Utilisation of Waste Plastics Admix with Laterite Soil for Production of Road Pavement Interlocking Blocks

Yamusa Bello Yamusa
Department of Civil Engineering, School of Engineering Technology, Nuhu Bamalli Polytechnic,
Zaria, Kaduna State, Nigeria
yamusabello@yahoo.com

Mubarak L. Liman
Department of Science Laboratory Technology, School of Applied Sciences, Nuhu Bamalli Polytechnic
Zaria, Kaduna State, Nigeria
mubarak.liman@gmail.com

Bilkisu Danjuma
Department of Civil Engineering, School of Engineering Technology, Nuhu Bamalli Polytechnic,
Zaria, Kaduna State, Nigeria
danjumabilkisu15@gmail.com

Abubakar Sani
Department of Civil Engineering, School of Engineering Technology, Nuhu Bamalli Polytechnic,
Zaria, Kaduna State, Nigeria
abubakarsani832@gmail.com

Yusuf Walliyullah
Department of Science Laboratory Technology, School of Applied Sciences, Nuhu Bamalli Polytechnic
Zaria, Kaduna State, Nigeria
yuswaliy@gmail.com
a)

Abstract

Plastic wastes are non-biodegradable and hence pile up in refuse dumps and streets constituting an eyesore and menace to the environment. Some of them end up in drainages and waterways where they block water passages resulting in flooding. This is in addition to the fatalities they cause to livestock and marine life that ingest them unknowingly. Globally, plastic waste proliferation has been recognized among the biggest environmental challenges mitigating the achievement of the United Nations Sustainable Development Goals (SDG). This research intends to transform the unwanted plastic wastes by mixing with laterite soil to produce road-paving interlocking blocks. Laterite soil was mixed with plastic waste at various proportions by respective weight denoted as P1 (60:40%), P2 (70:30%), and P3 (80:20%) to determine their usability as road paving material. Maximum compressive strength of 9.68, 10.40, and 6.88 N/mm^2 were achieved for P1, P2, and P3 respectively, implying the P2 mix has the best strength. The paving interlocking blocks made from plastic-laterite composite registered a relatively high performance and met the minimum compressive strength required by the Nigerian Building and Road Research Institute for interlocking paving blocks deployed for non-traffic use.

Keywords: Plastic waste; Laterite soil; Interlock paver block; Compressive strength; Waste management

1 Introduction

Nigeria is estimated to have a population of over 180 million people with an average daily per capita waste generation rate of 0.65kg per day (Orhorhoro & Oghoghorie, 2019). This amounts to 42 million tonnes of waste generated annually in Nigeria (Ike et al., 2018). The total global production of plastics recently is estimated at 8,300 million metric tons and Nigeria estimated plastics generation is about 25 million tons (Olanrewaju & Oyebade, 2019). Globally, plastic waste constitutes more than 60% of the total global municipal solid waste (MSW) of which was recovered and 78% disposed of. Therefore, converting these plastic wastes to useful products such as interlocks for road construction will go a long way in solving the plastic waste menace.

This research looks at the possibility of mixing this quantum of plastic waste with laterite soil. Laterite is a soil found in wet and hot tropical areas of the world that are rich in iron and aluminum (Ahmad et al., 2018). Due to the high content of iron oxide, laterite soils are reddish in color and are formed from the intense weathering of their parent rock. Persistent weathering, known as laterisation, results in a wide variability in their physical and chemical properties (Gidigasu, 2012). Laterite soil is the most common and abundant soil in Nigeria. Using this soil would help save a lot on cost of production of plastic-laterite paver blocks.

Soil reinforcement is undertaken for various ground improvement schemes in geotechnical engineering applications, encompassing backfill for earth-retaining structures, repair of slopes, landfill liners and covers, soil stabilization, and sub-grades for footings and pavements (Schlosser & Delage, 1988; Stanciu et al; Vaníček & Kazda, 2000). Technically, the soil has intrinsically high compressive strength but low tensile strength that is just restricted by the capability of the soil to resist applied shear stresses. Ground improvement is targeted to overcome the inability of the soil to capture any tensile loads and shear stresses which might result in deformation. Using tensile reinforcement improves the reliability and stability of geotechnical structures (Chebet & Kalumba, 2014). Plastics will be used as the tensile element in this regard.

Globally, the construction industry depends greatly on typical materials like sand, cement, and gravel which remain the major cause of natural materials' depletion (Sojobi, 2016). Local materials that are abundant and cheaper than conventional materials should be an alternative in construction (Yamusa, 2018). Utilization of abundant local materials to reduce construction costs to achieve sustainable development is paramount, especially in developing countries (Sojobi, 2016; Yamusa et al., 2016, 2017). Thus, laterite soil commonly available is investigated in composition with plastic waste to produce efficient, economic, and durable interlock blocks.

Paving blocks made from polyethylene/laterite composite could register higher performance relative to conventional concrete. They will lower the chances of surface rutting development, and eliminate spalling and weathering while minimizing susceptibility to cracking. If made and put into use, these blocks will not only reduce construction costs, especially those for repairs but also assist in environmental conservation. In this regard, it can be adjudged an innovative and remarkably feasible human project. Roads and walkways will be cheaply constructed, and with the increased durability, accessibility will be improved, and economic growth bolstered. In conclusion, this research could achieve its objectives and if applied, can help improve the quality of human life and mitigate the future of plastic waste.

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. These RPW were cleaned and air dried, and then taken to the laboratory for experimentation.

Laterite soil was bought from the available burrow 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 eliminate oversize gravel. The RPW and laterite soil are shown in Figure 1.

Fig. 1: Plastic Waste Bags and Laterite Soil

2.2 Physicochemical Tests on Waste Polyethylene Bags

Samples of waste Polyethylene bags were collected from recycling refuse dumps in the Sabon Gari area of Zaria, Nigeria, and transported as bales to the workshop at Nuhu Bamalli Polytechnic. They were sorted and classified; where only Transparent High Density Polyethylene (T-HDPE) were selected for use in this experiment.

The clean samples of waste T-HDPE obtained were freeze-dried overnight in a laboratory freezer at -12^{o}C to improve their crystallinity to allow for easy pulverization. They were subsequently ground in a pulverizer for 30 mins. until they become finely divided particles of less than ≤2mm diameter. Physicochemical assays including melting point, crystallinity, density, solubility, and index were determined using standard methods according to AOAC (1990). Determination of thermal physicochemical properties and degree of crystallinity: The enthalpies of fusion and degree of crystallinity were determined. The specific gravity and density were determined by the displacement method according to standards 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 test, particle size distribution test, Atterberg limit test, and compaction test. The sample was classified using the plasticity chart of the British Standard Classification System (BSI, 1999).

2.4 Mix Ratio of Waste Plastic and Laterite Soil

Creating a ratio mix for melting/solubilisation of the various classified waste plastics stream 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:

b) 60% laterite and 40% plastic contents by weight denoted as P1.

c) 70% laterite and 30% plastic contents by weight denoted as P2.

d) 80% laterite and 20% plastic contents by weight denoted as P3.

The waste plastic was put inside a lagged portable improvised plastic melting and mixing machine (mixer-densifier) at a temperature of about 180ºC and laterite was thereafter introduced and mixed. The densifier machine was fabricated through mechanical modification of a typical concrete mixer machine in such a way that a heating chamber was introduced with a heat-lagging covering to minimize heat loss. This machine automatically mixes the composite samples in a closely monitored and adjusted temperature to minimize the effect of thermal oxidation and its effect on molecular mass, ensuring preservation of physicochemical characteristics as well as the efficiency of the system. Three samples were taken after curing for the strength characteristic test. The test complies with (ASTM, 2014) for RPW.

2.5 Physicochemical Characteristics of Plastic-Laterite Interlock Bricks

Evaluation of the physicochemical characteristics of the produced materials and quality assessment checks in comparison with conventional concrete materials. In order to determine the load capacity of polyethylene and laterite composite, and to evaluate the effect of compressive strength, Compressive Test was carried out using a universal compressive machine tester (Model: Yes-3000; S/N: 110310) and Flexural strength was determined using universal flexural machine tester (Model: SEIDNER 3000; S/N: 5993).

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

b) Flexural Strength Test: Unlike the compressive strength test, the flexural strength test is to be carried out according to the BSI (2009a) standard on the composite samples that gave the highest compressive strength.

3 Results and Discussion

3.1 Physicochemical Properties of Waste Polyethylene Bags Sample

The physical test shown in Table 1 on the polyethylene shows varying properties with respect to thermal behaviors. The T-HDPE has a melting point of 148°C. The enthalpy of fusion and percentage crystallinity were 98.6J/g and 33.6% respectively. 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 depend on it.

Table 1: Physical Properties of Waste Polyethylene Bag Samples

Sample Description	Initial Melt. Temp/ Melting Point (°C)	Final Melting Temp (°C)	Enthalpy of Fusion (J/g)	Crystallinity (%)	Density (g/cm^3)
T-HDPE	148.00	163.10	98.60	33.64	0.954

3.2 Physical Properties of Laterite Soil

Results of the laboratory tests carried out to determine the physical properties of laterite soil samples are shown in Table 2. According to the British Standard (BS) classification, the soil sample is classified as a silty clay of medium plasticity (ML).

Table 2: Physical Properties of Laterite Soil

Property	Value
Specific gravity	2.70
% Fineness	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 Compressive Strength Test on Plastic-Laterite Blocks

Figure 2 shows the compressive strength at different mix ratios, where P1, P2 and P3 have 9.68 N/mm^2, 10.40 N/mm^2 and 6.88 N/mm^2 respectively. It was observed that the weight of the interlocking blocks increases with increase in the laterite content and decreases with increase in the plastic content. The blocks from the P2 mix ratio have the highest compressive strength, with an average of 10.4 N/mm^2. From the results obtained, these show that plastic-laterite interlocking paver blocks can be used in non-vehicular traffic areas such as public parks, building premises, footpaths, and landscaping because the compressive strength is adequate for the smooth service of users (Agyeman et al., 2019; Olofinnade et al., 2021). This also conforms with the minimum compressive strength of 3.45 N/mm^2 by Nigerian Building and Road Research Institute (NBRRI, 2006).

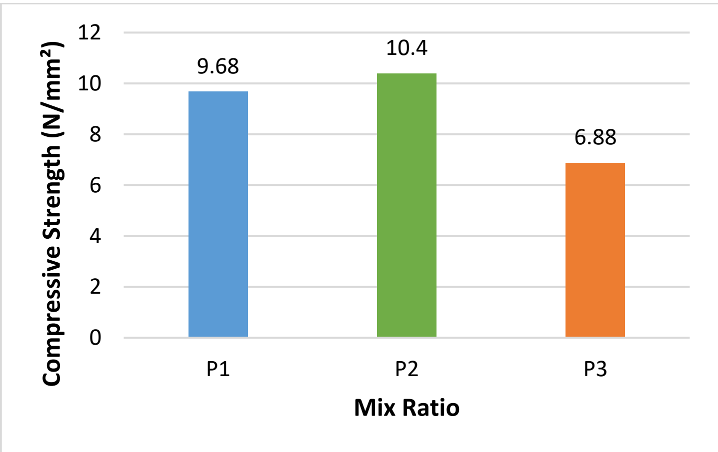

Fig. 2: Compressive Strength of Interlock at Different Mix Ratios

3.4 Flexural Strength Test on Plastic-Laterite Blocks

Figure 3 shows the flexural strength at different mix ratios, where P1, P2, and P3 have 7.14 N/mm^2, 5.10 N/mm^{2,} and 3.94 N/mm^2 respectively. It was observed that the weight of the interlock increases with an increase in the laterite content and decreases with increased plastic content. The interlocks from the 60:40 mix ratio have the highest flexural strength, with an average of 7.14 N/mm^2.

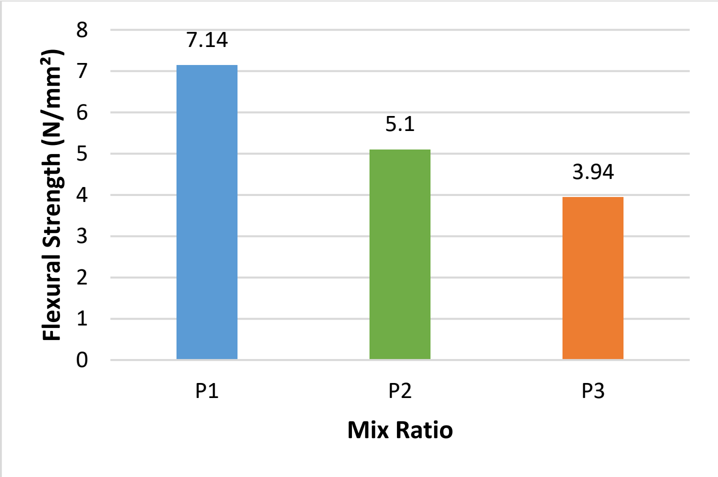

Fig. 3: Flexural Strength at different mix Ratios

The relationship between compressive strength and flexural strength of paving blocks is shown in Figure 4. It was observed that the flexural strength increased with an increase in compressive strength. A preceding study conducted by Djamaluddin *et al* (2020) likewise established that the flexural strength is directly proportional with the compressive strength.

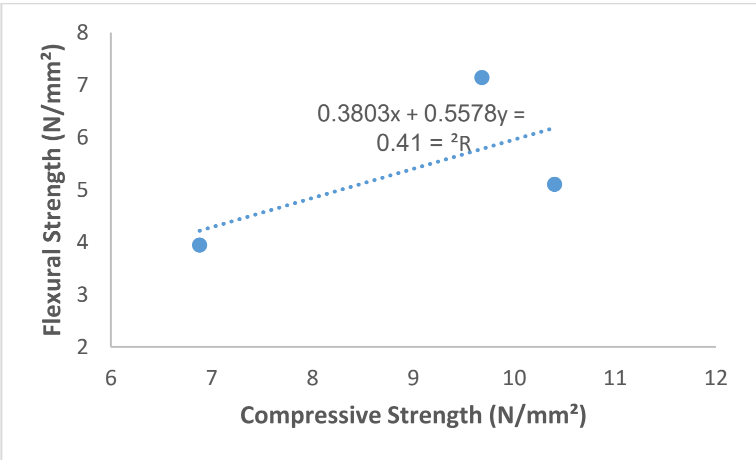

Fig. 4: Relationship between Flexural and Compressive Strength

3.5 Finished Product of Interlock blocks

Based on the analysed results, the plastic-laterite interlocking blocks were produced with the optimum mix ratio of 70-30. Figure 5 shows the finished product laid at the production workshop. Colorants were added to give different looks in order to enhance the aesthetic view where needed.

Fig. 5: Densifier Machine and Various Colors of Plastic-Laterite Interlock Bricks

4 Conclusion

This research efficiently demonstrates how to transform recyclable waste plastics into suitable paving construction materials i.e. interlocking blocks which can tremendously reduce environmental pollution. The results showed that the P2 ratio has the maximum compressive strength even though P1 and P3 also satisfy the requirement of the Nigerian Building and Road Research Institute (NBRRI) to be used for non-vehicular traffic pavements. Nonetheless, more tests such as water absorption and acid resistance need to be conducted in addition to compressive strength and flexural strength tests. In conclusion, the research brought about selection of best mix-ratio and production procedures leading to qualitative interlock products that are three times stronger than conventional concrete interlocking bricks that requires a minimum compressive strength of 3.45N/mm^2 by NBRRI. This can serve as a waste management approach that would decrease the problem of waste plastics in the society. Rather than the waste plastics going into landfills or incinerators they can be used as construction materials. Although this study shows that plastic waste can be curbed by utilizing it as a construction material, it was observed that its cost of production was high. This was due to the high consumption of liquefied petroleum gas (LPG). So, an alternative to LPG should be used to reduce cost.

Acknowledgment

This research work was supported by the National Research Fund (NRF) Grant of the Nigerian Tertiary Education Trust Fund (TETFund) Grant No: TETF/DR&D-CE/NRF-2020.

References

Agyeman, S., et al. (2019). Exploiting recycled plastic waste as an alternative binder for paving blocks production. *Case Studies in Construction Materials*, 11, e00246. doi.org/10.1016/j.cscm.2019.e00246.

Ahmad, et al. (2018). Effects of soil recompaction on permeability. *Science World Journal, 13*(3), 6-9.

AOAC. (1990). Official methods of analysis of the AOAC. Standard methods of the Association of Official Analytical Chemists, Maryland, USA.

ASTM. (2008). Standard test methods for density and specific gravity (relative density) of plastics by displacement. Committee d-20 on plastics: ASTM international. doi: 10.1520/ D0792-20.

ASTM. (2014). D638-14, 2014 standard test method for tensile properties of plastics. ASTM International, West Conshohocken, PA. doi**:** 10.1520/D0638-14.

BSI. (1990). Methods of testing soil for civil engineering purposes (BS1377: Part 1-9). British Standards Institute, London.

BSI. (1999). Code of practice for site investigations (BS 5930). British Standards Institute, London.

BSI. (2009a). Testing hardened concrete. Flexural strength of test specimens 12390-5 (2009). British Standards Institution, London.

BSI. (2009b). Testing hardened concrete; compressive strength of test specimens, part 3: BS EN 12390-3: 2009. British Standards Institute.

Chebet, F. & Kalumba, D. (2014). Laboratory investigation on re-using polyethylene (plastic) bag waste material for soil reinforcement in geotechnical engineering. *Civil Engineering and Urban Planning: An International Journal (CIVEJ), 1*(1), 67-82.

Djamaluddin, A. R., et al. (2020). Evaluation of sustainable concrete paving blocks incorporating processed waste tea ash. *Case Studies in Construction Materials*, 12, e00325. doi.org/10.1016/j.cscm.2019.e00325.

Gidigasu, M. (2012). Laterite soil engineering: Pedogenesis and engineering principles (Vol. 9): Elsevier.

Ike, C., *et al.* (2018). Solid waste management in Nigeria: Problems, prospects, and policies. *The Journal of Solid Waste Technology and Management, 44*(2), 163-172. doi:10.5276/JSWTM.2018.163.

NBRRI. (2006). Nigerian building and road research institute. *Newsletter, 1*, 15-17.

Olanrewaju, O. & Oyebade, A. (2019). Environmental menace of plastic waste in Nigeria: Challenges, policies and technological efforts. World Environmental Conservation Conference 2019.

Olofinnade, O., et al. (2021). Solid waste management in developing countries: Reusing of steel slag aggregate in eco-friendly interlocking concrete paving blocks production. *Case Studies in Construction Materials*, *14*, e00532. doi.org/10.1016/j.cscm.2021. e00532.

Orhorhoro, E. & Oghoghorie, O. (2019). Review on solid waste generation and management in sub-Saharan Africa: A case study of Nigeria. *Journal of Applied Sciences and Environmental Management, 23*(9), 1729-1737. doi: 10.4314/jasem.v23i9.19.

Schlosser, F. & Delage, P. (1988). Reinforced soil retaining structures and polymeric materials. *The application of polymeric reinforcement in soil retaining structures* (pp. 3-65): Springer. doi: 10.1007/978-94-009-1405-6_1.

Sojobi, A., O. (2016). Evaluation of the performance of eco-friendly lightweight interlocking concrete paving units incorporating sawdust wastes and laterite. *Cogent Engineering, 3*(1), 1255168. doi.org/10.1080/23311916.2016.1255168.

Stanciu, et al. (2019). Evolution of the design methods for reinforced soil works. Paper presented at the 15th Computational Civil Engineering CCE2019, Iasi, Romania.

Vaníček, I. & Kazda, I. (2000). Application and design of earth structures from the reinforced soils. *Acta Polytechnica, 40*(2).

Yamusa, Y. B. (2018). Effects of gradation on engineering properties of compacted laterite soil liner. PhD Thesis, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia.

Yamusa, et al. (2016). Effects of gradation on hydraulic conductivity properties of compacted laterite soil liner: A review. *International Journal of Scientific & Engineering Research, 7*(6), 1088-1091.

Yamusa, et al. (2017). Sustainable design of compacted laterite soil liner. Paper presented at the Global Civil Engineering Conference. DOI:10.1007/978-981-10-8016-6_84.

Cite as: Yamusa Y.B., Liman M.L, Danjuma B., ani A. & Walliyullah Y., "Utilisation of Waste Plastics Admix with Laterite Soil for Production of Road Pavement Interlock Blocks", *The 2nd International Conference on Civil Infrastructure and Construction (CIC 2023)*, Doha, Qatar, 5-8 February 2023, DOI: https://doi.org/10.29117/cic.2023.0079