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Application of Low-Density Polyethylene Waste as Binder in Sustainable Paving Bricks

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Abstract

Plastic waste disposal is a serious environmental issue especially in developing countries like Nigeria. Low-density polyethylene (LDPE) in solid state has been a recurring pollution problem to waterways, rivers, aquatic lives and even the soil. This paper experiments the application of LDPE waste as binding medium in sustainable paving bricks. The laboratory tests involved the use of washed and dried samples of the waste material melted into a thin paste and mixed with quarry dust, which passed through sieve 4.75 mm size at different mix ratio of 1:3, 1:4 and 1:5. The paving bricks were subjected to compressive test after 48 hrs of natural air curing and 24hrs of water absorption test. Tests results on the samples indicated that the compressive strength increased progressively from 7.93 - 11.93 N/mm² with increase in quarry dust content at specified different ratios. The water absorption test in particular indicates that the samples have low water absorption property that varies from 0.50 - 0.59% for all the mixes. For the heat resistant test, the paving bricks deform with visible cracks at 130 ºC. In addition, at 100 - 120 ºC, the bricks show no visible cracks or deformation. It is our suggestion therefore, that, replacement of cement as a binder with LDPE in the production of Pavement bricks will help reduce the associated hazards on the environment in particular.

Keywords: Low-Density Polyethylene, Pavement Brick, Quarry Dust, Environment, Sustainable.

Introduction

The world at large is rapidly evolving and so is the world's infrastructure. The infrastructure industry has witnessed a rapid and enormous growth in the last decade. This decade has proven to be a golden era for the infrastructure industry and the construction community, but with this rapid growth, the resources were utilized rapidly. Consequently, the infrastructure industry is facing a serious problem of shortage of construction materials due to the rapid depletion of the resources. Thus, as civil engineers it is part of our role to develop initiatives on how we can obtain eco-friendly construction materials. One of the ways to achieve this is by using cheap, available, durable and sustainable construction materials (Patel, Modhera & Panseriya, 2017). The use of low-density polyethylene (LDPE) has generated a large volume of waste that is ultimately detrimental to the environment. Due to its non-biodegradability and persistence, recycling processes have become one of the sustainable solutions for preventing environmental deterioration (Poonyakan, Rachakornkij, Wecharatana & Smittakorn, 2018).



Figure 1: Uncontrolled and indiscriminate disposal of Polyethylene wastes at Ungwa Sunday byYaka Street, Kaduna.

Developing countries (DCs) like Nigeria, typically have inadequate solid waste management, with no or low waste collection rates, which are primarily disposed by

dumping and have limited outlets for recyclable materials (Wilson, Velis & Cheeseman, 2006; Sohani et al. 2018). If harnessed, waste materials in DCs can provide livelihoods to entrepreneurial informal sector. The management of waste, particularly plastic wastes, has become a high profile environmental and public health issue (Wilson et al., 2006). Non-availability of local recycling infrastructures in DCs has led to uncontrolled and indiscriminate disposal of plastic wastes in culverts, open channels and dumping areas as indicated in Figure 1a and 1b. Plastic waste has become so common in DCs, particularly in Nigeria, where it has posed serious threats to marine ecosystems and biota. "It has been estimated that between 4.8 and 12.7 million metric tons of plastic waste was added to the oceans in 2010" (Jambeck et al., 2015). Studies have shown that 60–80% of marine litter is plastic, and poor waste management in DCs is a major cause and contributor to plastics pollution in the oceans (Grantham Institute, 2016). Despite the low biodegradability of plastics and the potential long-term adverse environmental impacts, single use polyethylene drinking water sachets are very widely used throughout much of Africa (Narayana, 2009; UNEP, 2005, Stoler, Weeks & Fink, 2012).

In Nigeria pollution of the environment by polyethylene waste bags or sachets have become a great concern and Kaduna is no exception despite the efforts made by the Kaduna State Ministry of Environment (K.S.M.E). Lack of adequate polyethylene waste recycling and the manpower to properly dispose the waste in Kaduna has been an issue (The Sun, 2024). Perhaps, a study to evaluate low-density polyethylene waste as binder in sustainable paving brick productions could remedy the predicament. Thus, the aim of this study is to evaluate the application of polythene waste as total replacement of cement in the production of eco-friendly paving bricks. The specific objectives of this research are to investigate the engineering properties (compressive strength) of samples of prepared polyethylene paving bricks, to determine water absorption content of polyethylene modified paving bricks, and finally, to determine the heat resistance of the paving bricks.

Literature Review

Waste Recycling

Recycling offers one means of reducing the impacts of waste disposal on the atmosphere. It involves using waste as material to manufacture a new product. Recycling involves altering the physical form of an object or material and making a

new object from the altered material. Recycling is a resource recovery practice that refers to the collection and reuse of waste materials such as empty beverage containers. The materials from which the items are made can be reprocessed into new products (Association of African Entrepreneurs, 2017). Material for recycling may be collected separately from general waste using dedicated bins and collection vehicles, a procedure called kerbside collection. In some communities, the owner of the waste is required to separate the materials into different bins (e.g. for paper, plastics, metals) prior to its collection. In other communities, all recyclable materials are placed in a single bin for collection, and the sorting is handled later at a central facility. The latter method is known as "single-stream recycling" (Department of Streets and Sanitation, Chicago 2013).

Recycling of Plastics

Utilization of plastic wastes, or plastic recycling, has become a viable and sustainable solution to avoid environmental impacts caused by plastic wastes (Jaseem, Kumar, & John, 2017). This is due to an improper waste management, particularly poor collection and segregation of plastic wastes. However, plastic waste recycling rate is relatively low in developing countries. Estimates have it that only one percent of plastic bags are recycled worldwide (Racape, 2019). Generally, plastic recycling process includes sorting into types based on different polymers, cleaning, chipping, and melting down into pellets. After that, the pellets are used to make plastic products such as plastic bags, containers, carpets, sleeping bags, and jacket insulation materials (Poonyakan et al., 2018). Amin, Khan & Saleem (2016) conducted a study on Performance evaluation of Asphalt Modified with Municipal Wastes for Sustainable Pavement Construction by varying percentage between 5 - 15% of high and low density polyethylene. They found out that the rutting and fatigue resistance of modified binder was significantly improved. In further research work, Poonyakan et al., (2018) studied potential use of plastic wastes for low thermal conductivity concrete. The result of thermal conductivity properties of concrete may however improve by addition of 30% LDPE.

Quarry Dust

Quarry dust is a by-product of the crushing process that is a concentrated material to use as aggregates for concreting purpose, especially as fine aggregate. In quarrying

activities, the rock has been crushed into various sizes; during the process the dust generated is called quarrying dust and it is formed as waste (Prakash & Rao, 2016). Quarry dust has been in the use for different activities in the construction industry, such as road construction and building materials. Quarry dust acts as lightweight aggregates in bricks, tiles, and blocks. Chitlange & Pajgade (2010) observed that there is consistent increase in the strength of plain concrete when natural sand replaces by quarry dust.

Paving Bricks

These are flat pieces of bricks, which are used to make a hard surface. They are used as floor finishes and are made out of mixture of sand, cement and water. Paving bricks are designed to last when installed in the ground. The paved surface can withstand hot and cold temperatures, snow and rain, and foot traffic. There are many individual choices with brick pavers as they are available in huge variety of shapes, colors, textures and thicknesses that can create basic patterns. Some of the advantages of brick paving include; slip-resistance surface, strength and durability, environmental friendly, flexibility integrity and quick installation (Well Laid Paving Perth, 2016).

Materials and Methods

Material Sourcing - Low Density Polyethylene (LDPE) and Quarry Dust

The low density polyethylene (LDPE) bags used in this research work were sourced from discarded 'pure' water sachets by scavengers. In addition to that, damaged water sachets were obtained from drinking water purification factories resident in Kaduna metropolis. Figure 2a and 2b show the collected LDPE sachets. The quarry dust on the other hand was purchased at Kabala Junction, in Kaduna metropolis. The quarry dust was packaged in a used cement bag and transported to Civil Engineering Laboratory for storage, testing and use in LDPE concrete mix. See Figure 2 (e).

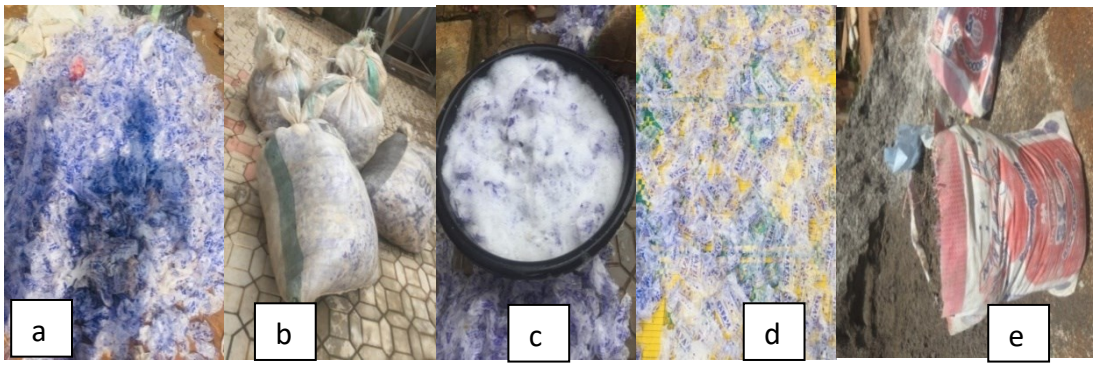


Figure 2: (a) Heap of collected LDPE pure water sachets(b) Water sachets packaged in bags (c) Washing of LDPE to remove dirt (d) Opened LDPE water sachets spread on a mat for drying (e) Quarry dust in used cement bags opened to be air dried

Pre-treatment of Sourced Materials

To enhance uses of the waste material as a binder in the polyethylene paving bricks, the material was first subjected to pre-treatment processes. A thorough washing of the sample material was conducted as indicated in Figure 2 (c). The sachets cut, opened individually, spread on the mat, and dried at ambient temperature as shown in Figure 2 (d). This process removes any trace of water or moisture from LDPE materials. The quarry dust was air dried to eliminate any undue influence of moisture content in it. The quarry dust passed through sieve 4.75 mm size and material smaller than 0.075 mm discarded.

Fabrication of the Mould

Mild steel sheet was used for the fabrication of brick moulds with size 230mm x135mm x45mm at Panteka Market, Kaduna, as shown in Figure 3a. The inner faces of the moulds were smoothly finished to ease the de-moulding process.

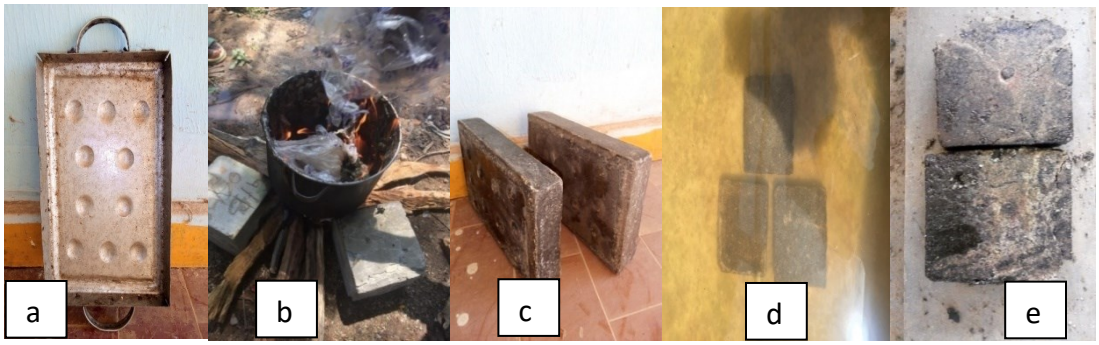


Figure 3: (a) Fabricated mould (b) Heating/mixing pan (c) Samples of cast paving bricks (d)
LDPE paving bricks immersed in water for water absorption test (e) LDPE paving bricks after compressive strength test

Formation of LDPE Concrete Mix

Pre-treated samples of LDPE were placed in a mixing pan, heated with firewood until everything melts into a thin paste, as shown Figure 3 (b). While still on fire, a pre-treated quarry dust added and mixed in order to form a smooth consistency of concrete.

The mixture was poured into the mould and compacted to cast the paving bricks as indicated in Figure 3 (c).

Experimental Procedures

The laboratory tests carried out in this study confirm to the general principles and procedures outlined and described in BS 1377: 1990. The produced samples of paving bricks were tested in the laboratory to assess their compressive strengths,water absorption qualities and heat resistance after 48hrs, 24hrs and 48hrs respectively.

Results and Discussion

Presentation of Results

Table 1: Compressive strength of LDPE Paving bricks at different LDPE/quarry-dust ratios

S/N	No. of trials	LDPE/quarry-dust ratio	Mass of sample (g)	Load at failure (kN)	Compressive strength (N/mm^2)	Density (kg/m^3)	Average compressive strength (N/mm^2)	Average density (kg/m^3)
1.	i	1:3	509	79.5	7.95	2040	7.93	2021
	ii	1:3	501	75.6	7.56	2004		
	ii	1:3	505	83.0	8.30	2020		
2.	i	1:4	500	96.7	9.67	2000	9.40	1990
	ii	1:4	489	92.3	9.23	1956		
	iii	1:4	504	92.9	9.29	2016		
3.	i	1:5	510	116.6	11.66	2040	11.93	2024
	ii	1:5	508	113.9	11.39	2032		
	iii	1:5	500	127.5	12.75	2000		

Table 2: Water absorption test of LDPE paving bricks at different LDPE/quarry-dust ratios

S/N	No. of trials	LDPE/Quarry-Dust ratio	Mass of dry LDPE brick sample (M_1) (g)	Mass of wet LDPE brick sample (M_2) (g)	Absorption capacity (%)	Average absorption capacity (%)
	i	1:3	509	511	0.39	0.59

1.	ii	1:3	505	509	0.79	
2.	i	1:4	500	503	0.60	0.51
	ii	1:4	489	491	0.41	
3.	i	1:5	510	513	0.58	0.50
	ii	1:5	508	510	0.39	

Table 3: Heat resistance test of LDPE paving bricks at different LDPE/quarry-dust ratios

S/N	LDPE/quarry-dust ratio	Time (min)	Temperature (°C)	Remarks
1	1:3	30	100	No observed changes
		60	110	No observed changes
		90	120	No observed changes
		120	130	Cracks and minor changes at edges
2	1:4	30	100	No observed changes
		60	110	No observed changes
		90	120	No observed changes
		120	130	Cracks and minor changes at edges
3	1:5	30	100	No observed changes
		60	110	No observed changes
		90	120	No observed changes
		120	130	Cracks and minor changes at edges

Discussion of Results

Table 1 presents the results of the compressive strength carried out on samples of pavement bricks produced at different LDPE/quarry-dust ratios. The result showed that the compressive strength of the LDPE pavement bricks increases steadily with increase in the quantity of quarry dust added. The values of compressive strength vary between 7.93 - 11.93 N/mm². This may be due to additional surface area provided by more aggregates in the mixed batches, which facilitate binding capability of LDPE material. Similarly, Sohani et al. (2018) affirm that the compressive strength of

LDPE/sand aggregates of 2:8 and 3:7 produced compressive strengths of 15.4 and 17.2 N/mm² respectively; but lower than those of conventional pavement bricks which are 25.6 N/mm² at ratio 1:3. Comparatively, the LDPE pavement bricks are less brittle to conventional bricks.

Table 2 indicates the results of water absorption test conducted on the LDPE/quarry-dust pavement bricks produced. The results indicated that water absorption characteristics of LDPE/quarry-dust bricks range from 0.50 - 0.59% that is far lower than that of conventional paving bricks having 3.7% as described by Sohani et al., (2018). The low water absorption property of LDPE/quarry-dust bricks presents unique advantage for its possible use as roofing material.

Table 3 shows the heat resistance test on LDPE/quarry-dust pavement bricks. The pavement bricks deformed with visible cracks at 130 ºC but remained unchanged at temperature ranging between 100 - 120 ºC. This characteristic is expected because the melting point of average low-density polyethylene is typically between 105 - 115 °C (Sohani et al., 2018).

Conclusion

The aim of this study was to evaluate the usability of polythene waste as total replacement of cement in the production of eco-friendly pavement bricks. The results of the study showed that compressive strengths of the LDPE/quarry-dust pavement bricks increase with increase in the quantity of quarry dust added. LDPE/quarry-dust paving bricks also have low water absorption quality that maybe explored in other construction applications. Further tests results showed that the LDPE/quarry-dust pavement bricks deformed with visible cracks at 130 ºC but remained unchanged at temperature ranging between 100 - 120 ºC.

Recommendation

From this work and its findings, we suggest the following recommendations.

- ❖ Further study to improve compressive strength of LDPE/quarry-dust by determining the optimum mix ratio, may be undertaken at various ratios.
- ❖ We also recommend that the mould for LDPE/quarry-dust pavement bricks should be fabricated to reflect the maximum standard thickness of 50 mm as specified by BS 6717.

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