastics can stay unchanged for as long as 4500years and they make up 5% of municipal solid waste that are toxic in nature [6]. In Nigeria, about 50-60 billion used water sachets are thrown into the streets [7] and generates about 990,344km^2 of land area daily [5]. Plastic waste are mainly treated by landfilling, incineration and recycling. The landfilling requires much land leading to loss of land for useful agriculture, blockage of drains and pipes, and causes pollution while its incineration releases toxic gases and particulates into the environment causing global warming. Recycling option is regarded as the best in that it reduces environmental impacts. According to Gu and Ozbakkaloglu [2], amid other recycling techniques, the use of plastic waste in construction is regarded the best as it reduces cost and has no pollution effect. Recycled plastic is widely used in mainstream construction products such as damp proof membrane, bitumen modification and aggregate replacement where its resilience and weight has substantial profits [3,6].

In the Nigerian society and the world at large, given the increasing environmental concern on waste plastic, and the need for proper disposal, there is need to test the effect of the material in concrete especially as damp proof material. The abundance of waste plastic and associated problems in disposal call for plastic harvesting to sanitize the environment and also create job opportunities. With recycling, the amount of waste plastic that ends up in landfills, dumpsites and incinerators will not only be reduced but also serve as a cheap and readily available raw material in construction industry for production of new and/or better grade materials that could serve as alternative to plain concrete. This could lead to savings in construction materials and hence reduce construction cost.

This study attempts to determine the possibility of recycling waste plastic by its inclusion in concrete through analyzing the effect of varying additions of waste plastic on the properties

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of cast concrete. The study also ascertains the use of waste plastic concrete mix as damp-proof material based on their performance criteria.

Materials and Mix Design

Materials

The materials used in this study are:

Cement: Dangote cement, a popular brand of Portland-limestone cement grade 42.5 produced by Dangote group of companies was used.

Fine aggregate: River sand from Ajibode Ibadan, Nigeria was used for fine aggregate. It has Specific gravity of 2.62, Bulk density of 1490kg/m³ and 2.03% absorption. Figure 1 presents the particle size distribution of sand.

Coarse aggregate: Granite crushed stone aggregates of maximum size 13.5mm, Specific gravity 2.57 and Bulk density 1660kg/m³ was used. Its particle size distribution is presented in figure 1.

Waste plastic: The waste plastic used were waste pure water sachet (PWS) obtained from "U.I Water", a packaged water producing organization on the University of Ibadan, campus. The PWS was crushed and ground to smaller particle sizes. The Specific gravity, Bulk density and absorption of plastic aggregate used was 0.35, 220kg/m³, and 0.2% respectively. Its particle size distribution is presented in figure 1.

Water: Clean, potable water obtained on campus was used in the mixing and curing regimes and in the absorption tests. The required amount of water was added to each mix as per the water-cement ratio for the mix.

Superplasticizers: CONPLAST SP 430 super-plasticizer admixture having a specific gravity of 1.2kg/l was used. It complies with ASTM-C-494 Type 'F ' as a high range water reducing admixture and Type G at high dosage.

Mix Design

Several trial mixes were prepared and slump determined in accordance with BS 1881 part 102 (1983) [8], before the final mix proportions and required amount of super plasticizer for acceptable slump could be established. Five treatments were done on the basis of percentage addition of waste plastic: these include 0% (control), 0.25, 0.5, 0.75 and 1.0%. A water-cement ratio of 0.45 was maintained for all treatments. The percentage of super plasticizer by weight of cement used was 2% and this was maintained for all treatments. The design mix used was 1:2:4. The equivalent weights of the materials per cubic meter of concrete are: Cement (342.85kg), Sand (685.71kg), Granite (1371.42kg) and Water (154.28kg).

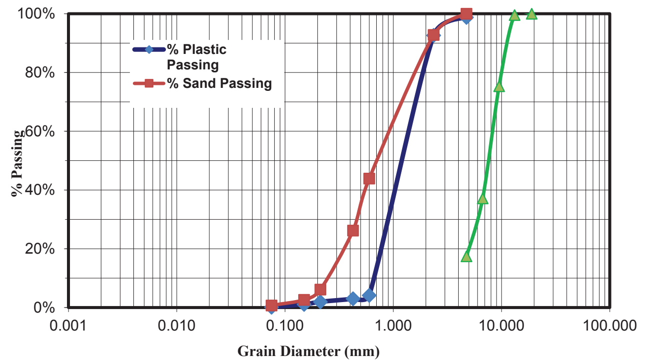

Figure 1: Grain size analysis for Fine, Plastic and Corse Aggregate.

Specimen preparation

Manual method of mixing was employed on a plain hard surface batching bay. Cement and sand were first mixed thoroughly on the plain surface in a dry state until homogeneity was achieved. The waste plastic aggregate were added and mixed properly with the fine aggregates after which the coarse aggregates were added to the mix. The required dosage of super plasticizer was added into the water to be used before applying to the concrete mix. Placement of the concrete into the moulds was done in three layers and a tamping rod was used to ensure adequate compaction of the concrete after each layer was placed in accordance to BS EN 12390 Part 2 [9]. The specimens were demoulded after 24 hours and placed in a water curing tank under a shade until testing. All specimens were moved to the laboratory for testing at 28 days of curing.

Testing of specimens

Compressive Strength Test: A total of 20 cubes of 100mm x 100mm x 100mm were cast for this test. Four from each mix were tested to determine the compressive strength at 28 days of curing in accordance with BS 1881 Part 116[10].

Splitting Tensile Strength Test: A total of 15 cylinders of 100mm dia. x 300mm length were cast for this test with three from each mix. The splitting tensile strength test was carried out as described by Chaudhary *et al.,* and Ijalana *et al.,* [11, 12], on the cast cylinder specimens at 28 days of curing. Prior to loading, two metal bars of 12mm diameter and length equal to that of the cylinder was placed below and above the cylinder along its length to ensure that the load was distributed equally along the length of the cylinder as much as possible. Loading was applied at a constant rate by the Universal Testing Machine.

Flexural Strength Test: A total of 20 beam specimens of 100mm x 100mm x 500mm each were cast. Four from each mix were tested to determine the flexural strength at 28 days of curing. The flexural test was performed according to BS 1881 Part 118 (1983) [13], using the two point loading method. The Universal Testing Machine was used to perform this test. The jig used was a single loading type, and a plate with two loading rollers was placed under the single loading point to create a two point loading.

Water Absorption (Soaking) Test: Three cylindrical specimen (100mm dia, x 100mm long) from each mix were selected for this test. The specimens were dried to constant weight at 105 ± 5°C. After 30 min. the specimens were removed from the water and weighed then returned to the water to complete the 24 hrs soak as described by Wilson et al. [14].

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***Water Absorption Rate (Sorptivity) Test*:** Three cylindrical specimen (100mm dia, x 100mm long) for each mix were selected for this test. The specimens were dried to constant weight at 105 ± 5°C. The procedure of the test was in accordance to ASTM C1585 – 04. In order to avoid a moisture exchange of the test specimens with the ambient air during the absorption experiment, polystyrene binder was used to seal the free surfaces against the penetration of water vapour.

Results and Discussion

Material analysis

The plastic aggregates had values of 0.35 and 0.22g/cm³ for specific gravity and bulk density respectively. These values are responsible for the slight increment in strength properties with increasing levels of waste plastic. The 0.2% water absorption of waste plastic, in line with the hydrophobic nature described by Gu and Ozbakkaloglu [2], contributed to the sudden rise in porosity and drop in strength of waste plastic concrete at higher waste plastic contents.

The values of specific gravity and bulk density were 2.62, 1.49g/cm³ and 2.57, 1.66g/cm³ for fine and coarse aggregates respectively. They had constant quantities in all the concrete mixes contributing to its density and compressive strength. Water absorption values for sand and gravel were 2.03% and 0.78%. Therefore, all the aggregates met the 5% combined aggregate absorption limit specified by CP 102 [15]. From the particle size analysis as shown in figure 1, the fine, plastic and coarse aggregates could be described as poorly graded medium sand, fine and sand-gravel respectively. The plastic aggregate being in the range of fine aggregate resulted in an increase in total fine aggregate thus, contributing to the reduction in workability of concrete.

Slump

Figure 2 shows that the slump is prone to decrease gradually with increasing waste plastic content. The reduction of slump with respect to reference concrete were 16, 26, 47, and 51% for plastic contents of 0.25, 0.50, 0.75 and 1.0% respectively. This reduction can be attributed to particle shape disparity resulting in less fluidity (Ismail and AL-Hashmi, 2008). Irrespective of the reduction in workability, the waste plastic concrete treatments had easy workability as they fall within the range of very low (0-25mm) to high (100-180mm) workability as described by Ismail and AL-Hashmi [16].

Compressive strength

The results of the compressive strength tests for waste plastic concrete treatments are shown in figure 3. The concrete with 0.75% waste plastic content has the highest strength followed by 0.50% plastic concrete while concrete containing 1% waste plastic showed the lowest strength. Compressive strength increased significantly with increase in waste plastic content from 0.25% to 0.75%, followed by substantial drop in concrete strength upon increasing the waste plastic content to 1%.

The corresponding percentage increment were 0.6, 3.1, and 12.6% for 0.25, 0.50 and 0.75% waste plastic content

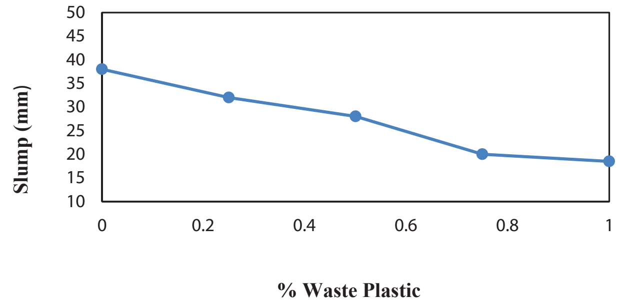

Figure 2: Slump of waste plastic concrete.

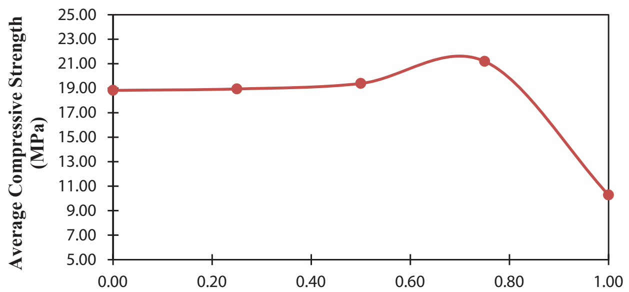

Figure 3: Average Compressive Strength at 28 days.

respectively while there was a 45.4% decrease in strength at 1% waste plastic content. This reduction in strength at 1% waste plastic content aligns with the study of Chaudhary et al. [11] and was attributed to low adhesive strength between plastic aggregate and the cement paste. Gu and Ozbakkaloglu [2], showed that strength of concrete containing plastic aggregate decrease with an increase in plastic content and attributed the development to lesser bond strength between the plastic surface and the cement paste, and reduced cement hydration reaction near the surface of plastic resulting from the hydrophobic nature of plastic. This trend of compressive strength is also in line with the observation of Kayali et al. [17]. Concrete containing waste plastic at 0, 0.25, 0.5 and 0.75% resulted in strength values higher than 17.24MPa which Ismail and AL-Hashmi [16], described as the minimum compressive strength for structural concrete in line with ASTM C55-11 for concrete building bricks. However, concrete containing waste plastic at 1.0% recorded strength value below 17.24MPa. This suggests that increase in waste plastic content of concrete has desirable effects on the compressive strength of concrete up to a certain percentage after which further addition may cause reduction in strength.

Splitting tensile strength

The results of the splitting tensile strength test with big cylindrical specimens figure 4 show that concrete containing 1% waste plastic has the highest splitting tensile strength of 1.74 MPa. The splitting tensile strength at 0.25% and 0.50% content averaged that of reference concrete as the change was almost negligible. Increasing waste plastic content beyond 0.5% content showed a significant increase in splitting tensile strength. The contribution of varying waste plastic contents on 28 days splitting tensile strength are -0.38, 0.25, 4.02 and 9.55% for 0, 0.25, 0.50, 0.75 and 1.00% waste plastic content

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respectively. This trend is similar to that reported by Suji et al. [18], Hsie et al. [19] and Nili & Afroughsabet [20], on splitting tensile strength of plastic fibre reinforced concrete in which concrete containing plastic fibres had higher splitting tensile strength than those of reference concrete, when the concrete has a comparatively low fibre content (less than 1%) [21-24].

Flexural strength

Figure 5 shows a slightly decreasing trend below reference concrete although the values average that of reference concrete. There was a rise in strength at 0.75% content beyond which the concrete showed a significant drop in flexural strength below reference concrete. The percentage increase in strength at 0.75% waste plastic content was 4.12% while the decrease was 2.79, 0.68 and 4.34% for waste contents 0.25, 0.50 and 1% respectively.

Water absorption (*Soaking*)

The result of 30 min and 24 hr water absorption of waste plastic concrete are shown in figure 6 and indicates that the behaviour of waste plastic in concrete at both time interval were similar. The only difference was the volume of water absorbed during the test, with the 24hr test having obviously a higher volume of water absorption due to the longer duration of waste plastic concrete in water. Due to increase in waste plastic content, there is a tendency for higher water absorption as compared to that of reference concrete. There was considerable rise in concrete water absorption upon increasing the waste plastic content to 1%. This trend can be attributed to the hydrophobic nature of waste plastic material which restricts the movement of water into and within the concrete up to 0.75% waste plastic content. Beyond this level there is bound

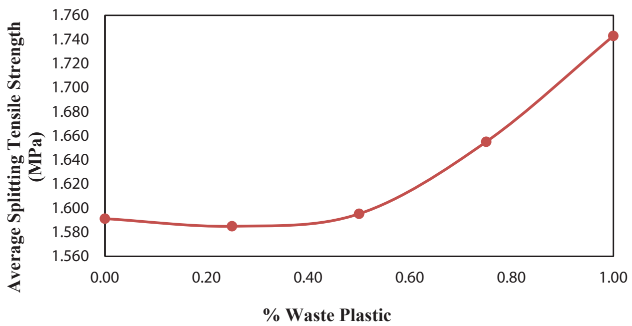

Figure 4: Average splitting tensile strength at 28days.

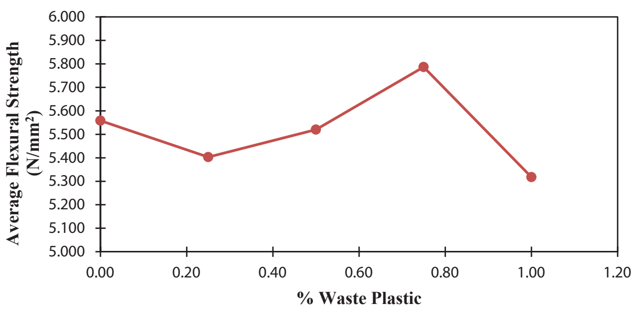

Figure 5: Flexural strength at 28 days.

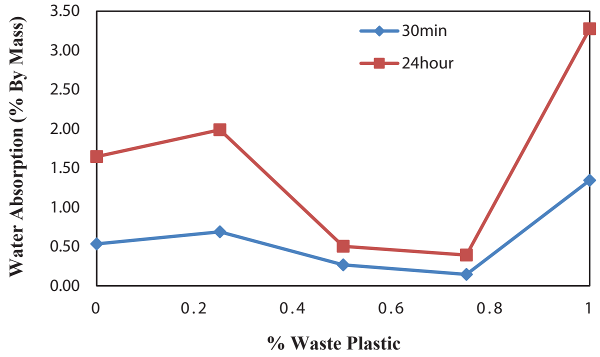

Figure 6: Water absorption (by soaking).

to be deterioration in the permeability properties of concrete, which according to Gu and Ozbakkaloglu [2], is attributed to plastic and natural aggregates not mixing sufficiently in the concrete matrix. All the water absorption values were lower than the maximum average absorption requirements for concrete building bricks which are 208, 240, and 288 kg/m^3 for normal, medium and lightweight brick respectively according to ASTM C55-11. Furthermore, the 0.5 and 0.75% waste plastic concrete met the requirements for concrete masonry units for catch basins and manholes (16kg/m^3) according to ASTM C139-11. The specified maximum water absorption for materials for damp-proof course is 4.5% for engineering bricks and 0.3% for slates by CP 102. All water absorption values met the former while the concrete with 0.75% waste plastic met the latter.

Water absorption rate (*sorptivity*)

According to ASTM C1858-04, the Initial Rate of Water Absorption (IRWA) is defined as the slope of the line, which is drawn by means of least squares using linear regression analysis, to fit the curve of Absorption (I) plotted versus the square root of time using points plotted from 60s to 6hrs. Secondary Rate of Water Absorption (SRWA) is calculated in the same manner as IRWA. For SRWA the points of time are plotted from 1day to 7days. To achieve the initial or secondary rate of water absorption using this method there should be a correlation coefficient, R of more than 0.98. In this study not all concrete treatments met this criteria as shown in table 1. Therefore, neither the initial nor secondary rate of water absorption can be determined under this ASTM standard. However, the overall water absorption regime in all the treatments have R values close to or greater than 0.98. Thus, an overall water absorption rate value was determined by the slope of the line, drawn using least squares, linear regression analysis, to fit the curve of Absorption (I) plotted against the square root of time using points from 1min to 8days as shown in figure 7 and the values of slope obtained as Sorptivity. These slope values were then plotted against waste plastic content figure 8. The trend observed in sorptivity is similar to that of water absorption by soaking figure 6. This confirms the behavioural pattern of waste plastic concrete in water medium.

Conclusion

The following conclusions were drawn from the study:

The compressive strength of waste plastic concrete

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Table 1: Water Absorption R^2 values for Plastic Concrete.

% Waste Plastic	Water Absorption R² values		
	Initial	Secondary	Overall
0.00	0.9219*	0.9823	0.9933
0.25	0.9591*	0.9793	0.9884
0.50	0.2198*	0.8305*	0.9551*
0.75	0.6551*	0.7285*	0.9520*
1.00	0.9762	0.9915	0.9902

**- R values less than 0.98*

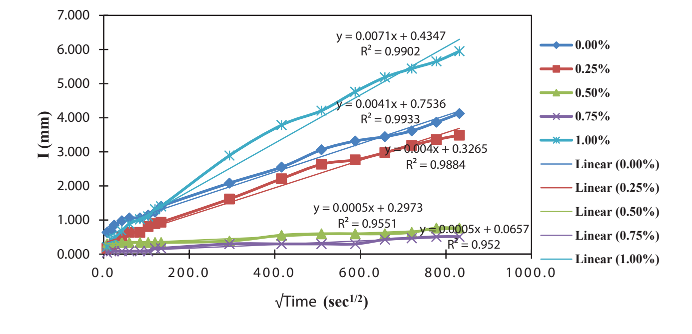

Figure 7: Rate of water absorption.

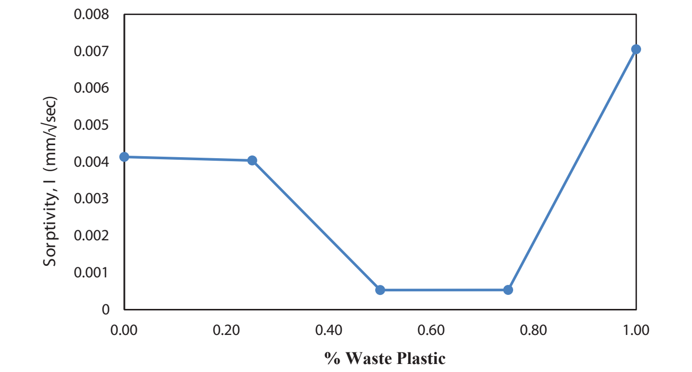

Figure 8: Overall water absorption rate of waste plastic concrete.

treatments tend to increase up to 0.75% waste plastic content after which further addition resulted in decline in strength.

Waste plastic treatments of 0.5% and 0.75% contents had the best compressive strengths.

Water absorption characteristics of waste plastic concrete tend to drop with increasing waste plastic content to a point at which further increase cause undesirable effects. The optimum water absorption (impermeability) were between 0.50% and 0.75% waste plastic content.

The prospects of potential use of waste plastic concrete in built environment is promising. Waste plastic concrete of 0.75% waste content with compressive strength, and water absorption values of 21.19MPa and 11.46kg/m³ respectively, met the ASTM C55-11 minimum compressive strength of 17.24MPa and water absorption of 208 kg/m³ for concrete building bricks and ASTM C139-11 of 16 kg/m³ for catch basins and manholes. It also met the CP 102 maximum water absorption for materials for damp-proof course of 4.5% for engineering bricks and 0.3% for slates.

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Recommendation

This study was limited to the physical properties of waste plastic and concrete. However, further research should be conducted on the chemical properties of waste plastic concrete such as long term performance (toxicity, reactivity, decomposition) of waste plastic materials in concrete. The environmental concerns of re-utilizing concrete containing waste plastic after service life should also be addressed.

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