Reusing Disposable Low-Density Polyethylene Waste Plastics for Flexible Paver Tile Construction for Outdoor Application

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Research Article

Keywords: LDPE waste plastics, sand, compressive strength, flexural strength, paver tile

Posted Date: March 13th, 2023

DOI: https://doi.org/10.21203/rs.3.rs-2564429/v1

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REUSING DISPOSABLE LOW-DENSITY POLYETHYLENE WASTE PLASTICS FOR FLEXIBLE PAVER TILE CONSTRUCTION FOR OUTDOOR APPLICATION

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REUSING DISPOSABLE LOW-DENSITY POLYETHYLENE (LDPE) WASTE PLASTICS FOR FLEXIBLE PAVER TILE CONSTRUCTION FOR OUTDOOR APPLICATION

Abstract

Plastic waste poses serious environmental problems as it is non-biodegradable and consists of several toxic chemicals that can pollute the environment. The use of this waste as a substitute material is gaining interest due to its environmental friendliness. Therefore, the aim of this study was to develop and characterize paver tiles from sand and waste plastics. First, waste plastic is collected, identified, grinded, and melted at temperature of 170°C. The sample sand was sieved to size of less than 0.75mm and mixed with plastic in specified proportion, then molded. Paving tiles were developed using hydraulic press with process parameters of plastic percentage from 10% to 40%, pressure from 1MPa to 5MPa and pressing time from 2 to 8 minutes. Individual and interaction effects of 3 process parameters on physico-mechanical properties like water absorption (WA), flexural strength (FS) and compressive strength (CS) were investigated and analyzed using BBD and Design -Expert13 software with p-values of 5%. The result showed that the optimum point was obtained at 25% of waste plastic, time of 5 minutes and pressure of 3MPa, resulting in maximum FS of 3.689MPa and CS of 4.141MPa, and overall average WA of Paver was 0.322%. Therefore, the developed tiles have better WA, FS and CS that meet the desired standard. From this finding, it can be concluded that reusing LDPE waste plastic with sand in the production of tiles is possible, and used for various outdoor applications. Therefore, making pavement tiles by reusing waste plastic is a promising option to protect our environment from pollution.

Keywords: LDPE waste plastics, sand, compressive strength, flexural strength, paver tile
1 Introduction

1.1 Background of study

Due to increase in population, urbanization, industrialization, changes in lifestyle and socio-economic conditions, plastic waste is increasing day by day (Alemayehu, Regasa et al. 2017, Kamsook, Phongphiphat et al. 2022). Plastic waste disposal has become a serious problem worldwide due to its non-biodegradability (Kebede, Ermolo et al. 2017, Babaremu, Okoya et al. 2022). In today's lifestyle, plastic is everywhere and its disposal is a big problem. Due to economic growth and shifting consumption patterns, the world's use of plastics is increasing rapidly (Ayeleru, Dlova et al. 2020, Hussein, Tsegaye et al. 2020). Globally, the consumption of plastic materials has increased from 5 million tons in the 1950s to 100 million tons in the 2000s (Chavan, Tamhane et al. 2018, Velis 2022). Due to increase in human population, development activities and changes in lifestyle and socio-economic conditions, the amount of plastic waste is increasing gradually (Koyachew 2016, Narancic and O'Connor 2019).

A Plastic is fabricated from synthetic and semi-synthetic organic material that can be molded (Avolio, Spina et al. 2019, Drzyzga and Prieto 2019). Plastics are high-molecular-mass organic polymers, but they frequently contain other ingredients (Huang, Wang et al. 2022, Mao, Chen et al. 2023). They are nearly always synthetic, derived primarily from petrochemicals. It is essentially a non-biodegradable material (Kibrekidusan 2017, Roy, Garnier et al. 2021). Plastics have distinct properties that make them superior to other materials in a variety of applications. Plastics have the following characteristics: corrosion and chemical resistance, a high strength-to-wet ratio, less electrical conductivity, a large variety of colors, and transparency (Alemayehu, Regasa et al. 2017, Shaikh, Khan et al. 2017, Shanmugavalli, Gowtham et al. 2017, Balu, Dutta et al. 2022).

In most developing countries (DCs), solid waste plastic management is insufficient, with small collection rates, dumping as the primary method of disposal, and few outlets for reusing potentially recyclable materials (Ayeleru, Dlova et al. 2020, Hussein, Tsegaye et al. 2020). Waste management, particularly waste plastics, has emerged as a high-profile Concern about the environment and the public's well-being (Verma, Vinoda et al. 2016, Ragossnig and Agamuthu 2021). In many DCs, recycling infrastructure for these materials does not exist (Wilson, Rodic et al. 2015). Dumping into waterways has serious consequences for the local communities. Not only are waste plastics unsightly, but they also clog urban drainage systems and sewers, resulting in flash floods. According to estimates, between 4.8 and 12.7 million tons of waste plastics were dumped into the oceans in 2014 (Jambeck, Geyer et al. 2015, Bardales Cruz, Saikawa et al. 2023). Down in ocean waterways, 60-80% of marine litter is plastic and poor waste management in DCs is a major cause and contributor to plastic in the oceans (Velis 2014, Ronkay, Molnar et al. 2021, Pradeep, Dash et al. 2022, Mao, Chen et al. 2023).

Paving block is flexible, attractive, workable, and low cost, with little to no maintenance required (Kumar 2014, Kumi-Larbi, Yunana et al. 2018). Natural resources are depleting globally, while waste generated by industry and residential areas is increasing significantly (Antelava, Damilos et al. 2019). Sustainable construction involves the use of non-conventional and innovative materials, as well as the recycling of waste materials, to compensate for a lack of natural resources and to find alternative ways to conserve the environment (Shanmugavalli, Gowtham et al. 2017, Antelava, Damilos et al. 2019).
Plastic waste is a serious problem in Ethiopia (Tassie Wegedie 2018, Antonopoulos, Faraca et al. 2021). Plastic waste is non-biodegradable waste that causes water, land and air pollution. Disposal of large quantities of plastic has emerged as a major environmental challenge (Ayeleru, Dlova et al. 2020, Ragossnig and Agamuthu 2021). Due to this, the amount of plastic waste in our environment is gradually increasing. They are mixed with municipal solid waste or dumped on land. According to (Erasu, Feye et al. 2018, Tadesse, Tefera et al. 2022) study, 80,235 tons of waste plastic is produced annually in Ethiopia. Their disposal can be by landfilling or by burning it. Both these processes have a significant impact on the environment. If they are burned, they pollute the air and if they are thrown away, they cause soil and water pollution. Waste plastic can be used in road construction and field tests have proved that plastic waste can withstand stress and be used after proper processing. An additive will improve the life of roads, and environmental issues (DibiMbozo, Mikla et al. 2017, Dao, Duong et al. 2023). The presence of waste plastic makes our environment unhealthy and unattractive. The solid waste management system in Akaki Kality Sub-city is inadequate because there are not enough baskets or other materials that separate plastic from organic waste, this condition increases the work of our sanitation employers. Much research has been done so far on recycling waste plastics for tile production and various efforts have been made to study the tile properties of different types of plastics (DibiMbozo, Mikla et al. 2017, Kumi-Larbi, Yunana et al. 2018, Noor and Rehman 2022, Pradeep, Dash et al. 2022, Dao, Duong et al. 2023). However, the water absorption, durability and compressive strength of paver tiles cannot be generalized as the properties vary with the ratio of sand and type of binder (plastic) and pressing pressure used in paver tiles. Therefore, the aim of the study was to produce and characterize paver tiles from sand and LDPE waste plastic using as a binder to improve the problem of plastic waste disposal.

2 Material and Methods

2.1 General framework

Figure 1 shows the general frame-work of the experiment, and the research was divided into five stages: sample collection, sample pre-treatment, sample analysis, tile production and characterization, and standard comparison. During the manufacture of sample tiles, plastic waste was used as a binder.

Figure 1: General framework diagram of paver tiles production

2.2 Material and equipment

The materials employed in this study have been plastics and fine aggregates [sand], and the main equipment used was a size analyzing sieve, digital balance, desiccator used to store samples in a moisture-free environment, drying chamber (oven), melting drum, wooden stirrer, molder, and compressive & flexural strength testing machines.

2.3 Methods

2.3.1 Collection of sample plastic waste

The plastic was obtained from Akaki Kality sub city around Kilinto and Tulu Dimtu areas, Addis Ababa, Ethiopia. The plastic waste samples were collected in five different days and mixed together based on the given symbols of plastic identification.
2.3.2 Sample Preparation

Sample pretreatment in the study included washing to remove impurities, drying, milling or grinding to reduce size, mixing based on its ratios with fine aggregates or sand and finally developing sample tiles. The high moisture content of above-standard of sand can be affected the quality of developed sample paver tiles, hence to reduce the influence moisture content of the sand below the standard is necessary (Rowe, Blankenship et al. 2012, Kumi-Larbi, Yunana et al. 2018), the sorted fine aggregate or sand is dried in the sun for 12 hours. Before using it for tile production, the dried sand is 0.75mm in size. In this study, less than or equal 0.75mm sand size was used to optimize the mixing ratio, pressing duration, and pressing pressure of prepared paver tiles to achieve minimum threshold compressive and flexural load.

2.4 Characterization of Raw Materials

2.4.1 Determination of Specific gravity of Sand and Plastic Wastes

Specific gravity of LDPE waste plastic & sand were determined using ASTM D2395-17 (ASTM 2008). The specific gravity waste plastic & sand were determined by dividing the mass of sand and plastic by their volumes. The volume of both waste plastic & sand was determined using the water displacement method with a graduated cylinder and distilled water, and the weight of both plastic and sand were measured with a digital electronic weighing balance. The density of purified or distilled water was assumed to be 1 g/cm3 and it was calculated as follows (Eq1).

\[
\text{Specific density of sample} = \frac{\text{Mass of the sample}}{\text{Volume of the sample} \times 1000}
\]

\[\text{Eq1}\]

2.4.2 Moisture content determination of sand

The sand moisture content was determined to see if the sand needed to be dried before mixing with the molten plastic. The collected sand was dried by the sun in the open air for half a day. This was done to remove surface water and moisture from sand in preparation for the subsequent processes. The moisture content of fine aggregate or sand (MCS) was determined using the ASTM D3173 standard grams of raw sample were oven-dried at 80 ° C for three hours to obtain a constant mass (ASTM 2008). The difference of the mass before drying and after drying to the mass before drying was used to determine moisture content of the sample (Eq2).

\[
\text{MCS} = \frac{\text{Wo} - \text{Wf}}{\text{Wo}} \times 100
\]

\[\text{Eq2}\]

Where: \(\text{Wo} = \) weight of sample and petri dish before drying (gram).
\(\text{Wf} = \) weight of sample and petri dish after drying (gram).

2.5 Design of the experiment

The experiment was designed in matrix of Design-Expert13 software by using Box-Behnken method (BBD) for optimization with carefully selected three treatment factors or variables (plastic to sand ratio, pressing duration, and tile pressing pressure) and three levels for each variable (Low, Center, and High) with assigned levels (-1, 0, and 1).
The intention of using this BBD method was to reduce and optimize the cost and the number of experiments to be performed (Wang, Nguyen et al. 2020). The interfacial effects of 3 variables and their influence on responses such as flexural strength, water absorption and compressive strength were studied to optimize the desired responses (dependent variable). such as water absorption, flexural and compressive strength were studied in this study. Factors such as plastic to sand ratio, pressing time and tile pressing pressure are denoted as X₁, X₂, and X₃, respectively. The experimental range of the true level of the factor level of the three independent variables is shown in Table 1 below.

Total experimental runs were calculated based on BBD from Equation (Eq3):

\[ N = K^2 + k + C_p \]  

Where, N – number of the experiment; k - number of factors; and C_p - a central replication point, that is 3 in this case (Cobas, Sanromán et al. 2014).

### Table 1: Factors and levels of process parameters

<table>
<thead>
<tr>
<th>Variables</th>
<th>Symbol</th>
<th>Actual value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic to sand ratio</td>
<td>X₁</td>
<td>-1 0 1</td>
</tr>
<tr>
<td>Pressing duration (min)</td>
<td>X₂</td>
<td>2 5 8</td>
</tr>
<tr>
<td>Pressing pressure (MPa)</td>
<td>X₃</td>
<td>1 3 5</td>
</tr>
</tbody>
</table>

A series of 15 experiments, including three replicates of a medium run, were conducted to optimize the degree of influence of the selected variables on the manufactured sample tiles. RSM with BBD design with 3 levels and 3 independent variables (Table 2) was created using Design-Expert version 13 software. BBD is a 2<sup>nd</sup>-order design based on three-level factorial designs (Aslan and Cebeci 2007). Using a 2<sup>nd</sup>-order polynomial equation, to optimize and predict the optimal point of the responses affected by the independent variable given by (Eq4).

\[ Y = a_0 + a_1X_1 + a_2X_2 + a_3X_3 + a_{12}X_1X_2 + a_{13}X_1X_3 + a_{23}X_2X_3 + a_{11}X_1^2 + a_{22}X_2^2 + a_{33}X_3^2 \]  

Table 2: Selected experimental runs

<table>
<thead>
<tr>
<th>Std Run</th>
<th>PS (A)</th>
<th>PD (B)</th>
<th>PP (C)</th>
<th>WA</th>
<th>FS</th>
<th>CS</th>
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<td>1</td>
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<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>8</td>
<td>0.25</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>9</td>
<td>0.4</td>
<td>5</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>10</td>
<td>0.1</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>11</td>
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<td>8</td>
<td>5</td>
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<tr>
<td>15</td>
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<td>0.25</td>
<td>5</td>
<td>3</td>
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<td></td>
</tr>
<tr>
<td>7</td>
<td>13</td>
<td>0.1</td>
<td>5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>14</td>
<td>0.1</td>
<td>8</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>0.4</td>
<td>2</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Key: PS = plastic to sand ratio, PD = pressing duration, PP = pressing pressure, WA = water absorption, FS = flexural strength and CS = compressive strength
2.6 Production of paver tile

2.6.1 Melting and Mixing

A shredded plastic waste was melted in a metal drum using a heating mantle as a heat source. Heating was continued until the plastic was completely melted. According (Kumar 2014) to suggest a melting temperature of 170°C, and above this temperature range plastic waste was completely melted and liquefied in 20 minutes. After the plastic is liquefied, it is mixed by hand with sand using a wooden mixer. Continuous stirring is followed to make the mixture as homogeneous as possible (Konin 2011). For the present study waste plastic composition was analyzed with plastic waste to sand composition of 1:10, 1:4 and 2:5.

2.6.2 Molding

The steel mold was used to produce the paver tile samples. The dimensions of the mold for the production of these paver tiles are sized to 105mm length, 40mm width and 40mm thickness as per British molten test standard. The mixture was prepared by changing the ratio of the composition of plastic waste to sand by using a total quantity of 1.5 kg. During compression in a hydraulic press, the mold is placed on a removable plate and the two pieces are held together by a compression frame. The compression pressure used was 1-5 MPa to develop sample paver tiles to determine the effect of pressure on its strength using an electrically powered hydraulic press. The duration of the pressure was necessary, for this study, 2-8 minutes were used to know the effect of the duration on the strength of the paver tile sample.

![Figure 4: sample discharged from the molder](image)

2.7 Paver tile characterization

To characterize the physical & mechanical properties of the developed paver tiles water absorption, flexural and compressive strength tests were conducted to determine the ability of the developed paver tiles to resist loads applied during construction and use within relative to building standards. Directly and indirectly describing the other physico-mechanical properties of the sample tiles led to favoring only the above three physical and mechanical properties as the main priorities of the developed sample tiles.

2.7.1 Water absorption test of sample tiles

Water absorption test is carried out with AASHTO T-85 test method by immersing the sample into water for twelve hours by following the standard given by AASHTO T-85. The water absorption test was done in order to determine the tendency to absorb water by developed paver tiles (Eq5).

\[
\text{Water absorption} = \frac{W_f - W_o}{W_o} \times 100\% \quad \text{Eq5}
\]

2.7.2 Flexural strength test of produced paver tile

From manufacturing to use, paver tiles continuously experience impact forces, compression and abrasion forces. Flexural strength measures the shear and impact forces that paving tiles can withstand during handling, transportation, construction and use. Paver tiles were prepared according to the British Moulton Test standard method; The specimen dimension was 105mm x 40mm x 40mm. Force was applied by a stiff cylinder with a diameter of 40mm acting on the
middle part of the sample until the first crack was visible in the tested tiles (samples). Flexural strength test is required to determine the amount of force that the tile can withstand in bending before breaking (Sultana, Akter et al. 2013). This test was done in the laboratory using a device called the LBG flexural testing machine. In this test the tested sample was maintained at its both ends and loaded at its central position by a gradually increasing load up to failure. The failure load was then recorded and used to determine the tensile stress, which was calculated as the following equation (Eq6) for a rectangular specimen under load in the 3-points bending setup.

\[ \sigma = \frac{2PL}{3bt^2} \]

Where, \( b = \) Span or width of the sample (mm), \( P = \) load (kN), \( \sigma = \) flexural strength (MPa), \( t = \) thickness of the tile (mm), \( L = \) total length of the tile (mm)

### 2.7.3 Compressive strength test of produced paver tile

Compressive strength refers to the ability of a structure to withstand a load that tends to shrink or reduce size) as opposed to a load that tends to stretch or resist being pushed together. Compressive strength depending on sand to plastic ratio, pressing conditions, method of mixing, curing conditions and moisture content during testing. Compressive strength is one of the most important properties of a pave tile (Noor and Rehman 2022). Furthermore, it is commonly considered to refer to many other properties of tiles such as tensile strength and modulus of elasticity. Compressive strength also gives a good overall picture of the quality of the tiles. Compressive strength test followed standard methods of AASHTO T-85. Then it was determined using the following equation (Eq7).

\[ P = \frac{F}{A} \]

\( P = \) applied pressure (MPa), \( F = \) crushing load (N), \( A = \) area of samples(tiles) contacted with the load (mm²)

### Figure 5: Compressive & flexural strength testing machine

### 2.8 Comparing the quality of developed paver tiles sample standard

The developed paver tiles were compared with standard construction pavement of Ethiopia, as well as British for their water absorption, flexural strength, and compressive strength.

### 3 Result and discussion

#### 3.1 Sample raw materials Characterizations

##### 3.1.1 Specific gravity of the sands and plastics

Specific gravity of the raw material is the fraction of weight of the sample and given volume of sample to the weight in air of an identical volume of purified water at stated temperature. Specific gravity of LDPE waste plastics and sand were determined in the laboratory by water displacement method from the graduating cylinder filled with distilled water and added into the graduating cylinder 25g of sand and plastic on it.
Table 3: Specific gravity of sand and plastic test results

<table>
<thead>
<tr>
<th>Test method</th>
<th>Raw Material</th>
<th>Specific gravity</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM D2395-17</td>
<td>Sand</td>
<td>2.52</td>
<td>2.0 - 2.66 for pure fine sand Ethiopian standard and British.</td>
</tr>
<tr>
<td></td>
<td>Plastic</td>
<td>0.917</td>
<td>0.91-0.96 from literature (Athanas 2011, Konin 2011, Kumi-Larbi, Yunana et al. 2018).</td>
</tr>
</tbody>
</table>

The specific gravities of sand and LDPE waste plastic are 2.52 and 0.917 as shown in Table 2. Specific gravity is the fraction of the density of the sample to the density of water. This result shows that the value of specific gravity for paver tile production met the standards index based on the standard specifications of Ethiopia and Britain and the literature. The specific gravity of the sand reflects the silt content of the sand and the higher the silt content, the higher the specific gravity. Therefore, this result indicates that the specific gravities of both raw materials were within the required range and could be taken directly into the production line without further adjustment. Specific gravity refers to the packaging of the material and the information about the ingredients related to the handling of the material to be reduced if necessary.

3.1.2 Moisture content

Table 4: Moisture content of sand and plastic test results

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Raw Material</th>
<th>Moisture content in %</th>
<th>Ethiopia Standard and British standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS 812-105.2</td>
<td>Sand</td>
<td>0.36</td>
<td>2-5%</td>
</tr>
<tr>
<td></td>
<td>Plastic</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Moisture is one of the basic requirements for building paver materials that must be determined before using raw materials for paver tile production as a feedstock. As shown in Table 3, the moisture content of sand and plastic was obtained as 0.36% and 0%, which is lower than the recommended standard (0.5%) for paver tile production. Moisture content is one indication of the quality of sand and plastic for paver tile production. Therefore, this result shows that the moisture of sun-dried sand is accepted for the production of paver tiles, which can be directly used to the production line without any further processing of moisture adjustment.

3.2 The yield of the Experiments for paver tiles developed

Table 5 Summarizes the results of the experimental and predicted value of the responses using Box- Behnken design expert software version 13.0.
Table 5: Actual and predicted values of water absorption, compressive & flexural strength of developed paver tiles

<table>
<thead>
<tr>
<th>Run</th>
<th>PS</th>
<th>PD (min)</th>
<th>PP (MPa)</th>
<th>Water absorption value</th>
<th>Flexural strength value</th>
<th>Compressive strength value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Experimental</td>
<td>Predicted</td>
<td>Experimental</td>
</tr>
<tr>
<td>1</td>
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<td>0.303</td>
<td>0.3033</td>
<td>3.69</td>
</tr>
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<td>2</td>
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<td>0.297</td>
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<td>3</td>
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<td>0.401</td>
<td>0.399</td>
<td>2.95</td>
</tr>
<tr>
<td>7</td>
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<td>0.275</td>
<td>0.277</td>
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<td>0.321</td>
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</tr>
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<td>0.415</td>
<td>0.4146</td>
<td>2.72</td>
</tr>
<tr>
<td>11</td>
<td>0.25</td>
<td>8</td>
<td>5</td>
<td>0.295</td>
<td>0.2926</td>
<td>3.57</td>
</tr>
<tr>
<td>12</td>
<td>0.25</td>
<td>5</td>
<td>3</td>
<td>0.305</td>
<td>0.3033</td>
<td>3.69</td>
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<td>0.1</td>
<td>5</td>
<td>5</td>
<td>0.361</td>
<td>0.3672</td>
<td>3.1</td>
</tr>
<tr>
<td>14</td>
<td>0.1</td>
<td>8</td>
<td>3</td>
<td>0.386</td>
<td>0.3821</td>
<td>3.06</td>
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<tr>
<td>15</td>
<td>0.4</td>
<td>2</td>
<td>3</td>
<td>0.287</td>
<td>0.2909</td>
<td>3.5</td>
</tr>
</tbody>
</table>

3.2.1 Statistical data analysis for the paver tile yields

Design -Expert software was used to statically analyze the results of the experimental data. Many statistical parameters such as lack of fit, predicted adjusted multiple correlation coefficient and coefficient of variation of different polynomial models were compared to select the best fitting polynomial model. The proposed second-degree polynomials were fitted using multiple regression to determine the conditions that led to the maximum water absorption, flexural strength, and compressive strength of paver tiles. Independent variables such as plastic to fine aggregate or sand ratio, pressing time and pressing pressure are denoted as A, B and C respectively in Design Expert software. Significant difference determined by ANOVA with significance less than or equal to 0.05 (5%) is shown in Table 6.

Table 6: Regression coefficient, fit statistics & P-values of responses of developed paver tiles using RSM

<table>
<thead>
<tr>
<th>Variable</th>
<th>Water absorption (%)</th>
<th>Flexural strength (MPa)</th>
<th>Compressive strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Regression coefficient</td>
<td>p-value</td>
<td>Regression coefficient</td>
</tr>
<tr>
<td>Intercept</td>
<td>0.2778</td>
<td>&lt;0.0001</td>
<td>3.51</td>
</tr>
<tr>
<td>A-PS</td>
<td>-0.0409</td>
<td>0.0006</td>
<td>0.1887</td>
</tr>
<tr>
<td>B-PD</td>
<td>-0.0046</td>
<td>0.4197</td>
<td>0.12</td>
</tr>
</tbody>
</table>
The $R^2$ values of the model were higher than 0.987 indicating that 98.7% and more of the total variation in paver tile production was described by the developed model. The predicted $R^2$ is consistent with the adj $R^2$ for the three models developed, i.e., the difference is less than 0.2. In the regression water absorption model, A, C, AB, AC, $A^2$, $B^2$ are significant terms from the p-value shown in Table 6. The terms AB and AC are the interaction effects of plastic to sand ratio, pressure duration and pressure effect on the water absorption property of the developed tiles. From the flexural & compressive strength model term A, B, C, AB, $A^2$, $B^2$, $C^2$ are significant model terms (Table 6). These terms had an important impact on both properties of the produced paver tiles with a p-value of less than or equal to 5%. For many insignificant model terms that were not described for in the model, model reduction was required to improve the model. Regression equation was found using second degree polynomials to represent the relationship between response and independent variables.

### 3.2.2 Diagnostics graphical model analysis

Before starting the implemented model, the first diagnostic plots or graphical analysis should be satisfied. If not, the model cannot be used for various applications and the model is not visible with graphical diagnostic design criteria. The most common diagnostic scheme used to check the adequacy of analysis of variance is the normalized probability plot of studentized residuals, and actual versus predicted plot.

1. **Normality plots of residuals**

Normal probability plots of residuals can be used to visualize the significance of the effect of a single factor or variable on responses. Residual plots are key notes that provide normalized residual plots for testing assumptions such as normality and constant variance.

**Figure 6: Normal plot of residuals of (a) water absorption (b) flexural strength (c) compressive strength**

As shown in Figure 6, residual analysis was required, and the above Studentized residual plots show that it is a good plot, so a good plot should be linear and normal (Konin 2011, Ibrahim 2017, Kumi-Larbi, Yunana et al. 2018). If it is nonlinear, it indicates that the non-normality of the model terms can be corrected by transformation (Ibrahim 2017). Normal probability schemes of residuals observed that most data points approach straight lines.
In other words, the model can adequately describe the physical and mechanical properties of paver tiles developed under specific parameters.

2. Predicted Vs Actual plots

The predicted versus actual shows what is predicted and what actual value of the experiment (Fig 7). The graph should be linear and if not linear, it shows there is error in the model.

**Figure 7: Predicted Vs Actual plots for (a) water absorption (b) flexural strength (c) compressive strength**

The actual versus predicted values were along the line of data developed by the model as shown in Figure 7. Therefore, the regression model equation is accurately developed, and the diagram showed that the three process variables have an effective correlation in paver tile production.

3.2.3 Influence of process variables on Water absorption of paver tiles

Water absorption has a strong influence on the tensile strength, compressive strength, and flexibility of paver tiles. The results showed that the water absorption of the developed paver tiles was in the range of 0.275% to 0.415% (Table 5). It was observed that the water absorption tendency decreased with increasing percentage of LDPE plastics in paver tiles. Water absorption of paver tiles should be as low as possible i.e., in the range of 0.5% to 0.8% i.e., British and Ethiopian building standard paver tiles. Paver tiles with high water absorb will cause swelling and disintegration during use. As the ratio of LDPE plastic binder increases, the water absorption of the developed paver tiles decreases. These particles are more interconnected and the pores between them can be minimized by using plastic binders.

As indicated in Table 6, the insignificant model terms for water absorption are B, C\(^2\) and BC. To reduce the model, the model terms BC and C\(^2\) are removed. Although factor B is not significant, it is not omitted because it supports the mathematical hierarchy. From the design -expert, it is often recommended to use the actual equation as it shows the real effect. Therefore, the final equation was obtained in terms of actual factors to predict the water absorption (WA) of paver tile (Eq8).

\[ WA=0.5675-1.2582*PS-0.0182*PD-0.0030*PP+0.0183*PS*PD+0.0283*PS*PP+1.4481*PS^2+0.0010*PD^2 \] --Eq8

For this model, R\(^2\) & adjusted R\(^2\) were obtained as 0.9931 and 0.9806 respectively. The graphical illustration of the interaction effect of independent variables on water absorption (WA) are shown in Figure 8. Increasing the LDPE plastic from 10 to 40% revealed a significant decrease in the water absorption ability of the paver tiles. WA as a function of LDPE plastic binder percentage and duration pressing by holding pressing pressure at center. The water absorption decreased from 0.415% to 0.275% as the proportion of LDPE plastic increased from 10% to 40%, and the pressure time increased from 2 to 8 minutes. Pressing duration is the duration for which the material is subjected to the highest pressure to minimize relaxation during the paver tile production process (Lamba, Kaur et al. 2022).

**Figure 8: Water absorption as a function of LDPE waste plastics percentage and pressing duration**

WA as a function of applied pressure and LDPE plastic binder percentage as shown in Figure 9. The WA capacity of paver tiles was found to range from 0.275% to 0.415% as the pressure and percentage of binder varied from 1 MPa to...
5 MPa and 10% to 40%, respectively. An increase in pressure and percentage of plastic can decrease the water absorption of paver tiles, while a low percentage of plastic and pressure can increase the water absorption of developed paver tiles.

Figure 9: Water absorption as a function of LDPE waste plastics percentage and pressing pressure

3.2.4 Influence of process variables on Flexural strength of paver tiles

In this study, flexural strength provides the tensile stress at which the paver tile failed before breaking, and the ability to resist internal subject actions such as shear and tensile. In this study, each developed paver tile was tested for its tensile or flexural strength using LBG Flexural testing machine, and the highest flexural strength of the developed paver tiles was 3.689 MPa and the minimum was 2.720 MPa (Table 5). The interaction model terms AC and BC (Table 6) are insignificant in the flexural strength response. Model reduction was performed to omit nonsignificant terms. Therefore, the final equation for predicting the flexural strength of paver tiles (FS) was obtained according to the actual factors (Eq9).

$$FS = 1.1173 + 10.8774*PS + 0.2637*PD + 0.1595*PP - 0.2067*PS*PD - 15.0315*PS^2 - 0.0183*PD^2 - 0.0204*PP^2 \quad \text{---Eq9}$$

For this study model, the $R^2$ & adj $R^2$ were obtained as 0.9872 and 0.9643 respectively. Flexural strength as a function of LDPE plastic ration and pressure, and holding pressing duration at the middle or center is shown in Figure 10. Flexural strength changed significantly as LDPE plastic binder increased from 10% to 40% and pressure increased from 1 MPa to 5 MPa. As shown in Table 5 above, the percentage of plastic up to 25% has a direct proportional relationship with the tensile or flexural strength of the developed paver tiles. But above this percentage the strength started to decrease.

Figure 10: Flexural strength as a function of LDPE waste plastic percentage and pressing pressure

3.2.5 Influence of process variables on Compressive strength of paver tiles

Compressive strength is the mechanical property of paver tile capacity to withstand loads that tend to shrink, and in contrast, to withstand loads that tend to stretch or resist being pushed together. In this study, each developed paver tile was tested its compressive strength by using compressive testing machine in laboratory follow by standard methods of AASHTO T-85 to determine the numerical value of each sample, and the highest compressive strength of the developed paver tile was 4.141 MPa and the minimum was 2.978 MPa (Table 5). The interaction terms AC and BC (Table 6) are insignificant in compressive strength response. Model reduction was performed to omit nonsignificant terms. Therefore, the final equation was obtained according to the actual factors to predict the compressive strength (CS) of paver tile (Eq10).

$$CS = 0.8241 + 12.8047*PS + 0.3588*PD + 0.3014*PP - 0.1928*PS*PD - 18.4833*PS^2 - 0.0265*PD^2 - 0.03975*PP^2 \quad \text{---Eq10}$$

For this model, $R^2$ & adj $R^2$ were obtained as 0.9928 and 0.9798 respectively. A graphical illustration of the interaction effect of independent variables on compressive strength (CS) is shown in Figure 11. Increasing the LDPE plastic from
10 to 40% revealed a significant increase in compressive strength (CS) of the paver tiles. The CS as a function of LDPE plastic ration and pressing pressure by holding pressing duration at the middle or center in Figure 11. The compressive strength increased from 2.978 MPa to 4.141 MPa as the proportion of LDPE plastic increased from 10% to 40% and the compression pressure increased from 1 MPa to 5 MPa. Most paver tiles are greater than or equal to 3MPa and can resist mechanical deflection and withstand loads during construction, use and transportation, and it is recommended to use it for outdoor use. Therefore, using this plastic as a binder can reduce the effect of pressure on tensile and compressive strength.

**Figure 11: Compressive strength as a function of LDPE waste plastics percentage and pressing pressure**

Figures 10 and 11 above show that: the flexural and compressive strength increased with the increase of waste plastic content from 10% to 25%, and then the strength drops significantly with the increase of waste plastic content up to 40%

The objective of determining the optimum operating variables for paver tiles was to achieve high quality, density, load resistance, and shear and tensile strength that would withstand flexible paving tiles. This study, predicted maximum tensile (flexural) and compressive strength are 3.689 MPa and 4.141 MPa with LDPE plastic binder percentage 25% (0.15kg), pressing time 5 minutes and pressure 3 MPa. Thus, the developed paver tiles conformed to the standard of being strong, densified, flexible (durable), and promised to withstand loads if used.

### 3.3 Comparing the physic- mechanical character of paver tile with standard

The quality of pavers tiles produced in the study was compared with Ethiopian and British pavers tiles standard. The outcome of water absorption of all developed paver tiles is presented in Table 5. The results indicate that the developed paver tiles were in the range of 0.275% to 0.415%, and the average water absorption of the developed paver tiles is 0.322%. From Table 5, when the amount or percentage of plastic increases, the water absorption of the sample tiles should be reduced. This was due to the hydrophobic properties of the plastic. From the results of the water absorption test, they conclude that, the tile’s ability to absorb water is agreed with the British and Ethiopian standards, which are below the range of 0.5% to 0.8%.

The flexural strength results given in Table 5 above show that the maximum flexural strength is 3.689 MPa. It was recorded as 25% of plastic binder, pressing time 3 minutes and pressing pressure 3 MPa. British (BS 4131) and Ethiopian standards require least flexural strength of 3 MPa for outdoor paver tiles. This shows that the manufactured sample tiles can withstand the load before breaking. Also, the maximum compressive strength was 4.141 MPa (Table 5), and it was recorded as 25% of plastic binder, pressing time 3 minutes and pressing pressure 3 MPa. According to British and Ethiopian standards, the minimum compressive strength required for outdoor paver tiles is 3 MPa in dry condition of tiles and 2 MPa in the wet condition of the tiles, and the manufactured paver tiles conform to this standard for both mechanical properties.
4 Conclusion

This study evaluated the physical and mechanical properties of paver tiles produced from LDPE waste plastics as binder and sands. The results of the developed paver tiles were compared with the standards for ability to absorb water, and its strength properties. Box Behken method with Design -Expert software was used to optimize the flexural or tensile and compressive strength of the paver tiles. The three selected independent variables and their interaction effects on the paver tiles were studied. The optimum value was investigated using Design Expert 13 software. The best combination was LDPE waste plastic to sand percentage 25%, pressing duration 5 minutes and pressing pressure 3 MPa was the optimum point to produce strong and flexible or durable paver tiles with flexural (tensile) strength 3.689 MPa and compressive strength 4.141 MPa. The maximum value obtained in both flexural (tensile) and compressive strength tests satisfied the minimum expected standard set by Ethiopia and Britain.

Therefore, tile samples produced from sand and plastic waste as binding agents have better compressive and flexural strength that satisfy the desired standard. Therefore, it can be concluded that waste plastic can be used as a binding agent with sand in the production of paver tile is possible. From these findings, plastic paver tiles have good strength and can be used for various applications such as walkways, recreational areas, non-traffic areas, light traffic roads and outdoor applications. In general, the reuse of disposable LDPE waste plastic for the production of outdoor tiles was environmentally friendly. Therefore, reusing LDPE waste plastic for paver tile production is a promising option to protect our environment from waste plastic pollution.
5 Statement of Declaration

A. Ethics Approval and Consent to Participate
Not applicable

B. Consent for Publication
Not applicable

C. Availability of Data and Materials
Data sharing not applicable to this article as no datasets generated or analyzed during the current study.

D. Funding
The data collection, data analysis and write-up of the study supported by researchers.

E. Authors’ Contributions:
Abu Duguma generated the idea and designed the study. Abu performed the data collection, experimental tests, data analysis and interpretation, and wrote the manuscript. Sinknesh performed the data collection and provided statistical support, read and revised the manuscript. Tadela performed the experimental design and testing for the sample and revised the manuscript. Marcos performed the statistical data analysis and revised the manuscript. Finally, all authors read and approved the final version of the manuscript.

F. Acknowledgments:
We wish to express our profound gratitude to the Energy and Environment research center of Dilla university staff for their supporting and appreciations regarding our works. The authors also wish to thank the Ethiopian Construction Agency that provided the laboratory tests material and given standard for this work; and the communities in the research area.

G. Competing Interests
The authors declare that they have no competing interests.

6 List of abbreviation
AASHTO: American Association of State Highway and Transportation Officials
ANOVA: Analysis of Variance
ASTM: American standard testing method
BBD: Box-Behnken Design
BS: British standard
CS: Compressive strength
FS: Flexural strength
LDPE: Low density polyethylene
MCS: Moisture content of sand
SRM: Surface response methodology
WA: Water absorption
7 References


Figure 1

General framework diagram of paver tiles production
<table>
<thead>
<tr>
<th>Symbols</th>
<th>Description</th>
<th>Commonly found in</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Polyethylene Terephthalate</td>
<td>Soda, water, and beer bottles; salad dressing containers</td>
</tr>
<tr>
<td>2</td>
<td>High Density Polyethylene</td>
<td>Milk jugs; household cleaner containers; juice bottles; yogurt tubs</td>
</tr>
<tr>
<td>3</td>
<td>Vinyl</td>
<td>Shampoo bottles; cooking oil bottles; medical equipment; piping</td>
</tr>
<tr>
<td>4</td>
<td>Low Density Polyethylene</td>
<td>Squeezable bottles; shopping bags; carpet; frozen food; food wraps</td>
</tr>
<tr>
<td>5</td>
<td>Polypropylene</td>
<td>Yogurt containers; ketchup bottles; syrup bottles; medicine bottles</td>
</tr>
<tr>
<td>6</td>
<td>Polystyrene</td>
<td>Meta trays; egg cartons; disposable plates and cups</td>
</tr>
<tr>
<td>7</td>
<td>Miscellaneous</td>
<td>Sunglasses; iPod cases; computer cases; bullet-proof materials</td>
</tr>
</tbody>
</table>

Figure 2

Symbol used to identify LDPE waste plastics
Figure 3

Raw material prepared for paver tiles development

Figure 4
sample discharged from the molder

Figure 5

Compressive & flexural strength testing machine
Figure 6

Normal plot of residuals of (a) water absorption (b) flexural strength (c) compressive strength
Figure 7

Predicted Vs Actual plots for (a) water absorption (b) flexural strength (c) compressive strength
Figure 8

Water absorption as a function of LDPE waste plastics percentage and pressing duration
Figure 9

Water absorption as a function of LDPE waste plastics percentage and pressing pressure
Figure 10

Flexural strength as a function of LDPE waste plastic percentage and pressing pressure

Supplementary Files

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- GraphicalAbstractbyAbu.pdf
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