Effect of Chemicals on Compressive Strength of Plastic-Laterite Interlock Paving Blocks

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Abstract

This research centres on the need to develop a simple but sustainable material for the utilization of the quantum of plastic wastes that litter our environment. The research uses waste plastics and laterite soil and converts them into construction materials (interlock blocks) with the help of the densifier, thereby reducing the plastic waste, which is a key contributor to environmental pollution. Literature has shown that concrete structure is prone to chemical actions; the durability of conventional concrete bricks gets affected by chemical effects. The chemicals may cause cracking of concrete, rutting, and deterioration of the structure. In the same vein, the plastic-laterite interlock bricks might not be free from such defects due to chemical action. Therefore, this research looks into the effects of different chemical curing conditions on the compressive strength of plastic-laterite paving blocks. Varying proportions of plastic wastes and laterite soil were mixed and processed into composite bricks and subjected to different chemical treatments; in acid, base, oil, and water for 3, 14, and 28 days relative to a concrete brick control. It was observed that samples cured in acid solution gave the lowest compressive strength, while those in base solution gave the highest. The paving interlock blocks made from polyethylene/laterite composite registered relative performance compared to concrete interlock bricks control. If made and put into use, these blocks will reduce construction costs, assist in environmental sustainability and improve circular economic growth. Therefore, using this innovative approach will bolster infrastructural projects and checkmate plastic pollution within our environment.

Keywords: Plastic waste; Laterite soil; Interlock bricks; Chemical effect; Compressive strength; Waste Management

1 Introduction

More production equals more waste; more waste creates environmental concerns of contamination. An economically viable solution to the waste problem should include the utilization of waste materials for new products, which could help in minimizing the heavy burden on the nation's landfills. The importance of recycling is huge because it saves natural resources, saves energy, reduces solid waste, reduces air, water, and land pollutants, and reduces greenhouse gases.

Waste polyethylene usage in road construction is trending. Some aggregates are water-loving (hydrophilic) such as concrete. Others like polyethylene and bitumen are water-hating (hydrophobic) in nature. Thus, polymers that are hydrophobic when added to asphalts mix make them repel the water and thereby increase the strength. Roads made of recyclable plastic wastes can bring about the reduction of these tons of waste in our environment by utilizing them as construction materials (Ansari et al., 2017).

Laterite soil is abundantly found in tropical parts of the world including Nigeria. Laterite soils are used for road sub bases or bases and other engineering applications (Yamusa et al., 2019). The viability of a project relies on the relative abundance of materials to be used which in turn helps in creating more economical construction (Yamusa et al., 2020), hence the justification of this research whereby laterite soil will be used as the major raw material.

In a report www.polygongroup.com (2022), natural freshwater has a neutral pH of 7. Alkaline has a pH above 7 while acidic is below 7. The main concrete binder i.e., Portland cement has a pH of 11 thus making it alkaline. Concrete deteriorates in an acidic solution by increasing its porosity, which makes it weak and lowers its strength. Therefore, the lower the pH the weaker concrete becomes. When cement in a concrete mixture reacts with the carbon dioxide in the air results in carbonation. Carbonation lowers concrete's pH, affecting its ability to hold the cementitious components within it together. When exposed to acidic environments, concrete dissolves into sand and rocks. The resulting pressure can cause the already weakened concrete around it to break and crack (www.polygongroup.com, 2022). In this study, the effects of chemical solutions i.e., acid, base, oil, and water were explored on the plastic-laterite paver blocks to analyze their significance on compressive strength.

2 Materials and Methods

2.1 Plastic Waste and Laterite Soil

The recyclable plastic waste (RPW) that was used in manufacturing the paving blocks was bought from collection points within the municipality gotten from refuse dumps, waterways, and landfill sites, and then sorted and classified. Thereafter, the RPWs were dry-cleaned and taken for experimentation in the laboratory.

Laterite soil was bought from the available borrow pits within the catchment area (Zaria city) of this research. The soil was powdered using a mechanical grinder and then sieved through a 5mm aperture to reduce oversize gravel. The RPW and laterite soil were as shown in Figure 1.

Fig. 1: Plastic waste bags and laterite soil

2.2 Physicochemical Tests on Waste Polyethylene Bags

The samples of waste Polyethylene bags were sorted at the Civil Engineering Workshop in Nuhu Bamalli Polytechnic and classified into three dominant categories viz.,

1) Transparent Low-Density Polyethylene (T-LDPE).
2) Transparent High-Density Polyethylene (T-HDPE).
3) Black Low-Density Polyethylene (B-LDPE).
4) Mixed Polyethylene comprising of 3 categories above (M-HLPE).

Thereafter, the determination of chemical composition/percentage purity, thermal physicochemical properties, degree of crystallinity, and specific gravity was carried out as described in (ASTM, 2008).

2.3 Physicochemical Tests on Laterite Soil

The laterite soil samples undergo the following physical property tests adopting the British Standard (BSI, 1990). Specific gravity, particle size distribution, atterberg limit (plasticity chart of British Standard Classification System) (BSI, 1999), linear shrinkage test, and compaction test.

2.4 Mix Ratio of Waste Plastic and Laterite Soil

Creating a ratio mix for melting/solubilization of the various classified waste plastics stream with laterite soil based on their known physicochemical characteristics; the mix proportions of laterite and plastic waste materials were obtained by weight. The following mix ratios were investigated:

a) 60% laterite and 40% plastic contents by weight denoted as P1.
b) 70% laterite and 30% plastic contents by weight denoted as P2.
c) 80% laterite and 20% plastic contents by weight denoted as P3.
d) Concrete control mixing ratio of 1:2:4 by weight denoted as P4.

2.5 Physicochemical Characteristics of Plastic-Laterite Interlock Bricks

Evaluation of the physicochemical characteristics of the produced interlocking bricks and quality assessment checks in comparison with conventional concrete materials; to determine the loading capacity of polyethylene and laterite composite, and to evaluate the effect of compressive strength, tests conducted include compressive strength, water absorption, and effects of chemicals on the produced paving interlocks.

a) Effects of Chemicals*:* This was carried out according to ASTM modified method. Respective samples were immersed in mild acid and mild base for 3, 14, and 28 days to test for the effect of the chemicals on the physicochemical characteristics of the products. Subsequently, the samples were washed and checked for any defect and were then subjected to compressive strength to determine their response as a result of the chemical effect.

b) Compressive Strength Test**:** To determine the loading capacity on the strength of mixed polyethylene-laterite bricks, the compressive test was carried out using a universal compressive machine tester. The test complies with BSI (2009) for control paving blocks. Three samples per mix were tested and average strength was determined by averaging the three results.

3 Results and Discussion

3.1 Physicochemical Properties of Waste Polyethylene Bags Sample

The results from Table 1 show similar levels of purity among the samples, in particular, the T-LDP and T-HDPE have pure polyethylene at 98% while the B-LDPE and M-HLPE have polyethylene purity percentages of about 92%. The lower percentages in the latter might be because B-LDPE is mostly used for multiple uses in grocery packing which might result in it harboring more impurities than other samples.

Table 1: Percentage purity of various samples of waste polyethylene bags

Sample Description	W1 (g)	W2 (g)	% Purity
T-LDPE	500	490	98.00
T-HDPE	500	492	98.40
B-LDPE	500	484	91.80
M-HLPE	500	481	92.20

While the physical test, shown in Table 2, on the various samples of polyethylene shows varying properties concerning thermal behaviors. The T-HDPE had a higher melting point (148°C) than the LDPE while the mixed sample M-HDPE has a melting point of 132°C. The enthalpy of fusion and percentage crystallinity (33%) is lowest in T-HDPE when compared to LDPE, which have a percentage crystallinity of 61% and 56% for T-LDPE and B-LDPE, respectively. Interestingly, the M-HLPE had an average percentage crystallinity of about 50%. The crystallinity of the samples is an important physical parameter in this project since the melt flow, hardness, and brittleness of the bricks to be produced are dependent on it. The M-HLPE was the sample of choice used for the study since polyethylene plastic wastes exist in mixed form and the novelty of the research lies in the ability of the process to utilize these mixed wastes with poor recyclable value.

Table 2: Physical properties of waste polyethylene bags samples

Sample Description	Initial Melt Temp/ Melting Point (°C)	Final Melt Temperature (°C)	Enthalpy of Fusion (J/g)	Crystallinity (%)
T-LDPE	112.50	126.70	180.40	61.34
T-HDPE	148.00	163.10	98.60	33.64
B-LDPE	114.20	125.50	165.80	56.46
M-HLPE	132.00	158.80	149.20	50.40

3.2 Physical Properties of Laterite Soil

Table 3 presents laboratory results on the physical properties of the laterite soil used in this study. According to the British Standard (BS) classification, the soil sample is classified as silty clay of medium plasticity (ML).

Table 3: Physical properties of laterite soil

Property	Value
Specific gravity	2.70
% Fines	10
% Sand	70
% Gravel	20
OMC, %	16
MDD, Mg/m^3	1.6
Liquid limit, %	47
Plastic limit, %	31
Plasticity Index, %	16
Linear Shrinkage, %	5
BS Classification	ML
Colour	Brown

3.3 Effect of Acid Curing on Compressive Strength

The effect of acid curing can be seen in Figure 2, where compressive strength increase with an increasing number of days, especially for concrete cured in acid for 28 days. The positive influence of test piece aging in aqueous media on their mechanical properties (compressive strength) was demonstrated. This result corresponds to Šiler et al., (2016) where a different effect of the pH environment on hydration was observed.

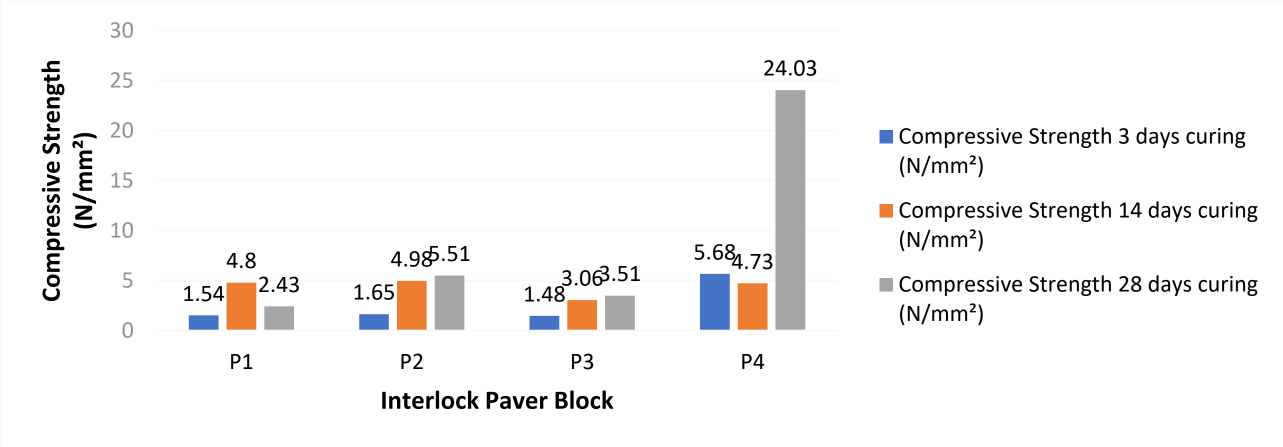

Fig. 2: Compressive strength of paver blocks after acid curing

3.4 Effect of Base Curing on Compressive Strength

The effect of acid curing can be seen in Figure 3. The compressive strength increased significantly for all mix ratios especially concrete cured with a base solution. These values indicate compressive strength performs better in an alkaline medium. Similar findings were also reported by Dutta et al., (2020) saying that the main reason behind the phenomena is that in alkaline media, both the formation of calcium carbonate and calcium silicate hydrate increases with time. These two elements of Portland cement are responsible for the hardening of cement composite. Thus, the compressive strength of concrete increases in the long run for all the tested series. In this study, the compressive strength at 14 days gives the peak values for P1 and P2, whereas, P3 and P4 show maximum compressive strength at 28 days. This depicts that plastic-laterite paver blocks P3 with a 20-80% mix ratio indicate similar properties with concrete because laterite soil has a concentration of iron and aluminum oxides (the sesqui oxides gibbsite and goethite), which act as cementing agents (Yamusa, 2018).

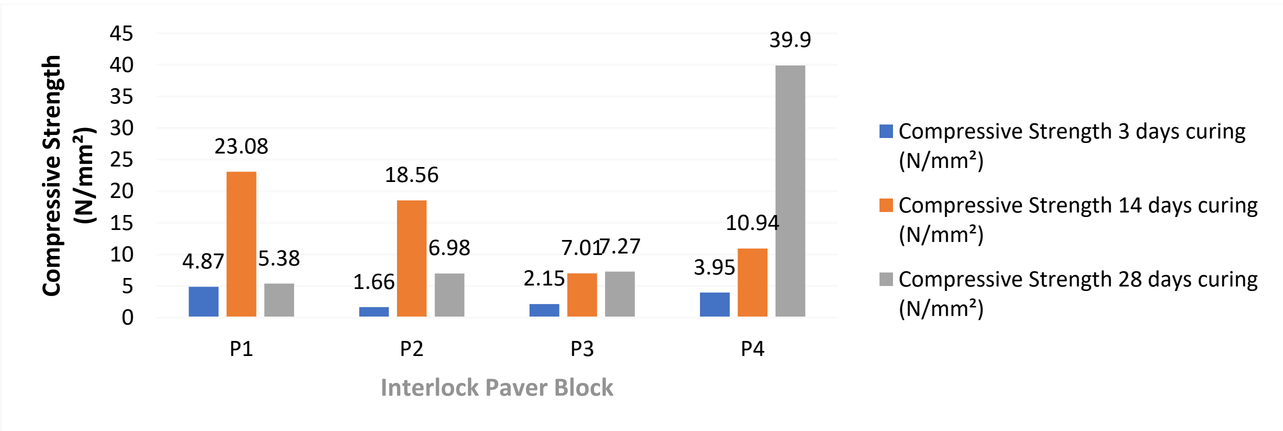

Fig. 3: Compressive strength of paver blocks after base curing

3.5 Effect of Oil Curing on Compressive Strength

The effect of engine oil curing can be seen in Figure 4. The compressive strength increased significantly for all mix ratios, especially for 14 days of curing. The reason may be attributed to what was observed by, Shafiq et al., (2018), that the chemical composition of used engine oil showed the presence SO_3 content which may be the reason for the plasticizing effect. In general, a small dosage of used engine oil caused a substantial reduction in the coefficient of oxygen permeability and porosity of all concrete mixes, which is an indicator of enhanced long-term durability.

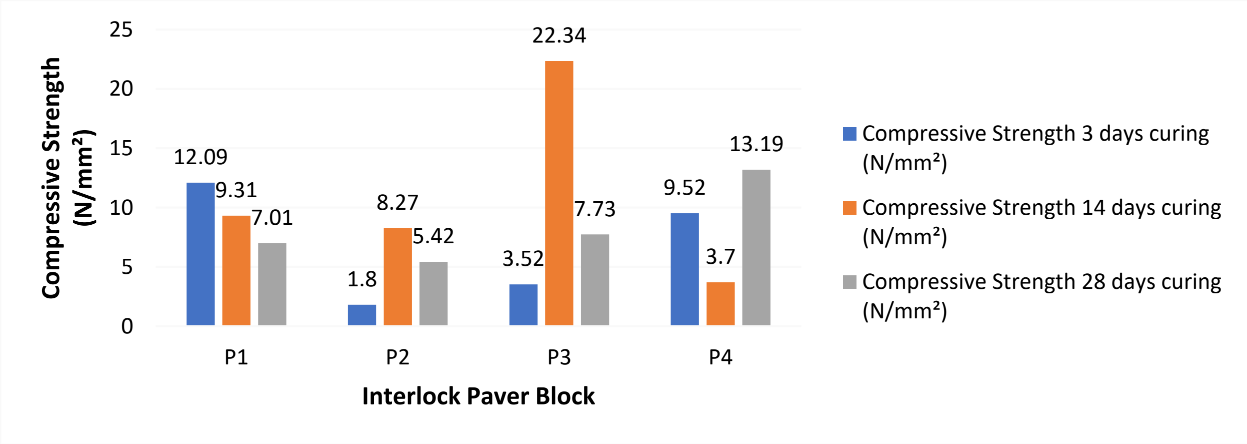

Fig. 4: Compressive strength of paver blocks using engine oil curing

3.6 Effect of Water Curing on Compressive Strength

Figure 5 displays the effect of water curing on compressive strength. The hydrophilic nature of the concrete block makes it absorb higher water in comparison with the hydrophobic nature of RPW blocks that absorbed less water as the results indicated. Similar results were reported by some researchers in the literature (Agyeman et al., 2019and Youssef et al., 2015).

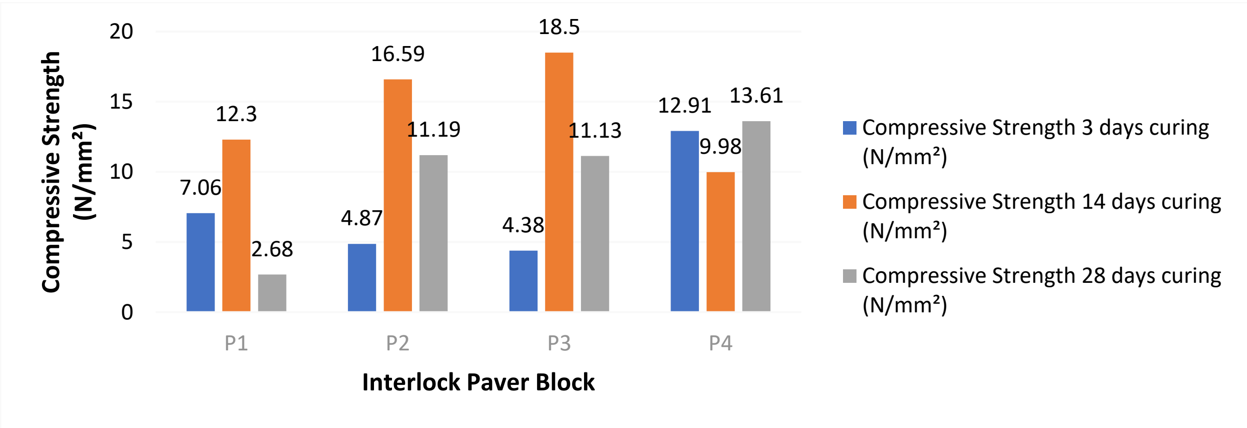

Fig. 5: Compressive strength of paver blocks after water curing

3.7 Evaluating the Effect of Chemicals on RPW Blocks for Pavement Construction Purposes

\Compressive strength is one of the significant physico- mechanical property parameters when evaluating the quality of paving blocks Agyeman et al., (2019). Figure 6 depicts the variance of compressive strengths across the various samples of paver blocks in different media. The most common solvent that pavements are exposed to is water and it can be seen that the compressive strength of all three plastic paver blocks (P1, P2, and P3) are relatively higher than that of concrete control (P4). This affirms that the plasticised paver bricks will serve well in presence of water. On the other hand, the acidic and oil environments significantly resulted in a decline in the compressive strength of the paver blocks. Acids are known to be corrosive and can hydrolyse composites of laterites and cement while the effect of the oil might be attributed to its ability to percolate and create hydrophobic environments within the blocks which can affect the compressive strength. The effect of the base can be seen to have shown the best curing for compressive strength, particularly for the P1 and P2 samples. The decline for P3 and P4 might not be unrelated to the high content of laterite or sand in the two samples. Therefore the P1 mix is adjudged as the best mix-ratio for compressive strength that requires a minimum compressive strength of 3.45 MPa required by the Nigerian Building and Road Research Institute.

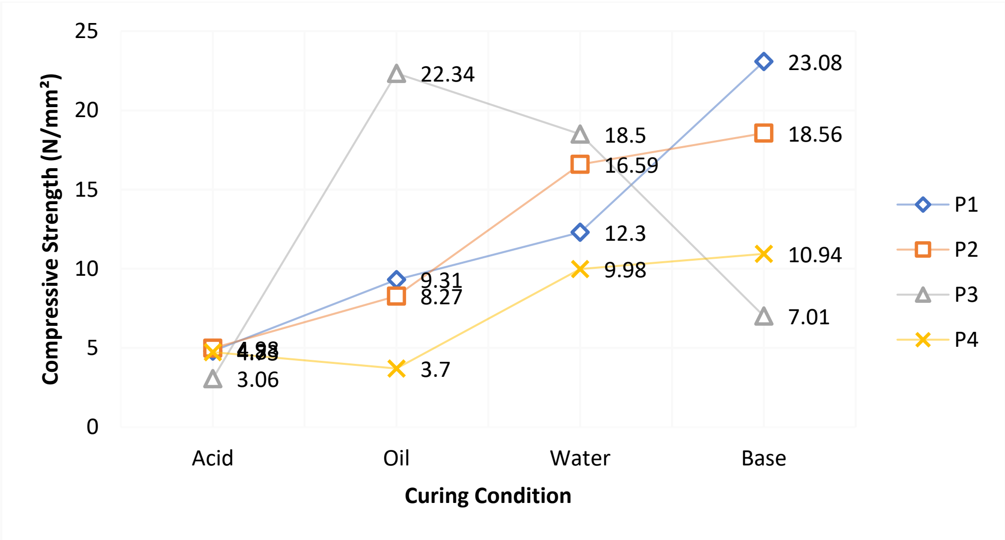

Fig. 6: Compressive strength of blocks under different curing conditions for 14 days

4 Conclusion

In conclusion, the research invented an auto-mechanical densifier machine that simplifies the plastic melting and mixing with laterite for efficient mass production of the interlocking bricks, which makes economic sense and promotes sustainability. The results indicated that the concrete paving blocks absorbed more water (hydrophilic) than the RPW paving blocks as they were gauged to be hydrophobic. The compressive strength increased significantly for all mix ratios after days of curing. Relatively, the effect of the base showed the best curing for compressive strength, particularly for the P1 and P2 samples.The research brought about the selection of the best mix-ratio and production procedures leading to qualitative interlock products that are similar or even stronger than conventional concrete interlocking bricks and which can withstand exposure to varying environmental solvents. However, more research and investigations are needed and are underway to ascertain the long-term resilience of the plastic-laterite paver bricks when exposed to real-life environmental conditions, which include routine exposure to chemicals as well as freezing or scorching temperature extremes.

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