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Influence of Coarse Aggregate on the Physical and Mechanical Performance of Paving Blocks made using Waste Plastic

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Abstract

Urbanization, changes in life style and development of many activities are leading to a widespread pollution of landscape by plastic bags. Plastic bags waste management has become a real concern for the society globally because they are widely used, they are non-biodegradable and they show an anaesthetic view. Solutions have been scientifically found by simply recycling those bags for the sake of sustainability and the improvement of road material properties. Waste plastic bags have been used for totally replacing the conventional cement in concrete paving blocks to improve desired engineering properties of paving blocks for road pavement. This paper aims at evaluating the influence of coarse aggregate on the mechanical and physical properties of paving blocks made using melted Low Density Polyethylene (LDPE). Melted LDPE are mixed as binder with sand and coarse aggregate to make paving blocks for road pavement purposes. In conventional paving blocks making process, cement paste is used as binder. Cement can technically be replaced with melted plastic waste to make paving blocks more flexible as concrete blocks are basically used for rigid pavement. Paving blocks containing LDPE, sand and coarse aggregate with different mix ratios were prepared, tested and the results were discussed. Paving blocks made using waste LDPE plastic and sand, with addition of 5% of coarse aggregate show better mechanical properties, flexibility, and more resistant to water absorption.

Keywords: LDPE waste plastic, pollution, coarse aggregate, paving blocks, engineering properties

I. INTRODUCTION

Paving blocks have become the choice for urban road's surfacing and carriageway, especially on the sections where the bearing capacity of the soil is weak. Cement is basically the main constitutive material of those stones. Due to problems of environmental pollution and cost of cement production, some studies have been done to find sustainable and high performing binders that are gradually replacing cement and asphalt in the field of road construction [1]. Therefore, molten plastic has been found to be one of the strong and durable binding materials used for the manufacturing of paving blocks [2]. Besides their ease in application, they provide as well the freedom in design by colouring the material; they offer to be easily shaped with a wide variety of dimension. The major importance is their compressive strength and the way they behave against the physical impact of the environment. The Indonesian Standard categorizes strength of plastic paving blocks to their purposes i.e., for parking areas, pedestrian walking areas and surfacing of heavy traffic roads in case of weak soil bearing capacity.

Materials like sand and coarse aggregate, used in this study were acquired locally, in Kenya, from different certified suppliers. Plastic bags considering as waste materials seen littering the environment has been brought from surroundings areas. The use of LDPE plastic bags as total replacement for cement shows a better advantage for environmental protection and the considerable reduction in cost of paving blocks.

With the objective of assessing the influence of aggregate in the physical and mechanical properties of paving blocks made with waste LDPE as binding material, a critical review of literature has been done. Jnr et al. [3] attempted to reuse LDPE plastic bags as binder for making paving blocks, with an aim of investigating the effect of sand particle size and sand to plastic ratio on compressive strength, density and water absorption. From the test results, an observation was made that the use of angular shape of sand passing through 4.75 mm sieve gives better properties of the blocks. The ratio mix of 3 (75% sand + 25% plastic), also shows better performance. Shanmugavalli et al. [4] also attempted to totally replace cement with plastics in paver blocks to reduce the cost of paver block construction as compare to the normal concrete blocks. The effects of quarry dust and ceramic waste were investigated in the mixture of plastic and coarse aggregate. Compressive strength was investigated as well as the heat resistance of blocks, progressively placed in the oven at 50, 100 and 150°C. It was observed that paving blocks made using plastic waste, coarse aggregate, quarry dust and ceramic waste have shown better result. Gawande et al. [5] successfully investigated the partial replacement of bitumen by waste plastic as binder for the purpose of roads and flexible pavement. Dinesh et al. [2] also shows that plastic waste can be used as replacement of cement for environmental protection, low cost of paving blocks without subsequent change of engineering strength.

Therefore, this study aims at characterising paving blocks made using waste LDPE plastic as binder with fine aggregate, and to evaluate the effects of coarse aggregate on the mechanical and physical properties of the resulting paving blocks.

II. MATERIALS AND METHODS

A. Materials

1) LDPE plastic waste

LDPE plastics indicated as resin number 4 including plastic bags, were collected from the surrounding areas. Water bags, non-woven and film plastic are usually made of LDPE. After washing and drying, plastics were stored at a dried place to avoid moisture. Some relevant properties are indicated in table 1.

Table I : Properties Of Ldpe Plastic

Properties	Value
Technical name	Low Density Polyethylène
Chemical Formula	$(C_2H_4)_n$
Melting Temperature	150°C
Molding Temperature	40°C
Drying time	2 hours at 79°C
Tensile strength	7 MPa
Flexural strength	6 MPa
Specific Gravity	0.92
Shrink rate	2.5%
Water Absorption	0.002 % by wt in 24 hours

2) Sand

Fine aggregate was collected from a certified selling point around Nairobi. Sand was dried and sieved according to BS 812-part 103-1 test sieve. The characteristics are shown in table 2.

Table II: Properties of Sand

Properties of sand	Value
Size range	0.075 mm - 5 mm
Bulk density	1614.19 kg/m^3
Voids value	0.35
Specific Gravity	2.332
Fineness modulus	2.44
Colour	Brown
Particles Shape	Angular

3) Coarse Aggregate

Normal weight aggregates were obtained locally; coarse aggregates were dried and sieved in accordance with the BS 812-part 103-1 test sieve. The size of coarse aggregate was ranged from 10 to 4 mm. For small precast material such as paving blocks, the maximum size of coarse aggregate is about 10 mm. Characteristics are shown in table 3.

Table III: Properties Of Coarse Aggregate

Properties of Coarse Aggregate	Value
Size range	4 mm - 10 mm
Bulk density	1418.42 kg/m^3
Voids value	0.48
Specific Gravity	2.584
Colour	Greyish black
Particles shape	Angular

B. Methods

1) Control Mix

A control mix was designed in order to determine the mix by sand to plastic (s/p) ratio that presents the best properties (principally compressive strength) according to the study carried out by other researchers [6]. The mix ratio was 1:1, 2:1, 3:1, 4:1, respectively representing the ratio of fine aggregate (sand) and plastic in the mix. The control mix design is clearly illustrated in the table below.

Table IV: Control Mix Design

Sand to plastic ratio mix		Quantity (g)	
Mix Ratio	Content (%)	Plastic	Sand
1	50% sand and 50% plastic	6000	6000
2	66.6% sand and 33.3% plastic	2983.5	5967
3	75% sand and 25% plastic	3568.5	10705.5
4	80% sand and 20% plastic	3000	12000

2) Mix design

From the control mix showing the best properties in terms of compressive strength, a mix design was casted with a progressive and systematic addition of 0, 5, 10, 15, and 20% of coarse aggregate by percentage of weight of sand in the optimum control mix. The mix design is illustrated in table 5.

Table V: Mix Design

Mix with % of Ballast		Quantity (g)		
Ballast %	Content (%)	Plastic	Sand	Ballast
0	0% of sand by weight	3000	9000	0
5	5% of sand by weight	3500	10500	525
10	10% of sand by weight	3500	10500	1050
15	15% of sand by weight	3500	10500	1575
20	20% of sand by weight	3500	10500	2100

3) Preparation of specimen

Fire was lighted under a metal drum and gently heated. After selection, washing and drying, LDPE plastics were added progressively into the drum. A small piece of plastic was lighted on top of the drum filled with LDPE, using a small flame to help it melt down. Precaution should be taken to avoid a huge fire in the drum and the progressive addition of plastic pieces should be on the side of the melted ones inside the drum. When the suitable quantity of plastic was completely melted at 150°C, an indicated quantity of sand was added as well as the coarse aggregate eventually. The solution was mixed, using a trowel, in hot condition for 10 minutes to ensure that the mix was completely homogenous and the aggregate well coated by the melted binder. The moulds were prepared and well stabilized. Moulds were correctly oiled to facilitate demoulding after the specimen was dry. The hot solution was poured inside the mould and consistently vibrated with a steel rod to avoid any risk of segregation [7]. Fig. 1 shows an overview of the process.

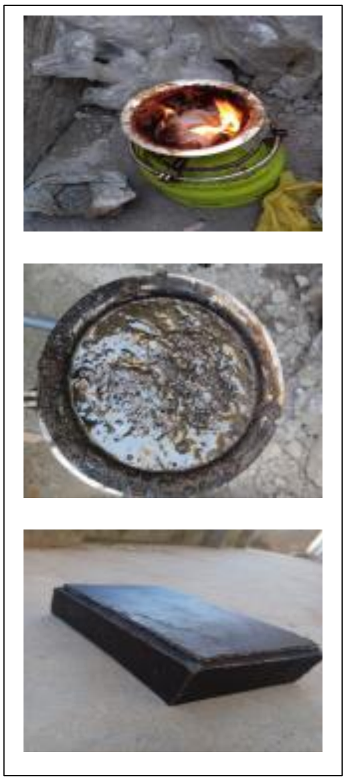

Fig. 1: Preparation process of specimen

Paving blocks were left to harden under the shade for 2 days [8]. Specimens of size 220 mm by 110 mm by 80 mm were made and tested according to the EN BS 1338:2003 standard for test procedures on paving blocks. Compressive strength, tensile splitting strength and water absorption were then evaluated.

III. TESTS AND PROCEDURES

A. Compressive Strength

Three (3) specimens of each mix design were taken to the lab for testing. The test was carried out as per the EN BS 1338:2003 standard for compressive strength test on paving blocks. Fig. 2 illustrates the test setup in the compressive testing machine.

Fig. 2: Compressive strength test setup

B. Tensile Splitting strength test

A compressive testing machine was used for the tensile splitting strength test, as per the set up showed in Fig.3. The testing procedure was followed according to the EN BS 1338:2003 standard for tensile splitting test on paving blocks

Fig. 3: Tensile splitting strength test setup

C. Water absorption test

Water absorption test was carried out as per the EN BS 1338:2003 standard for water absorption ability test on paving blocks. Fig.4 show the block specimen immersed in water. They were maintained immersed for 4 hours and then wiped with a cotton material and weigh to evaluate the water absorption capacity of the block.

Fig. 4: Water absorption test

IV. RESULTS AND DISCUSSION

A. Compressive strength

Fig. 5 shows the variation of the compressive strength, for each value of sand to plastic ratio (s/p). The control mix (0% addition of coarse aggregate) test results showed an optimum ratio of 3:1, giving the maximum compressive strength of 11.248 MPa.

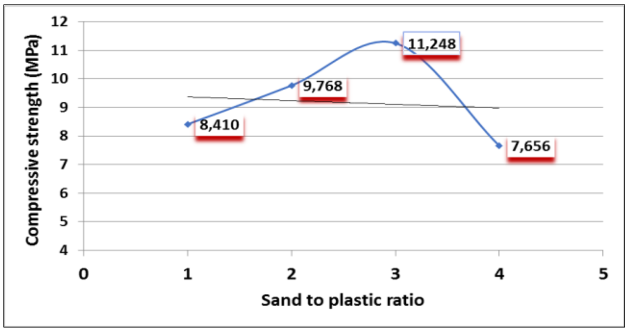

Fig. 5: Compressive strength curve result for control mix

In Fig. 6, the mix ratio 3:1 of sand to plastic by weight was used to assess the influence of coarse aggregate in the resulting paving blocks. It is noticed from the figure that there was an increment in compressive strength (from 11.248 MPa to 15.452 MPa) due to an addition of coarse aggregate from 0% to 5%. After 5%, the compressive strength started decreasing.

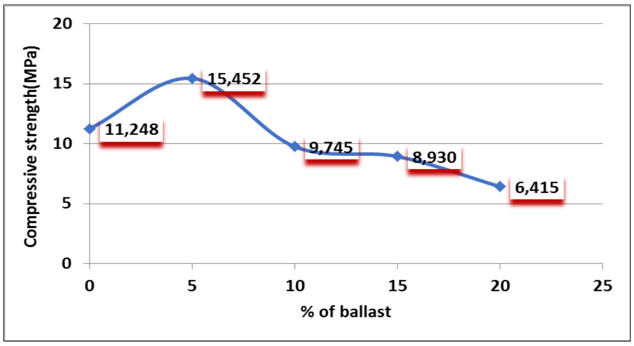

Fig. 6: Influence of the amount of coarse aggregate addition in compressive strength of paving blocks

In Fig.7, two compressive strength results carried out on specimens with 0% and 5% addition of coarse aggregate are compared. Compressive strengths of blocks with 5% of coarse aggregate are higher than those of blocks without coarse aggregate (at the same s/p ratio). A maximum value of 15.452 MPa was attained at the optimal s/p ratio of 3. The material is stronger when the bonding between the aggregate and the binder is total and optimal. The bonding relationship is between the aggregate themselves on one hand and the aggregate and the binder on the other hand. In this specific case, an optimal addition of 5% of coarse aggregate contribute to an increase in the density of the paving block, which increases the compressive strength [9].

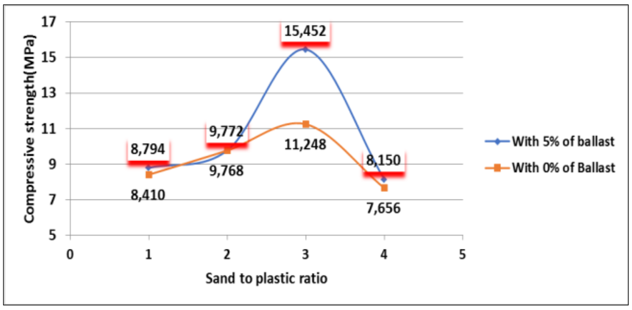

Fig. 7: Influence of addition of coarse aggregate in compressive strength

B. Tensile splitting strength

The comparison of tensile splitting strength of blocks with 0% and 5% of coarse aggregate (Fig. 8) shows a slight increment in tensile strength at the optimum s:p ratio (s/p = 3). Similarly, at the optimal s/p ratio of 3, the maximum splitting tensile strength of 2.818 MPa was attained. Further increase in the s/p ratio led to a reduction in the splitting tensile strength of the blocks. Generally, an optimal addition of 5% of coarse aggregate marginally contributed to an increase in the density of the paving block, which contributed to a slight increase in the tensile splitting strength.

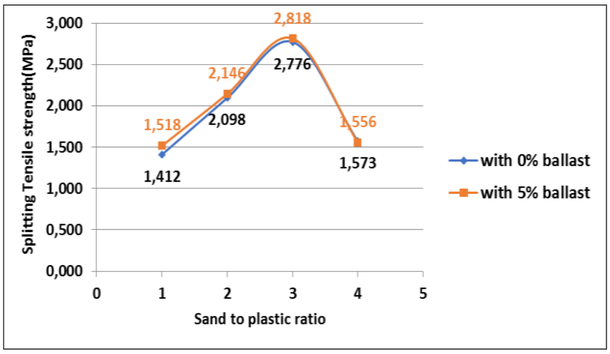

Fig. 8: Influence of addition of coarse aggregate in tensile splitting strength

C. Water absorption test

Fig.9 presents the variation of water absorption and sand to plastic ratio. The figure shows a slight increment of water absorption capacity of the blocks, which was due to the increasing volume of voids in the blocks as much as the coarse aggregates were added experimentally. The comparison of water absorption of blocks with 0% and 5% of coarse aggregate at the optimum s/p ratio (s/p = 3) shows almost no significant difference ($p < 0.055$)

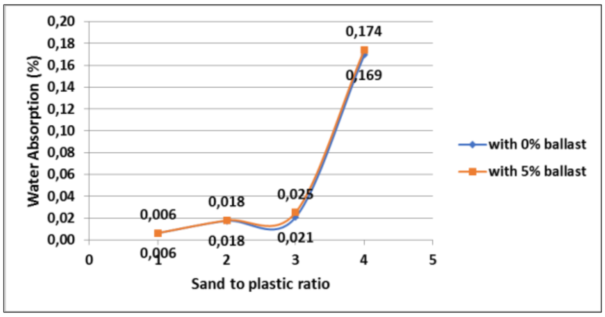

Fig. 9: Influence of addition of coarse aggregate in water absorption ability of paving blocks

V. CONCLUSIONS

- Sand and coarse aggregates present a very good bonding connexion with melted LDPE plastic as binder.
- Sand and coarse aggregate of small size (between 4 mm and 10 mm) and angular shape can be used as main composition material for making paving blocks with melted plastic as binder.
- Coarse aggregate of small size increase the strength of paving blocks made with LDPE and sand only.
- The compressive strength (15.452 MPa) of paving blocks made with LDPE plastic and aggregate approaches the compressive strength of an ordinary C20 concrete paving block.
- The use of LDPE plastic waste offers a better way of disposal of waste plastic bags for environmental protection.
- LDPE plastic waste paving blocks present a better resistance against aggressive effect of water than concrete paving blocks.
- The mechanical properties of LDPE plastic paving blocks are relatively low compared to the concrete ones (C20, C25, C30). Hence, they can be used for gardens, cycle ways, pedestrian ways and light traffic roads.

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