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Utilization of Low Density Polyethylene (LDPE) Plastic wastes in the Production of Paving Tiles

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Abstract
Low density polyethylene (LDPE) plastics are non-biodegradable, and the improper disposal of the used plastic leads to accumulations of solid wastes which are detrimental to the environment. In this work, waste LDPE plastics were utilized in the production of paving tiles to curb the potential menace. The tiles were produced by mixing sharp sand with molten plastics in varying ratios of 1:1, 1:2, 1:3 and 1:4 plastic-to-sand. The mixture was allowed to cure for 28 days, and characterized using standard procedures. The results showed that the compressive strength increases from 1.099 N/mm^2 to 1.787 N/mm^2 as the sand component of the ratio increases from 1 to 3. Further increase of sand in the ratio results to a decrease in compressive strength, to 1.581 N/mm^2. At this ratio, the tile (sample) could withstand up to a maximum load of 39 KN before failure occurs as against 29 KN for a conventional sand-cement composite (control). Furthermore, the average frictional coefficient of the sample and control were 0.372 N/kg and 0.289 N/Kg respectively. This is an indication that ratio 1:3 is the optimum mixture for LDPE-based tile; and the plastic-sand bonded tiles could replace the sand-cement composite for engineering constructions.

1. Introduction
Plastics in general are amongst the materials used in the modern engineering products in the global market today. Plastic consists of a wide range of synthetic and semi-synthetic organic compounds which could be molded into different solid shapes because of its malleability property [1]. Plastic material exist in different forms such as bags, furniture, cups, basins, drinking and food containers, and these could become waste material after the intended purpose. Plastic wastes are global phenomenon, and the negative effects are felt all through the universe. The damages from the accumulated plastic wastes to our environment are irreplaceable because of the hazardous effects to both plant and human life [2]. Therefore, the need for proper disposal, and if possible recycle of these wastes into useful products is necessary to curb the nuisance it causes to the environment.

Plastics are categorized as thermoplastics and thermosetting plastics. These categories of polymer are differentiated based on their behavior in the presence of heat. Thermoplastics have low melting point, and therefore can be recycled or reformed by exposure to heat, while thermosetting plastics have high melting point. Thermosetting plastics could withstand higher temperatures without losing its rigidity, and as such, thermosetting materials cannot be re-molded or recycled by applying heat [3]. Thermoplastics constitute about 80% of all plastic that are commonly used while thermosetting plastics constitute about 20% [4]. Some plastics are safe to be recycled, while some are not. Plastic wastes that cannot be recycled litter the environment, some parts are used in illegal landfilling while some are incinerated for harvesting of energy which gives off significant emission of hazardous gasses including carbon dioxide (CO_2). The abatement of CO_2 emission from incineration of plastic wastes outweighs the benefit of the energy generated [5].

The recycling of waste plastic materials especially wastes generated from polyethylene in some developing countries can provide employment and means of livelihoods to the informal entrepreneurial sectors [6]. Because there is little or no infrastructure for local recycling, waste plastics have little or no value in developing countries. The utilization of earth-based clay material for tiles and blocks will result in depletion of resource, and environmental degradation. LDPE plastics and Polyethylene Terephthalate (PET) bottles are the types of plastics that are mostly used for various purposes such as packaging of food and water. In most cases, after the consumption of the food items, the plastics are disposed indiscriminately thereby posing a great environmental problem. It has been specifies that empty LDPE and PET wastes are rampant in all the nooks and crannies of the landscape of most developing countries. Because plastics are non-biodegradable materials, the wastes accumulate in the soil and cause several problems for the plants [2]. For example, plastic wastes in the soil prevent water from getting to the root of the plants, and restricts the stretching of the plant roots. Plastic wastes in the water body hinder the exchange of gases for respiration by plants and animals [6]. Despite the long-term adverse environmental impacts of plastics, LDPE and PET bottles are very widely used in Africa [7]. Most of the inter-state roads in Nigeria are lined up with millions of waste plastic materials deposited by travellers. Some of these wastes find their ways into drains and canals, thereby blocking and clogging the drains, then hindering the free flow of water and consequently leading to flooding [4]. Dumping of plastics into waterways has severe adverse effects on local communities. Waste plastics are not only unsightly, but cause flash floods and pools providing fertile ground for breeding of mosquitos and other waterborne diseases. Because of the extensive use of LDPE and PET plastics, and the indiscriminate and uncontrolled dumping of wastes plastic into water bodies in developing countries, pollution have so increased to such an extent that they are now a major environmental issue in many parts of Africa [8]. It is estimated that 15–40% of waste plastic dumped into water bodies in these countries contributes to about 5.25 trillion estimated pieces of plastic debris in the oceans currently [7]. The rate of increase of waste plastics in municipal solid waste is estimated to be doubling every 10 years. This is owed to the rapid in urbanization, population growth, and changes in developmental activities and life style. According to recent studies, waste plastics are estimated to remain on earth surface for about 450 to 500 years without degradation [9, 10].

In view of all the hazards that accompanied the improper disposal of plastic wastes, the need then arises for an alternative means to manage these plastic wastes. The only means to adequately taken care of several tons of plastic wastes being disposed is through the adoption of recycling process, and this process of recycling contributes to a cleaner environment [8]. Recycling of Plastic waste is a process of recovering the wastes and turning the scrap plastics into useable products that can be sent back to the manufacturing chains. The large volume of materials required in the manufacturing industries as feedstock is potentially a major area for the recycle of waste plastic materials [11]. Plastic recycling is widely used globally and has the advantage of removing plastics from the waste stream for a long period. Recycling of waste plastics has the benefits of reducing environmental impacts that may arise as a result of indiscriminate burning of plastics materials. Reuse of waste plastics in industrial construction has been embraced by many researchers [12, 13]. The rate of production of plastic containers far exceeds the rate at which the waste generated is recycling thereby shifting equilibrium in the world's ecology and increasing landfill sites [14, 15]. Manufacturing paving slabs from plastic waste is characterized by the fact that it does not require a high investment and it primarily uses plastic packaging, namely; bags and transparent film made of polypropylene and polyethylene. This will generate revenue, create job opportunities and reduce the hazards associated with improper disposal of plastic wastes [16]. Therefore, this study focused on the manufacturing of paving tiles by mixing sand and waste plastics at different ratios. The characterization of the paving tiles will provide some information regarding the suitability of the sand-plastic composite for use in engineering constructions.

2. Material and Methods

2.1 Collection of raw materials

The LDPE plastic wastes (water sachet, food bags, food wrap, films and storage bags) were collected from dump sites and eateries within the University of Benin, Benin City, Nigeria. The LDPE plastic materials were sorted and washed with soap water to get rid of contaminants such as oil and dirt, thereafter sun dried and then shredded to smaller sizes.

Sharp sand was collected from a building construction site. The sand was oven-dried, and sieved to get uniform sizes (<500 μm) to avoid pores in the finished product. The LDPE plastics and sand were weighed separately to obtain the plastic-to-sand ratio of 1:1, 1:2, 1:3 and 1:4 respectively. Each ratio was produced in duplicates.

2.2 Production of paving tiles

The plastics were placed in a melting barrel, gradually heated to about 160 ^{o}C – 170 ^{o}C until the plastics were completely melted to a slurry form. The sand was added, and mixed thoroughly until a homogeneous mixture was attained [9]. The hot mixture was then poured into aluminum molds. The mixture was compacted using a compactor to prevent air bubbles. The molds were earlier lubricated with engine oil or grease to ease the removal of tiles. The mixture was allowed to cool for twenty-four hours thereafter removed. The tiles were left to cure for 28 days before qualitative analyses were carried out (see Figure 1).

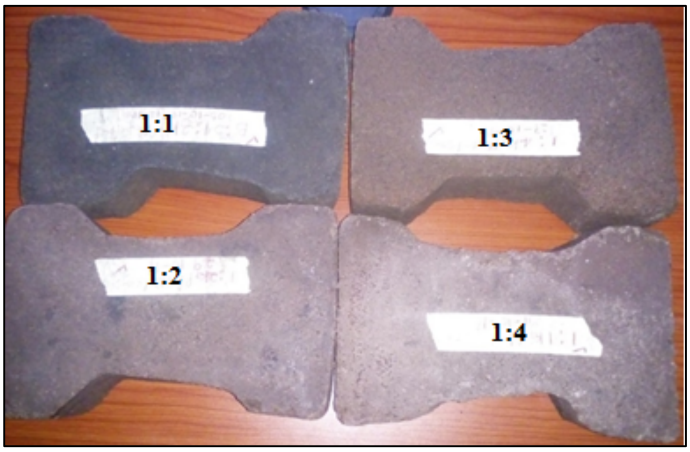

Figure 1: Manufactured paving tiles of various plastic-to-sand ratios

2.3 Qualitative tests on the plastic-sand tile

2.3.1 Water absorption test: The paving tiles were subjected to water absorption test. In the cold water absorption test, the weight of the composite was taken using digital weighing balance (model PM 4800) before immersion into the water. After 24 hours of immersion, the composite was removed and allowed to drain on a wire mesh for about one minute. Any visible water droplet on the surface was removed with damp cloth and then reweighed. The amount of water absorbed was recorded [17, 18].

2.3.2 Compression test: A digital Matest Universal Testing Machine (Figure 2) was used for the compression test following the method described in previous work [10]. The dimension of the tiles was first taken, and the surface area calculated. The samples were placed on machine; load was applied continuously until there was a noticeable fracture in the composite material. The failure (maximum) load was thereby obtained and recorded. Comprehensive strength was calculated from the maximum load obtained using Equation (1).

$$Compressive\ strength = \frac{Maximum\ load \times 1000\ (N)}{Surface\ area\ (mm^2)} \tag{1}$$

Figure 2: The Universal Testing Machine (U.T.M)

2.3.3 Tensile Strength and Modulus of Elasticity test

The Tensile strength and modulus of elasticity of the tiles produced were determined using the values obtained from the compression test as expressed in the Equations (2) and (3)

$$Tensile\ strength = \sqrt[0.7]{F_{KC}} \tag{2}$$

$$Modulus\ of\ Elasticity = \sqrt[5000]{F_{KC}} \tag{3}$$

Where F_{KC} is characteristic compressive strength [10].

2.3.4 Frictional coefficient test: The sample was placed on a level platform, placed on it was a known mass of match box. With one end of the paving tile in position, the opposite end was continuously raised so that the tile will incline at an angle known as angle of inclination or angle of repose (Ø). This angle was increased until the mass placed on top of the paving tile rolled off, and at this point Ø was recorded (see Figure 3 for frictional coefficient test machine) [8].

$$Frictional\ Coefficient = Tan(\emptyset) \tag{4}$$

Qualitative testing is an important process in the production of paving tiles. This is to ascertain the suitability of the tiles for the purpose it was intended. Several qualitative tests were performed on the paving tiles according to standard procedures. Crushing test was first carried out on the samples obtained from the various ratios of 1:1, 1:2, 1:3 and 1:4 plastic-to-sand. Then the compressive strength was calculated from the values obtained from the crushing test (Figure 4).

Figure 3: Frictional coefficient test machine

The results showed that the compressive strength increases from 1.099 N/mm^2 to 1.787 N/mm^2 as the sand component of the ratio increases from 1 to 3. Further increase in ratio to 4 resulted in a decrease in compressive strength, to 1.581 N/mm^2. This gave the indication that ratio 1:3 plastic-to-sand is the optimum mixture for LPDE-based paving tiles. At this ratio, the tile could withstand up to a maximum load of 39 KN before failure occurred. This is in conformation with previous work where it was reported that the ratio of 1:3 plastic-quarry dust was the best of all the ratios studied [17]. In another study where PET plastics were used, it was reported that the plastic-soil ratio of 1:4 has the maximum compressive strength [2].

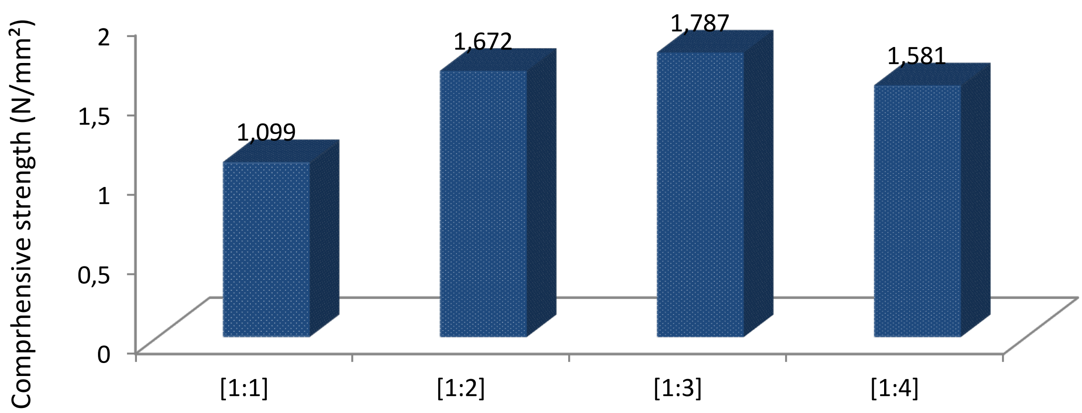

Figure 4: Variation of comprhensive strength with plastic-to-sand ratio

Qualitative tests such as density, water absorption (cold and hot), tensile strength, friction coefficient and modulus of elasticity were performed on the paving tile of ratio 1:3 plastic-to-sand and compared with the tests on the conventional sand-cement tiles of the same dimension (control). The tests include the water absorption test, tensile strength, resistance to compression or crushing test, modulus of elasticity, frictional test, flammability test and density. Figure 5 shows the results of the physical tests (weight, density and water absorption). The water absorption of the sample and the control are 1.61 % and 1.89 % respectively. These values fell within the acceptable standard values. It was stated in ASTM C 902 standard that for MX paver class, a maximum of 14 % cold water absorption is required [19].

ASTM C 902 standard for MX-brick specification are for pedestrian and light traffic paving brick intended for exterior with no freezing conditions. Water absorption test is one of the qualitative factors that can affect the durability of paving tiles. The concrete tiles with high level of water absorption have low resistance to chloride and sulfate, and has low resistance to water penetration [20].

The average density of the sample and the control are 2070kg/m^3 and 2340kg/m^3 respectively. It was specified that the density of paving tiles ranging between 1200 and 2400 kg/m^3 [19]. It was also stated the density of paving tiles should not be less than 1500 kg/m^3 as recommended in Indian standard (IS 1237:2012). The density of a paver tiles will influence other properties of the material such as porosity, compressive strength, thermal conductivity and durability. Tiles of lower density than specified by the manufacturer shall not be used as these may not be adequate to support heavy loads such as water tanks. The increase in density of paving tile brings about increase in compressive strength and decrease in absorbed moisture into the tile [21].

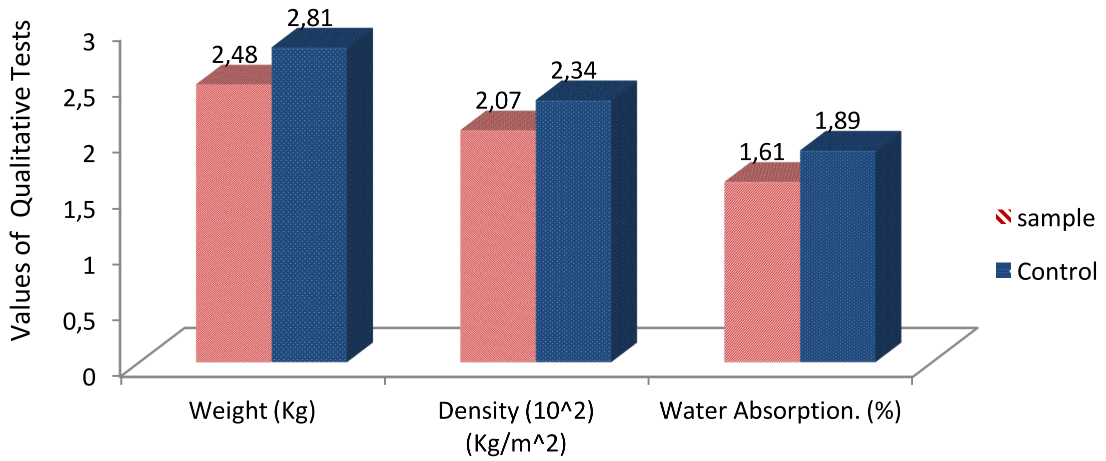

Figure 5: Comparative values of Physical Test for sample and control

Density of a brick has a great impact on the strength and failure load of the product [3]. To determine the failure load, the paver was placed between two steel pads of the crushing machine where the load was then applied vertically until fracture occurred. The average value of the failure load obtained for this study was 39 KN. This value conforms considerably with the value obtained from previous study where the failure load was recorded as 34 KN for a plastic-sand brick [8]. Meanwhile, Figure 6 shows that the failure load of the sand-cement paver determined using the same condition was 29 KN. This is an indication that the plastic-sand paver is considerably stronger than the sand-cement composite. Compressive strength of a brick is determined from the failure load. It is the maximum load per surface area of a material. The maximum load is the load at which the brick is unable to resist any further load increase [18]. It is otherwise defined as the load the brick is able to bear without breakage [22]. In this study, the compressive strength is recorded as 1.787 N/mm^2. Tensile Strength and Modulus of Elasticity of a brick depends on the failure load.

The frictional coefficient is used to obtain the slip properties of a paving tile [8]. The value of frictional coefficient of the paving tile produced in this study was given as 0.372N/kg (Figure 6). This low value obtained is an indication that the risk of slipping on the paving tile is reduced. However, the cement-sand composite with 0.289 N/Kg has a lower risk of slipping than the plastic-sand tile which in turn reduces the injuries caused by slipping when walking on the tiles. This is a draw back for the plastic-sand paving tile which can be improved upon in subsequent experimentations.

The paving tiles are intended to be used as light traffic paving bricks for exterior in a region with no freezing conditions. Freeze-thaw weathering is common in regions where the temperature often drops below freezing at night, it does not happen much in warm climates [23]. Freezing-thawing is important because it represents a process where a phase change occurs at an exact temperature [24]. Freeze-thaw occurs when water continually seeps into cracks of rocks or concretes, freezes and expands, eventually breaking the rock or concrete apart.

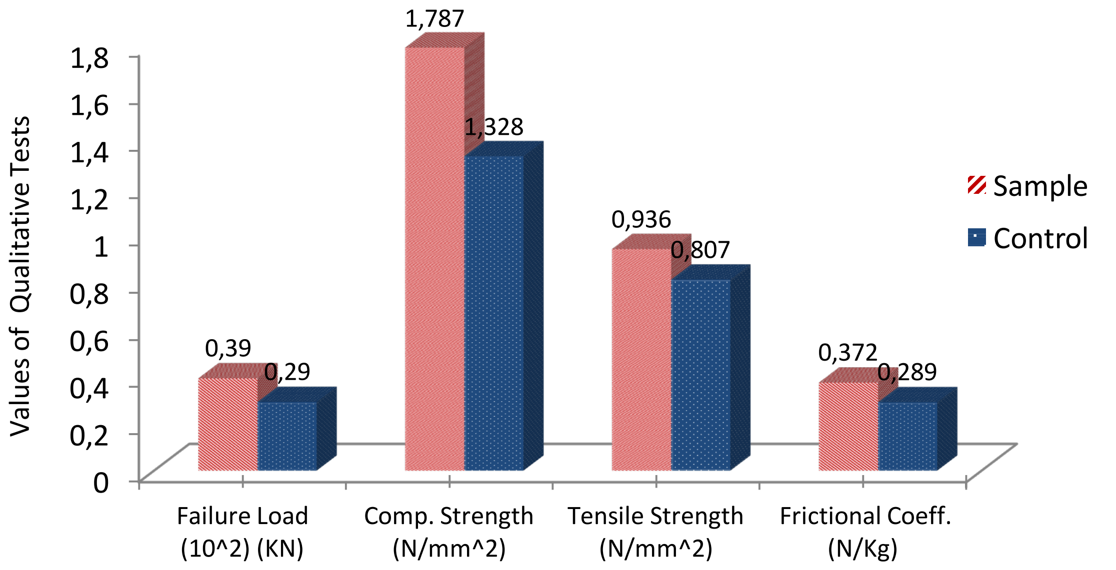

Figure 6: Comparative values of Mechanical Tests for Sample and Control

Conclusion

It is a known fact that waste LDPE plastics are non-biodegradable and can cause a lot of nuisance to the environment if not properly disposed. Therefore, converting the waste plastics to useful products such as paving tiles is highly recommendable. In converting waste LDPE plastics to paving tiles, the ratio of 1:3 plastic-to-sand was achieved as the optimum mixture which could withstand up to a maximum load of 39 KN before failure occurred as against 29 KN for sand-cement composite. It was however ascertained that, the plastic-sand tile has a higher frictional coefficient of 0.372N/kg than the sand-cement composite (0.289 N/Kg). This may result to higher risk of slipping when walking on the plastic-sand tiles.

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