

Compressive Strength and Durability of Polymer Concrete Pave Stone Production Utilizing Municipal Polythene Water Sachet: Mitigating Environmental Pollution

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Abstract- The improper disposal of Waste Polythene Water Sachets (WPWS) has become a significant environmental concern, contributing to drainage blockages, soil degradation, and pollutants to the environment. This study explores the potential of repurposing WPWS as a replacement for Ordinary Portland Cement (OPC) in the production of concrete paving stones. Experimental mixes were prepared with replacement levels of 50%, 60%, and 70% WPWS alongside a control in triplicate samples, and each specimen was cured using portable water for 7, 14, and 28 days before subjecting the concrete stones specimen on compressive strength and sorptivity tests. The result indicates linear increase in strength development across all curing age and 28-days provides 4304.76, 2819.04 and 2990.47 kg/m³ densities of concrete and compressive strength of 20.1, 18.2 and 19.9 N/mm² for pave stones impregnated with WPWS by 50, 60 and 70% respectively. The durability of the polymer concrete was minimally affected through sorptivity haven significant value of inflow of water at the middle age curing of pave stone at 70% replacement compared with 50 and 60% of WPWS but however, minimal value of 1.0954 (mm/min^{-0.5}) was obtained at 70% of WPWS at 28-days compare to control, 50 and 60% replacement. The perception of this study demonstrates that incorporating WPWS into paving stones offers a sustainable waste management solution, reduces environmental hazards, and aligns with circular economy principles. These findings provide a foundation for optimizing mix design and enhancing the bonding characteristics of recycled polyethylene materials in concrete production.

Index Terms: Compressive Strength, Sorptivity and Water Absorption, WPWS, Polymer Concrete, Environmental Pollution

I. INTRODUCTION

The utilization of concrete as a number one engineering construction material cannot be underrated based on its modelling characteristics and a tool for expanding and modernizing construction

infrastructure globally. This fundamental structural material provides modification or adjustment to promote its uses. Waste polythene water sachet (WPWS) is a specific modification to produce interlocking paved stone by replacing ordinary Portland cement (OPC). The polythene water sachet PWS is among the most consumed substances by average Nigerian and after been utilized, it becomes hazardous to environment as a result of non-biodegradability [1]. [2] is of the opinion that WPWS had its strength depreciated for some period of time while is embedded in the soil. This action contaminates the soil fertility and in-turn affect the vegetation [3]. WPWS and plastics causes serious treat and nuisance to the environment [4]. While disrupting the serenity of the environment, WPWS ushered mosquitoes and other pathogenic organisms becomes volatile like epidemic cholera, dysentery among others through food and water contaminations [5]-[6]. The process of burning and land-filling of WPWS has a negative impact on the health and people's wellbeing. It is also not sustainable due to the release of carbon monoxide and nitrous oxide, which are major contributors to the global warming [7]-[8]-[9]. With these significant treats posed by municipal polythene waste, many researchers have intensified efforts in utilizing municipal wastes polythene water sachet into interlocking, owing to poor source segregation and lack of inexpensive technologies, strategies for its proper utilization should be developed. [10] cited the significant value of the production of interlocking paved stone through incorporation of WPWS for structural, environmental and materials engineers for its sustainability and eco-friendly, that can possess excellent mechanical properties through compressive and tensile strengths, toughness, water absorption which are critical for the durability and high-performance for any light weight concrete. In another study by [11-12], the WPWS

was used as an admixture to produce interlocking paved stones and determined their compressive strengths after 28 days of curing and the polythene had good interaction with the conventional materials.

Increase in want for sustainable construction material has engaged researchers to explore alternative to conventional concrete material that promote concrete integrity and environmentally conserve [13], one such innovation is the incorporation of WPWS in concrete production, particularly for paving stones. Study by [14] the concrete pave stones are employed at the shoulder blade beside road and some strategic parking lots. In recent time, concrete pave stone has been employed in substitution of wiring course in some road works in Lagos – Nigeria. Concrete pave stones were used for entranceways alignment, provide sideway pattern for pedestrianism in highway construction works. Furthermore, with a good sub-grade PWS pave stones had proved long-term use than the conventional concrete pave stones or asphalt installation in case of durability [15]. Inclusion of polythene waste decreases concrete water absorption capacity due to its hydrophobic nature, which reduce the pores and inhibit water ingress, this lowering water absorption enhances the long-term durability of concrete [16].

However, traditional concrete pave stones production relies heavily on natural aggregates and OPC, both of which have significant environmental footprints. OPC alone accounts for approximately 8% of global CO₂ emissions [17]. Thus, many studies have been exploring various waste materials, including polythene water sachet waste, fly ash, and recycled aggregates, as partial substitution to conventional concrete aggregates aimed to enhance sustainability of concrete without compromising its mechanical properties [18]. Among these, WPWS has gained attention due to its lightweight nature, chemical resistance, and potential for enhancing toughness in concrete applications especially in production of interlocking pave stones. [19] in their study, inclusion of shredded WPWS into concrete mixtures can modify workability, density, strength and durability properties. By [20], many researchers experienced a slight reduction in compressive strength when polythene water sachet exceeds 10% in partial replacement of cement in producing pave stone for effective remedy in concreting, however, others recommended 2 – 5% replacement should be adopted to achieve a good load bearing pave stones while

improving flexibility and crack resistance [21]. Mix design and Proper curing techniques enhances hydration and improve the compressive strength and durability of pave stones [22].

Modification of this concrete pave stone as a structural component through integrating admixture will impact its aesthetics provided its structural integrity is not at stake resulting from imposed loads of the stone. Therefore, this study seeks to experiment the effects on strength and durability of incorporating the WPWS to replace OPC in different proportions.

II. MATERIALS AND METHODS

This section explains the materials used in this study and the methods that were adopted to assess the compressive strength and durability of pave stones produced by integrating WPWS for replacing of OPC in different proportions. The materials include WPWS, OPC, aggregates (sand and granite) and water. The WPWS as an admixture were sourced from different waste dumping sites within Ile-Oluji axis, covered a latitude of 7° 12' 47'' N and 4° 52' 8'' E. The sourced WPWS were rinsed using portable water to enable them free from impurities that may retard the polythene efficiency in terms of strength and durability properties development on concrete pave stones according to [18]. The OPC grade-35.2 were employed which was manufactured by Lafarge Cement Company in Nigeria, the fine aggregate used passes through 4.75 mm and satisfies the fine gravel limit and granite angular sizes between 15 – 20 mm were used that satisfied the recommendation of (BS 882, 1992). Potable water free from suspended particles as specified in (BS EN 1008, 1997) was utilized for the concreting.

(a) Batching, Mixing and Casting of Cubes and Cylindrical Concretes.

The conventional aggregates (sand and granite) together with OPC were mixed together homogeneously by virtue of batching by weigh. Steel mould of 150 x 100 x 70 mm were prepared before adding water to the mixed to produce concrete cubes for the control using ratio 1:1.5:3, with w/c of 0.58 according to [19]. Thus, already rinsed WPWS was air-dried under room temperature. The dried concrete mixes were employed using the same mix ratio, varied OPC with WPWS by 50, 60 and 70% respectively. Each percentage of WPWS were melted

at $115 \pm 04^\circ \text{C}$ before adding the dried concrete. A desired homogenous mixture was maintained to achieve water-cement concrete matrix and the liquified WPWS act as secondary binder for the mixed concrete and later filled the concrete specimen into the rectangular and cylindrical steel mould of $150 \times 100 \times 70 \text{ mm}$ and $100 \times 100 \text{ mm}$ for compressive strength and sorptivity tests, having a total of 72 concrete pave stones specimen.

(b) Compressive Strength Test

Each percentage replacement of the specimen (0,50, 60 and 70%) were subjected to 7, 14 and 28 days of curing using clean water that conformed with British standard [23] After every curing time, the cubes were air dried at room temperature for 24 hours as shown in Plate 1, then their densities were determined by weighing the cubes before crushing the specimen using universal testing machine to evaluate their compressive strength through the Equation 1.

$$\sigma = \frac{F}{A} \text{ (N/mm}^2\text{)} \quad (1)$$

Where; F is the applied axial load on the surface of concrete cube in (N), A is the surface area of concrete



Plate 1: Compressive strength and sorptivity tests of concrete pave stone made from WPWS

Then different in weight ΔW (g) at time t (min), area of exposed concrete sample A (mm^2) and density of water d (g/mm^2) were used to evaluate the sorptivity and water absorption capacity for the concrete samples by using Equation 2.

$$S = \frac{\Delta W}{A d \sqrt{t}} \text{ (mm/min}^{-0.4}\text{)} \quad (2)$$

Where:

- ΔW represent change in weight ($W_2 - W_1$) (g),
- A is the area of concrete specimen subjected for water penetration (mm),
- d is the density of water (g/mm^2),
- t is time taken when the specimen was exposed (min) and

cube in (mm^2) and σ is the compressive strength (N/mm^2).

(c) Sorptivity and Water Absorption Test

The 50 mm diameter by 100 mm long of cylindrical steel mould were arranged and placed on a non-absorbed surface material, poured already mixed polymer concrete as explained earlier inside the cylinder and compacted. The concretes were transferred for curing the same period as the cubes after 24 hours of demould. The samples were removed from curing and then left for 24 hours to enable their water to drain before subjecting the samples for oven dry as shown in Plate 1. The concrete samples were oven dried at 105°C and their initial mass was taken as W_1 , then samples were sealed with candle wax leaving only one face exposed to assess the rate of water ingress of the concrete. The samples were submerged inside water at 100 mm above the surface of the samples. Absorption process was timing for 30 minutes using stope watch, then samples were removed from the water and weighed again taken as W_2 .

S is the rate of sorptivity ($\text{mm/min}^{-0.4}$)

III. RESULTS AND DISCUSSION

This section comprises of the results and discussion of the test that were carried out on the densities, compressive strengths and durability of concrete pave stones that contained WPWS, cured for 7, 14 and 28 days respectively through Figure 1-3.

(a) Density of Polymer Concrete Pave Stone

The density is relatively the mass of each concrete specimen utilized in this study to the volume of the concrete, measured in (kg/m^3), which were evaluated in the Figure 1.

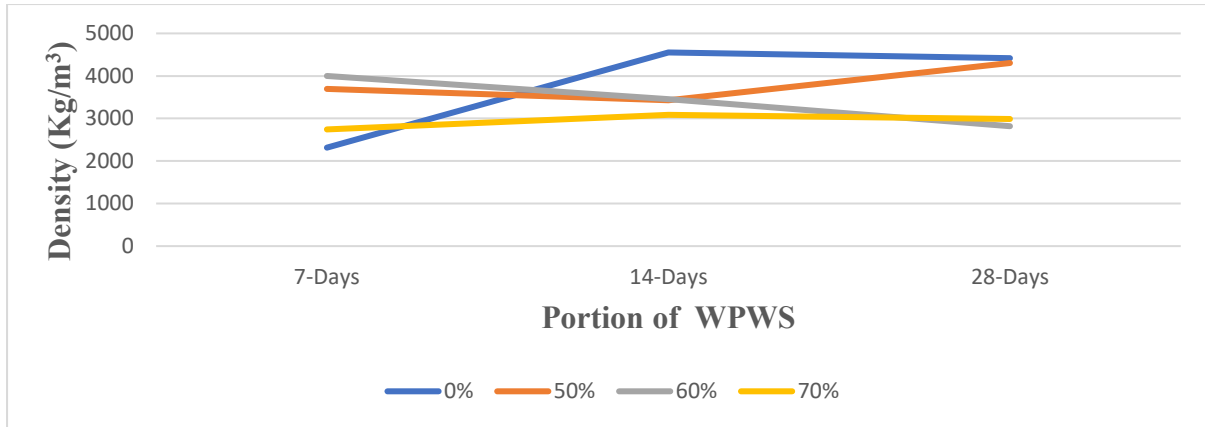


Figure 1: Density of Concrete for Different Doses of WPWS

From Figure 1, the result shows that 50, 60 and 70% substitution of WPWS at 7-days produced densities of 3695.23, 4000, and 2742.85 (kg/m³) values far higher than the control samples. This shows early strength development of the pave stones. 50% maintained its strength ability and produced 4304.76 (kg/m³) of density slightly lower than the 0% of WPWS at 28-days of curing. This indicated that the density of 0% replacement increases at the middle-age of curing periods but decreases between 14- and 28-days. There is decrease trend in density across 28-days of curing from 50% to 70% of WPWS replacement.

However, all percentage replacement of OPC by WPWS increases at 7-days curing with increased in percentage of WPWS. This indicates that concrete pave stone produced using WPWS within this percentage replacements can provide strength with additional value of 4304.76 (kg/m³) of polymer concrete for the replacement of OPC by WPWS at 28-days of curing, which proves good strength and durability for the polymer pave stones that will in-turn have resistance to wearing. It will also provide less water ingress for the pave concrete and the black colouration of polymer concrete will enhance the aesthetic patterns of the stones.

(b) Compressive Strength of Concrete Pave Stone Produced Using WPWS

The summary of compressive strength of the concrete pave specimen after curing days were shown in

Figure 2. From the Figure, the result shows that compressive strength of concrete pave stones for the control mix recorded a low strength of 12.20 N/mm² under a load of 183000 N at 7-days curing period against 50 and 60% pave stone concrete containing WPWS, suggesting that incorporating a high percentage of WPWS can marginally improve concrete performance at the early stage. On the other hand, 0% incorporation of WPWS pave stone produced higher value of 16.70 (N/mm²) strength at 14-days curing, over scoring the other pave stones that contains WPWS of 15.80, 15.90 and 15.10 (N/mm²) at 50%, 60% and 70% respectively. Interestingly, increase in curing ages produces increased in values for all concrete pave stones impregnated with WPWS, thus this proved strength development for the polymer concrete based on the percentage replacement values used in this study. 50% replacement of OPC by WPWS in production of pave stone had average compressive strength value of 20.1(N/mm²) thus, competed with the control specimen of 20.4 (N/mm²) compressive strength, implies that blending 50% replacement of OPC by WPWS in concrete pave stone making can adversely developed good strength at the optimum 28-days of curing period. This also in line with the study [10] Overly, the compressive strength of concrete pave stone specimen containing WPWS increases with increased in curing ages and increased in percentage of WPWS.

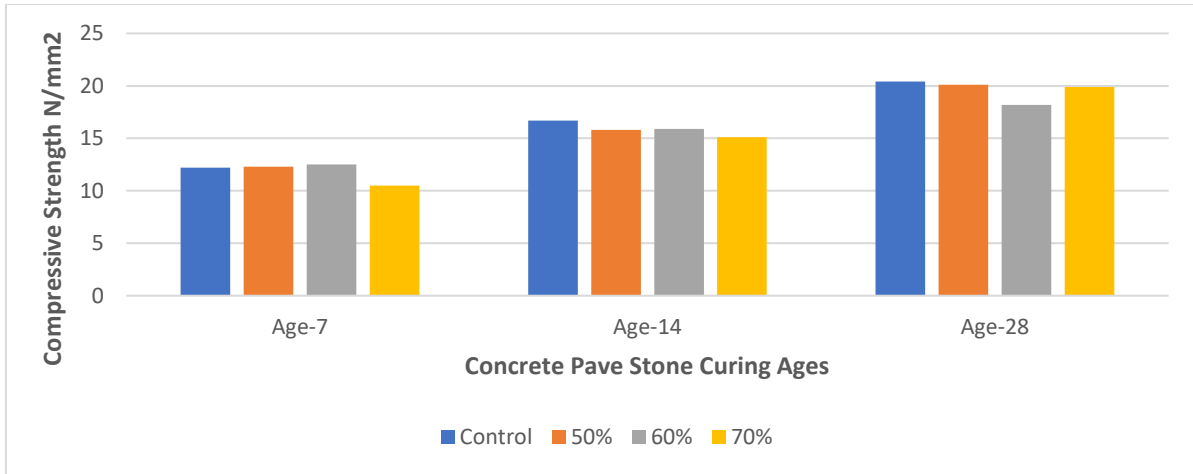


Figure 2: Average compressive strengths of concrete pave stone incorporated with WPWS

(c) *Durability of Concrete Pave Stone Produced Containing WPWS*

The result of sorptivity and water assessment of concrete pave stone specimen were presented in Figure 3. From the Figure, there is decrease in sorptivity and water absorption for all concrete specimen at age 7-days curing with increased in percentage replacement of WPWS against the control. This indicating the concrete stones are impermeable at early stage of curing, whereby 60% replacement of cement by WPWS provides lesser water absorption capacity of 1.0954 (mm/min⁻⁰⁴) against 2.5195 (mm/min⁻⁰⁴) for the control. Thus, the

middle age curing enjoyed little inflow of water on the pave stone through 50-70% increase in percentage replacement of WPWS, but decreased against the control. However, at 28-days, 60 and 70% pave stones specimen containing WPWS had the same water absorption capacity of 1.0954 (mm/min⁻⁰⁴) lower than 1.6432 (mm/min⁻⁰⁴) for the control. At 28-days ultimate curing period the durability of the concrete stones was influenced by WPWS, having linear decreased in water absorption strength with increased in percentage of WPWS. Hence, this outcome fit well going by the study of [16]

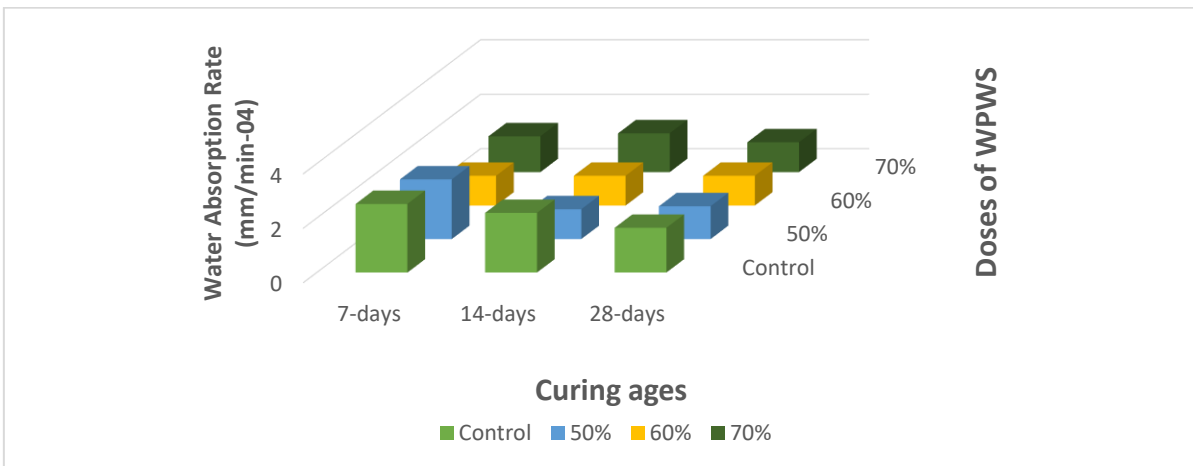


Figure 3: Sorptivity and Water Absorption Assessment of Concrete Pave Stones Containing WPWS at Different Curing Age.

IV. CONCLUSIONS AND RECOMMENDATIONS

The following are the conclusions and recommendations from this study:

- i. As curing ascends in age, there was an uptick in compressive strength of concrete pave stones with increase in percentage replacement of OPC by WPWS which indicates that the stones have resistance to axial load.

- ii. Compressive strength of concrete pave stones was influenced by percentage replacement of WPWS at 50% at ultimate 28 days of curing with an approximate value of 20.1 N/mm².
- iii. The sorptivity and water absorption ability of concrete stones specimen impregnated with WPWS at 28-days of curing possessed long-term strength and resistant to water ingress compare to middle-age curing.
- iv. Further research should explore additional percentage replacement of WPWS to assess the strength suitability of polythene water sachet in production of polymer concrete.
- v. Other curing methods and extension of curing period beyond 28 days should be considered by other researchers to examine the compressive strength and durability for utilizing waste polythene in partial replacement of OPC to produce polymer concrete.
- vi. WPWS should be subjected to laboratory assessment to determine its chemical properties to create room for additional admixture like pozzolan, that will enhance durability capacity of the polymer concrete pave stones against water ingress.

V. ACKNOWLEDGEMENT

The researchers appreciate the Management of Federal Polytechnics, Ile-Oluji, Ondo State, Nigeria for granting the approval of this research sponsored by the tertiary education trust fund (TETFUND) of Nigeria via its Institutional-Based Research (IBR)

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