

Production and Evaluation of the Durability of Laterite, Interlocking Paver Block Incorporating Glass Powder

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Abstract

High cost of construction materials has made building out of reach to average Nigerians. This has given rise to inward sourcing for local waste as an alternative to conventional ones. Laterite interlocking paver blocks were evaluated in this research. Grain size analysis, Liquid limit, Plastic limits was carried out on a collected laterite soil sample, X-ray fluorescence test was carried out on glass powder, compressive, split tensile strengths, acid attack, density and water absorption were carried out on the LIPB. The percentage of particles passing sieve number 200 is greater than 35%. LL was 43.24%, PL was 26.09%. and PI was 17.5%. XRF ($\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O}_3$) of glass powder is 61.92%. it is classified as class - C pozzolan. Paver blocks of 300 x 150 100mm were produced from laterite and cement using 1:4 ratios. Glass powder was used to replace cement in three varied percentages of 10, 20 and 30 respectively, sample with 10% replacement had the highest compressive strength of 7.80N/mm² compared with 0% replacement of 8.30N/mm² and the lowest compressive strength of 3.49N/mm² was observed at 30% replacement When samples were immersed in acid water solutions of magnesium sulphate and hydrochloric acid, there was a significant reduction in compressive strength. Tensile strength of 1.19N/mm² was observed at both 0% and 10%, while the lowest tensile strength of 0.62N/mm² was observed at 30% replacement. The maximum density obtained is 1408.73 kgm⁻³, below the minimum value of 1810 kgm⁻³ recommended by the Nigerian Building and Road Research Institute. This may be due to the physical properties of the laterite soil or the glass powder used. Water absorption capacity of the specimens at 0, 10, 20 and 30% were 9.55, 4.23, 9.51 and 3.54, respectively. all samples produced satisfied the maximum water absorption of 12% recommended by the Nigerian Industrial Standard and 12.5% water absorption recommended by the Nigerian Building and Road Research Institute. Replacement of cement with glass powder up to 10% is effective, sustainable and economical. The use of Laterite Interlocking Paver Block is not advisable in an acid-prone environment.

Keywords: Durability, Laterite, Glass Powder, Compressive Strength, Paver Block.

Introduction

Block paving is an attractive practice involving precast interlocking concrete paver blocks, utilized for exterior flooring. Paver blocks are widely used in various countries for highways,

airports, streets, local roads, parking lots, industrial facilities, and other types of infrastructure (Bamidele and Olutunji, 2018) over the past two decades to address issues in providing paved paths in areas where traditional paving methods are impractical, or due to road congestion and geological conditions. They are available in various colors and shapes such as square, rectangular, zig-zag, dumbbell, wavy, cosmic, etc., with interlocking patterns that allow them to connect securely with adjacent blocks (Subhash *et al.*, 2019).

Laterite is a key material used for sub-base and base courses in pavement layers. It is the most common of all tropical soil in Nigeria mostly used for highway construction (Biswal *et al.*, 2018). Lateritic soils are known as highly weathered natural material with a high concentration of hydrated oxides of iron or aluminium due to the residual accumulation or absolute enrichment caused by the solution, movement, and chemical precipitation of aluminium, iron and manganite (Oluyemi - Ayibiowu, 2019). They typically do not meet the standards required by road agency for high traffic road pavement and, in certain circumstances, medium to light traffic as well which can be related to their particle size characteristics, the strength of gravel particles, the degree of compaction, the volume of traffic, the weather condition and the geography of the area (Biswal *et al.*, 2018). Lateritic soils swell when wet and contract when dry (Setiawan and Fitriansyah, 2020). Colours ranges from yellowish to reddish - brown depending on the content of iron and aluminium sesquioxides (Mengue *et al.*, 2017).

The most commonly used additive for soil modification or stabilization is Ordinary Portland Cement (OPC) (Ahmed *et al.*, 2022). The price of OPC has surged significantly due to the sharp increase in energy costs since the 1970s, leading to high stabilization costs. Consequently, the search for effective locally available industrial or agricultural waste materials as stabilizing agents to enhance the properties of poor soils has become essential (Ayanlola *et al.*, 2024). Limited work has been carried out on the durability aspect of this emerging construction materials especially in acid prone environments. So many research studies have been carried out on laterized concrete; most of these studies focused on its mechanical and elastic properties. Studies on the compressive strength of laterized concrete have shown encouraging results, but lack of sufficient technical data had limited its wider application in road construction works. This brings about the need for this research works to evaluate other relevant characteristics of laterized concrete incorporating glass powder.

Statement of Problem

Generally, glass does not harm the environment because it does not emit pollutants. However, it can pose risks to humans and animals if not handled carefully, and it is less environmentally friendly due to its non-biodegradable nature. Using laterite and glass powder to produce pavement blocks reduces the cost of purchasing pavement materials and makes our environment more sustainable.

Literature Review

Raheem and Sulaimon (2013) investigated sawdust ash as a partial replacement for cement in producing sandcrete hollow blocks. They concluded that at 10%, sawdust ash is adequate for use in sandcrete hollow blocks for non-load bearing walls in construction, but did not consider economical laterite soil. Kamau and Ahmed (2017) reviewed corn cob ash as a supplementary cementitious material and concluded that the compressive strength of CCA achieved by most authors is suitable for structural concrete, but they did not take into account the use of glass powder, whose preparation method is less complex than that of CCA. Oyebisi *et al.* (2018) also conducted a comparative study of corn cob ash-based lateritic interlocking and sandcrete hollow blocks, concluding that the inclusion of corn cob ash in LIB production should be promoted, as it has been shown to enhance nearly all the properties of lateritic interlocking blocks. The interlocking discussed by the authors pertains to walling, while this research focuses on pavement interlocking blocks. Danladi *et al.* (2025) describe soil stabilization as the modification or control of soil properties, encompassing the increase or decrease of soil characteristics in response to variations in environmental conditions, such as moisture or pressure. The stability of structures built on soil relies on the soil strength and its interaction with water (Anand and Kumar, 2022). Therefore, it is crucial to make soils that are deficient in strength useful and to meet geotechnical engineering design requirements. Glass is one of the most versatile substances on Earth, utilized in numerous applications and various forms.

Glass forms naturally when rocks high in silicates melt at high temperatures and cool before developing a crystalline structure. Obsidian, or volcanic glass, is a well-known example of naturally occurring glass. It is a mixture of silica sand, lime, and other materials (Olofinnade *et al.*, 2017). Crushed glass (CG) is a product created by crushing waste glass and is used in a wide range of applications. One of its most significant contributions to construction is its use as aggregate and glass powder as a partial substitute for cement (Adesope and Ayanlola, 2024).

Materials and Methods

The material and methods employed in the production of LIPB and testing are discussed below.

Grain Size Analysis

Apparatus used includes a set of sieves, a weighing balance, a mechanical sieve shaker, a wash bottle, a measuring can, a porcelain dish, and a mortar and pestle. A representative sample of 200 g was placed on sieve No. 800, and the system was shaken for 15 minutes. The sieves were removed and carefully weighed along with their contents. The weight of the material passing (g) and the percent passing were estimated from:

Weight of material passing = weight of dry sample – weight retained on the sieve

$$\% \text{ weight retained} = \frac{\text{weight retained}}{\text{total dry weight of sample}} \times 100\% \quad 1$$

$$\% \text{ weight passing} = 100\% - \text{percent retained} \quad 2$$

$$\text{Cumulative \% weight retained} = \frac{\text{cumulative weight}}{\text{total dry weight sample}} \times 100\% \quad 3$$

Liquid Limit

A sample weighing 20g was taken from material passing a 425mm BS sieve. The sample was mixed with water to a consistency of a thick paste and allowed to stand in an airtight container for 24 hours to allow water to permeate through the soil mass. A portion of the sticky soil was placed in a cup of the liquid limit apparatus and leveled; the grooving tools were used to divide the soil sample along the diameter through the center of the hinge. The crank was turned at the rate of 2 revolutions per second, the cup was lifted and dropped until the two parts of the soil came into contact at the bottom of the groove along a distance of 13mm. the number of blows with which this occurred was recorded. A little of the remaining soil sample was added to the cup and mixed with the soil in the cup. The operation was repeated until two consecutive runs gave the same number of blows for closure. A quantity of soil from the sample that flowed together was removed with a spatula and placed in a container, and the moisture content was determined.

Plastic Limit

A sample weighing 20g was taken from the material passing the No. 425mm BS test sieve. The sample was mixed with water to make a malleable but not sticky ball. It was rolled between the palms of the hand until it began to dry and crack. Half of the sample was rolled further to a length of 5cm and a thickness of 6mm. the thread formed during the process was rolled between the tip of the finger of one hand and the surface of a glass plate. The thread was rolled to about 3 mm in 5 – 10 complete movements (forward and backward). The soil was formed into a thread and rolled out again. The procedure was repeated until the thread sheared both transversely and longitudinally. The portion of the crumbled soil thread was gathered and transferred immediately to the container for moisture determination.

Plastic Index

$$PI = LL - PL$$

Preparation of Glass Powder

Waste glass was collected from different refuse dump in Igboora, washed and sundried. The glass was grounded into smaller pieces using hammer mill and further grounded into powder using silver crest blender (Model: Sc 2030B) and sieved using sieve size 0.362mm. the glass powder was then taken to the laboratory for X – ray fluorescence (XRF)



Plate 1: Prepared Glass Powder (Source: Ayanlola, *et al.*, 2024)

Production of Paver Block

Cement and laterite were measured using a 1:4 mix ratio; the percentage of cement was varied. It was thoroughly mixed with water to achieve plastic form; the mixture was then poured into the plastic mould in 3 steps and compacted manually by tapping on a flat surface. The percentage of cement was varied to accommodate glass powder at 10%, 20%, and 30%, respectively. After 24 hours, the samples were demoulded and weighed, then immersed in water for 28 days, curing, after which it was wiped with a clean cloth and weighed again. The produced samples were taken to the laboratory for compressive strength and split tensile strength tests.



Plate 2: Prepared LIPB (Source: Ayanlola, *et al.*, 2024)

Chemical Attack

Magnesium Sulphate and Hydrochloric acid were used for the test. The acid water was prepared by measuring 100 ml of Magnesium sulphate and HCl into 500 ml of distilled water. More water was added until the desired concentration was achieved at 0.1 mole. The acid solutions were allowed to cool down for 1 hour. The LIPB, after 28 days curing, were weighed, then soaked in the acid solutions in a plastic container and this container was closed for 24 hours. The specimens were removed from the acid solutions, wiped dry, and crushed, all crushing was done on the edge face with a 3mm thick flat plate placed at the top and bottom of the sample for even distribution of load (Olugbenga, 2014).

Results and Discussion

Grain Size Analysis

The result of the grain size analysis is presented in Figure 1. The percentage of particles passing sieve number 200 for the sample was greater than 35% (Olaniyan *et al.*, 2020). The value was higher, requiring the soil to be stabilized for use as base and sub-base courses in highway transportation.

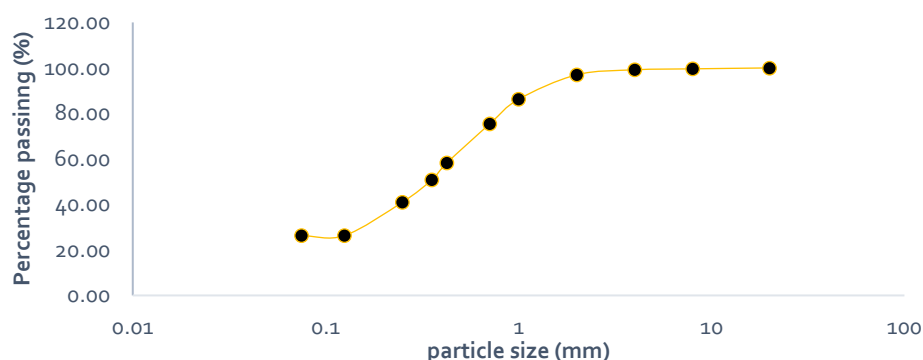


Figure 1: Grain Size Analysis

Atterberg's Limits

The results of Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) are presented in Figure 2. LL was 43.24%, PL was 26.09%, and PI was 17.5%. These values suggest that the laterite sample exhibits high water absorption capacity due to a large surface area from the presence of a finer fraction in the sample (Obioma, 2023). This also justifies the requirement for use, as the LL and PI do not exceed 80% and 55%, respectively, according to the Federal Ministry of Works and Housing (FMWH, 2011). The values align with those of 42% and 25% obtained by (Obioma, 2023 and Joshua *et al.*, 2014).

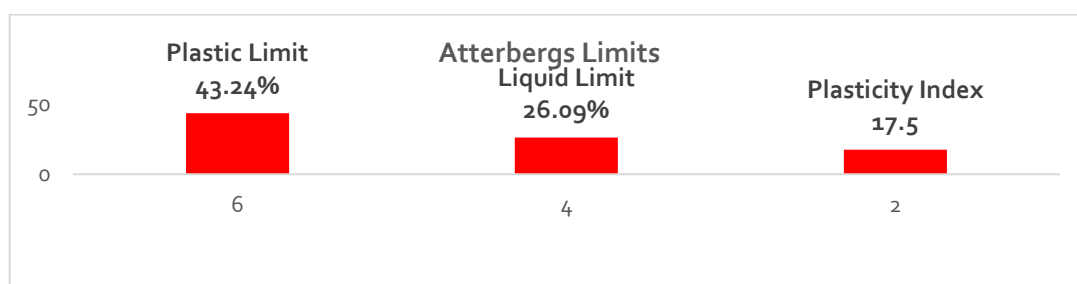


Figure 2: Atterberg's Limits Result

Pozzolanicity of Glass Powder

The glass powder pozzolanicity result is shown in Table 1 above. It is observed that glass powder is suitable as it satisfies the ASTM C618 (2015) classification, which specifies $\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O} \geq 70\%$ as class F. Since the glass powder sample used has the addition of the three materials to be 61.92%, it is therefore classified as class C Pozzolan

Table 1: Pozzolanicity of Glass Powder

Material	Properties (%)	ASTMC 618 – 91 Specification
CaO	10.55	$\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O} < 70$
SiO_2	40.15	
Al_2O_3	11.22	
Fe_2O	1.83	
MgO	0.25	
K_2O		$\leq 4\%$
	$\text{SiO}_2 + \text{Al}_2\text{O}_3 + \text{Fe}_2\text{O} = 61.92$	

LL = 43.24%, PL = 26.09%, PI = 17.5

Compressive Strength Result

Figure 3 shows the average compressive strengths of laterite interlocking paver blocks. At the control and 10% glass powder substitution, the compressive strengths are 8.30 and 7.80. These values are greater than 7.45 N/m^2 recorded by (Mose *et al.*, 2020), but lower at 20% and 30%, respectively (4.92 and 3.49). It could be observed that the incorporation of 10% glass powder resulted in a compressive strength reduction of 6.02%. The strength reduction is higher at 20% and 30% replacement, which are 40.72% and 57.95%, respectively, (4.92 N/m^2 , 3.49 N/m^2). It could be observed that 10% incorporation of glass powder reduced the compressive strength by 6.02%. The strength reduction is higher with 20% and 30% replacement, which are 40.72% and 57.95%, respectively.

Split Tensile Strength Result

From Figure 3, the average tensile strengths of laterite interlocking paver blocks are 0.62 N/mm² and 0.62 N/mm², respectively. It was observed that from 0% to 10% partial replacement, the tensile strength remains the same. However, at 20% to 30% partial replacement, there is a decrease of 50.63% and 80.65%, respectively. Tensile strength increases with compressive strength but decreases with an increase in glass powder replacement. This strongly agrees with (Ephraim *et al.*, 2016). replacement.

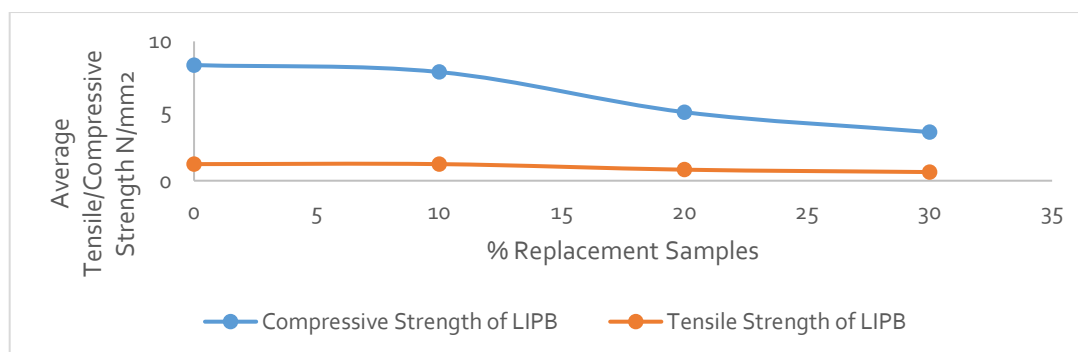


Fig. 3: Compressive and Split Tensile Strengths of Laterite Interlocking Paver Block

Chemical Attack on LIPB

From Figure 4, when samples were immersed in acid water solutions of Magnesium sulphate and HCl of 0.1M for 24 hours, there was a significant reduction in the compressive strength of the LIPB at all glass powder replacement levels (more than half of the compressive strength at the control). The reductions were 53.0%, 55.0%, 62.0%, 45.0% for HCl and 57.0%, 55.0%, 62.0% and 45.0% for MgSO₄. It can be observed that the glass powder replacement performance in MgSO₄ and HCl solutions was below that of the control at all stages. This is in line with Kamau *et al.* (2014), who reported significant deterioration in the strength of specimens when subjected to attack by Na₂SO₄ and MgSO₄. Adesanya and Raheem (2010) also reported a good performance of CCA replaced specimens in hydrochloric acid (HCl) for replacement up to 20%, after which there was a significant reduction in the compressive strength (Kamau *et al.*, 2014).

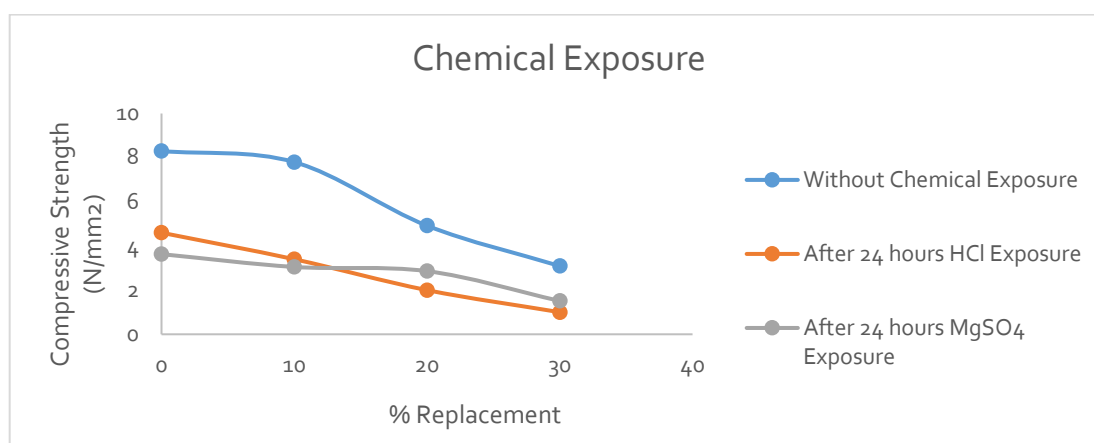


Fig. 4: Compressive Strength of LIPB Before and After Immersion in $MgSO_4$ and HCl

Density Result

The Density of LIPB ranges from 1293.65 Kg/m^3 – 1408.73 Kg/m^3 . Figure 5 showed that, the maximum density obtained is 1408.73 Kg/m^3 which is below the minimum value of 1810 Kg/m^3 recommended by the Nigerian Building and Road Research Institute (NBRRI, 2006). This may be due to the physical properties of the laterite soil or that of the glass powder used.

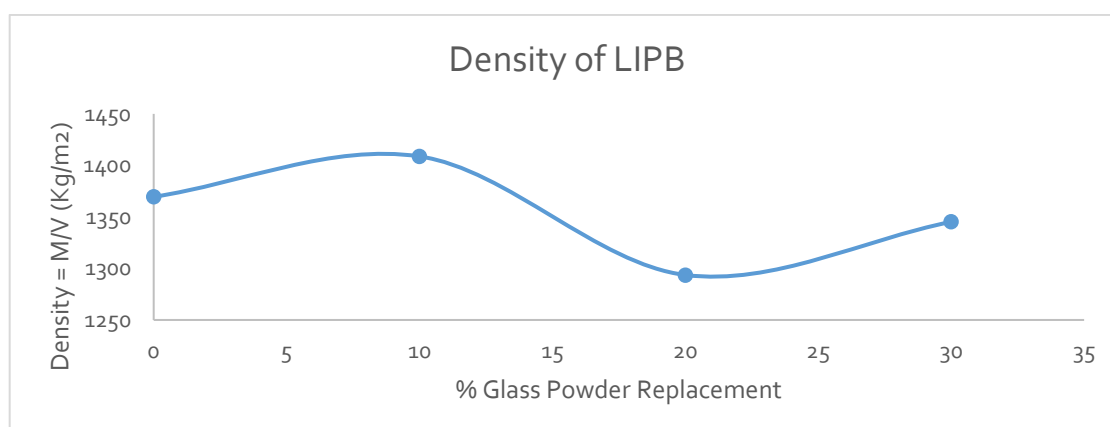


Fig. 5: Density of LIPB

Water Absorption Result

Figure 6 shows the water absorption of all LIPB produced after 28 days of curing. The results are 9.55%, 4.23%, 9.51%, and 3.54%, for 0%, 10%, 20% and 30% glass powder replacement, respectively. All samples produced satisfied the maximum water absorption of 12% recommended by the Nigerian Industrial Standard (NIS, 2004) and 12.5% water absorption recommended (NBRRI, 2006).

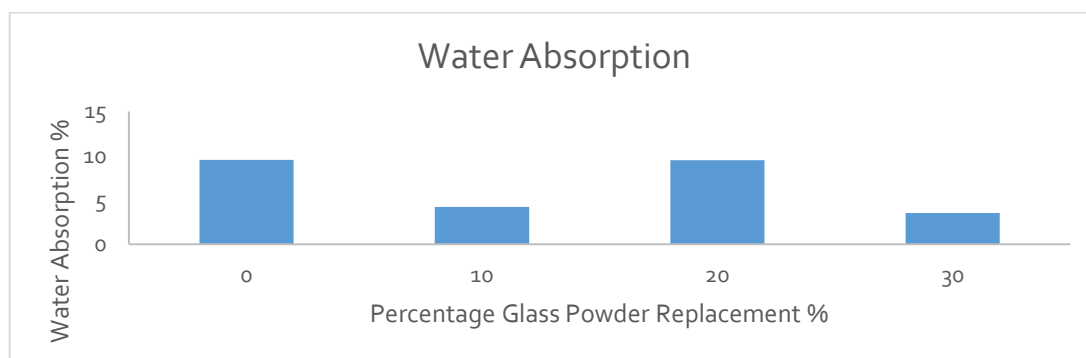


Fig. 6: Water Absorption of LIPB

Table 2: Analysis of Variance (ANOVA) Summary

Source	DF	SS	MS	F-Stat	P-Value
Between Groups	3	408.44	136.15	3.11	0.06703
Within Groups	12	526.24	43.85		
Total	15	934.68			

p-value (0.06703): Since this value is greater than 0.05, the differences in compressive strength across replacement levels are not statistically significant at the 95% confidence level. This means that, while there are visible changes in compressive strength, they might not be strongly influenced by replacement level alone. Other factors like curing conditions, material composition, or environmental effects may be playing a larger role in durability. If a more relaxed significance level (like 90% confidence, $p < 0.10$) is acceptable, the results might indicate some influence.

Conclusion and Recommendations

Conclusion

These results show that an increase in glass powder content leads to a decrease in both compressive and split tensile strengths. Furthermore, replacing 10% of cement with glass powder is effective, eco-friendly, and economical. However, using LIPB is not advisable in areas susceptible to acid exposure.

Recommendation

The LIPB produced can be utilized in low-capacity paved paths, such as walkways. Further research should be conducted on other supplementary cementitious materials.

Conflict of Interest

No conflict of interest.

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