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The Compressive Strength of Load Bearing Low Density Polyethylene (LDPE) - Bonded Concrete Blocks

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Abstract

Responding to the world's increasing demand for concrete's alternative bonding materials that could lower the reliance on Portland cement, without compromising the compressive strength, is a research activity that currently drives the construction industry. An experiment was conducted to determine the effect of sand:plastic ratio on the compressive strength of LDPE bonded sand mortar. The experiment had five treatments, which were the mix ratios (1:2, 1:3, 1:4 and 1:5) excluding the control. The control was the standard concrete block (sand:Portland cement fabricated using the local 1:5 mix) and a water/cement ratio of 0.5. Tests conducted were compressive strength and water absorption tests. Each specimen was 100 mm x 60 mm hexagonal block. Each treatment including the control had three replications and the compressive strength was tested after 7, 14 and 21 days of curing. The results reflected that the mean compressive strength for the LDPE-bonded concrete blocks 1:2, 1:3, 1:4, 1:5 and the control were 1.35 N/mm^2, 4.95 N/mm^2, 9.92 N/mm^2, 8.5 N/mm^2 and 8.80 N/mm^2, respectively after 21 days of specimen aging. The compressive strength of the different ratios increased with a decrease in the amount of plastic in the mix ratio until treatment 5, where the compressive strength decreased. The 1:2, 1:3, 1:4 and 1:5 mix ratio LDPE-bonded concrete blocks had compressive strengths that were significantly different ($P<0.05$) from the control. The experiment reflected that after 21 days, the water absorption of the LDPE-bonded concrete blocks with the mix ratios 1:2, 1:3, 1:4, 1:5 and the control were 1.68%, 2.35%, 4.57%, 5.65% and 6.8% for treatment 2, 3, 4 and 5, respectively.

Keywords

Compressive Strength, Load Bearing, Low Density Polyethylene (LPDE), Bonded Concrete Blocks

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1. Introduction

Concrete is one of the most used man-made materials on earth. The material is the foundation of modern development, putting roofs over the heads of billions, fortifying defences against the natural disasters and providing structure for healthcare, education, transport, energy and industry [8]. It is an important construction material used extensively in buildings, bridges, roads and dams. Concrete, till now has been made of materials consisting of water, cement and aggregate, which are mixed at a certain ratio to achieve best results. When the materials are mixed together, they form a paste which gradually hardens over time, yet when re-enforced with steel, it is the material that ensures that dams don't burst, tower blocks don't fall, roads don't buckle and the electricity grid remains connected.

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Concrete use dates back many centuries and can be traced back to the Romanian times where it was industrially used. The first major users of concrete were the Egyptians around 2500 BC and the Romans from 300 BC [6]. It can last for many centuries and many structures made during the Roman times still stand today, the Pantheon and Colosseum in Rome are testament to the durability of concrete, which till now has been a composite of sand aggregate (usually gravel or stone), cement and water. The oldest known surviving concrete is to be found in the former Yugoslavia and was thought to have been laid in 5,600 BC using red lime as the cement [15]. The material has taken civilization upwards up to 163 storeys high in the case of the Burj Khalifa skyscraper, creating living space out of air. This was made possible by load bearing concrete blocks, which carry the weight of the entire structure ensuring that it does not crumble down.

The determination behind finding alternative binder or cement replacement materials in response to the increasing costs and scarcity of cement that result from high cement demand has led to the discovery of the unrealized industrial by- products and agricultural wastes as cementitious materials [10, 14]. Plastic-bonded sand paver blocks were first produced using waste plastics in the Cameroon by Pierre Kamsouloum in 2006 [9]. The use of plastic as a bonding material is not widely practiced; instead plastics pollute the environment and contribute to the filling up of landfills [1, 2].

Plastic is a very versatile material [13]. Due to the industrial revolution, and its large scale production, plastic seems to be a cheaper and an effective raw material. Today, every vital sector of the economy starting from agriculture to packaging, automobile, electronics, electrical, building construction, communication sectors has been virtually revolutionized by the applications of plastics. Plastic is a non-biodegradable material and researchers found that the material can remain on earth for 4500 years without degradation [12].

Concrete is one of the most used building materials in the construction industry. It is used to make concrete blocks, which are used to bring life to the design of many architects. The compressive strength of concrete should be of the standard value so that the buildings, roads, and many more constructed do not fail and lead to many causalities. The material should be durable and be able to withstand environmental factors so that the structures made are still standing centuries from today. The key element in the manufacturing of the concrete is Portland cement. Research related to the use of plastic in building applications is principally about its combination with cement [16]. However, it is worth noting that a lot of energy is spent in the making of the cement; hence the high costs associated with it.

LDPE-bonded sand is a strong, tough material with compressive strengths of up to 27 MPa when produced under optimum processing conditions. Higher sand additions reduce porosity and increase density, which ranged from 1.46 g/cm^3 to 1.91 g/cm^3 [11]. Increasing the amount of sand increased the compressive strength for additions up to 75%, resulting in the maximum compressive strength of 27.3 MPa. Increasing the sand addition reduces the ductility of the material. However, sand additions above 75% reduce the compressive strength because the LDPE binder volume is not sufficient to properly coat and bind the sand grains together. A brick made with 2 kg of laterite soil, 60% of plastic and 2% of bitumen gives a compressive strength of 11.10 N/mm^2, which is higher than the requirement of third class bricks 3.19 N/mm^2 [3]. As the percentage of the plastic increases, the compressive strength of the brick decreases.

Eswatini has numerous concrete manufacturing companies which use the rather expensive Portland cement as a bonding agent for concrete blocks. The cement is mixed with water and sand (aggregate) at a certain mix ratio to obtain standard compressive strength. The production process of cement is rather complex and costly which leads to the high costs of the concrete blocks. The global use of Portland cement has increased from under 2 million tons in 1880 to 1.3 billion tons in 1996 [7]. It is worth noting that the total volume of cement production amounted to 4.2 billion tonnes in 2019 [5]. However, it was reflected that the production of this amount of cement demands a huge amount of natural resources [4]. Alternative bonding materials that could lower the reliance on the rather expensive Portland cement, could offer a much needed relieve to the construction industry in developing counties including the Kingdom of Eswatini, hence this study. The objectives of the study were; (i) To determine the effect of sand to plastic mix ratio on the compressive strength of LDPE-bonded concrete blocks, (ii) to determine the effect of specimen aging on the compressive strength of LDPE-bonded concrete blocks and iii) to assess the water absorption of the LDPE-bonded concrete blocks.

2. Methodology

2.1. Research Design

The study was an experiment with four treatments (T), in which 100 x 60 mm (hexagonal) plastic:sand blocks were fabricated using different mixes (sand:plastic); 1:2, 1:3, 1:4 and 1:5 (Table 1). Each treatment had three replications including the control (T_1). The control was the standard concrete block (sand:Portland cement fabricated using the standard local mix of 1:5) and a water/cement ratio of 0.5.

Table 1. Experimental treatments.

Treatment	Mix Ratio
T_1	1:5 (w/c 0.5)
T_2	1:2
T_3	1:3
T_4	1:4
T_5	1:5

2.2. Material Preparation

The materials used during the course of the experiment were sand and plastic (LDPE). The LDPE was collected from the University of Eswatini (UNESWA) dumpsite at Luyengo Campus (in the form of grocery bags, shopping bags, squeezable bottles, shrink wraps, etc.). The LDPE was washed to remove impurities and dried in open air until no moisture was present. The dried plastic was then shredded. The fine aggregate (sand) was purchased from local aggregate suppliers. It was then transported to the experimental site, where it was sieved using a 10 mm test sieve to ensure uniformity.

2.3. Fabrication of Blocks

The shredded LDPE was heated in a metal drum. A wooden stirring rod was used for stirring the LDPE to distribute the heat until it was liquid (black). The correct proportion of sand was added into the drum as stirring continued. A homogenous LDPE-bonded sand mortar was formed after a few minutes of stirring. The LDPE-bonded sand mortar was transferred into block moulds and compacted. The samples were then allowed to harden for 2 hours. The blocks were removed from the moulds leaving an LDPE-bonded concrete block. The compressive strength failure load of the fabricated LDPE-bonded concrete blocks was tested after 7 days, 14 days and 21 days of curing.

2.4. Compressive Strength Load Failure Test

The failure load of the LDPE-bonded concrete blocks was determined using the Prolkon Cube Press load testing machine. Equation 1 was then used to calculate the compressive strength of the LDPE-bonded concrete blocks.

$$\sigma_c = F/A \qquad (1)$$

Where: σ_c - Compressive strength (N/mm^2).

F - Failure load (N).

A - Area of bed face (mm^2).

2.5. Water Absorption

The absorption of water was conducted for all the block sets including the control (T_1). Each treatment including the control, which had three replications were tested for water absorption. The sample blocks were oven dried for 24 hours at a temperature of 100 - 105°C until the mass was constant and the dry weights (W_1) were measured. The same blocks were immersed in water for 24 hours and the wet weights (W_2) were measured. The proportion of water absorption of the LDPE-bonded concrete blocks was determined using equation 2.

$$\text{Water Absorption} = \frac{W_2 - W_1}{W_1} \text{ X } 100\% \qquad (2)$$

Where:

W_1 - Oven dry weight.

W_2 - Wet weight.

2.6. Data Analysis

The SPSS statistical package version 2.0 was used to analyse the data collected, which included the properties of the samples that were confirmed through the various tests. The paired test and One Way ANOVA at 5% level was used for mean separation.

3. Results and Discussion

3.1. Compressive Strength of LDPE-Bonded Concrete Block Results

The results reflected that the optimum compressive strength (9.92 N/mm^2) of the LDPE-bonded concrete blocks was achieved at a mix of 1:4 (Table 2). The compressive strength was 8.79 N/mm^2, 9.52 N/mm^2 and 9.92 N/mm^2 after 7, 14 and 21 days, respectively.

Table 2. Effect of sand to plastic ratio on the compressive strength of LDPE-bonded blocks.

Mix ratio	Compressive strength at 7 days (N/mm^2)	Compressive strength at 14 days (N/mm^2)	Compressive strength at 21 days (N/mm^2)
Control (T_1)	4.43	4.52	4.69
1:2 (T_2)	1.21	1.23	1.35
1:3 (T_3)	4.8	4.83	4.95
1:4 (T_4)	8.79	9.52	9.92
1:5 (T_5)	7.15	8.13	8.50

The results in Table 3 indicated that there was a relationship between the compressive strength and the plastic:sand mix ratio of the LDPE bonded concrete blocks. The compressive strength increased with an increase in the amount of sand until treatment 5 (mix ratio 1:5), where the compressive strength decreased. Decreasing the amount of plastic increased the compressive strength for additions up to treatment 4 (mix 1:4). This is where the maximum compressive strength of 9.92 N/mm^2 was produced after 21 days of curing.

Table 3. LPDE-bonded concrete block compressive strength treatments analysis of variance.

Treatment		Mean Difference	Standard Error	Sig. (P-value)
T_1	T_2	-3.33333*	0.84327	0.003
	T_3	-6.33333*	0.84327	0.000
	T_4	-9.33333*	0.84327	0.000
	T_5	-12.33333*	0.84327	0.000
T_2	T_1	3.33333*	0.84327	0.003
	T_3	-3.00000*	0.84327	0.005
	T_4	-6.00000*	0.84327	0.000
	T_5	-9.00000*	0.84327	0.000
T_3	T_1	6.33333*	0.84327	0.000
	T_2	3.00000*	0.84327	0.005
	T_4	-3.00000*	0.84327	0.005
	T_5	-6.00000*	0.84327	0.000
T_4	T_1	9.33333*	0.84327	0.000
	T_2	6.00000*	0.84327	0.000
	T_3	3.00000*	0.84327	0.005
	T_5	-3.00000*	0.84327	0.005
T_5	T_1	12.33333*	0.84327	0.000
	T_2	9.00000*	0.84327	0.000
	T_3	6.00000*	0.84327	0.000
	T_4	3.00000*	0.84327	0.005

*. The mean difference is significant at the 0.05 level.

All the treatments were found to be significantly different from the control (P< 0.05). This meant that the amount of plastic (LDPE) in the ratio of the blocks affected the compressive strength of the blocks fabricated. The mean compressive strengths for T_2, T_3, T_4, T_5 and the T_1 (control) were 1.35 N/mm^2, 4.95 N/mm^2, 9.92 N/mm^2, 8.50 N/mm^2 and 4.69 N/mm^2 after 21 days of specimen aging, respectively. The variation of compressive strengths could be attributed to the amount of plastic (LDPE) present in the respective concrete mix batches.

The compressive strengths for the 1:5 mix of LDPE:sand (8.50 N/mm^2) and that of the control which had no plastic (4.69 N/mm^2), had a mean difference of 3.81 N/mm^2, which was significantly different (P < 0.05). The compressive strengths of the T_5 (1:5 mix) and the mean compressive strengths of the LDPE-bonded concrete blocks with mix ratios of 1:4, 1:3 and 1:2 was also significantly different (P< 0.05).

3.2. Effect of Specimen Aging on the Compressive Strength of LDPE-Bonded Concrete Block Results

The results reflected that the control had a compressive strength of 4.69 N/mm^2 after 21 days, while treatment T_2 (mix. 1:2) developed a compressive strength of 1.35 N/mm^2 (Figure 1). The mean compressive strength of the control was significantly different (P<0.05) from T_2. On the other hand treatment T_3 (mix 1:3) which was also cured for 21 days was also significantly different from the control (P<0.05).

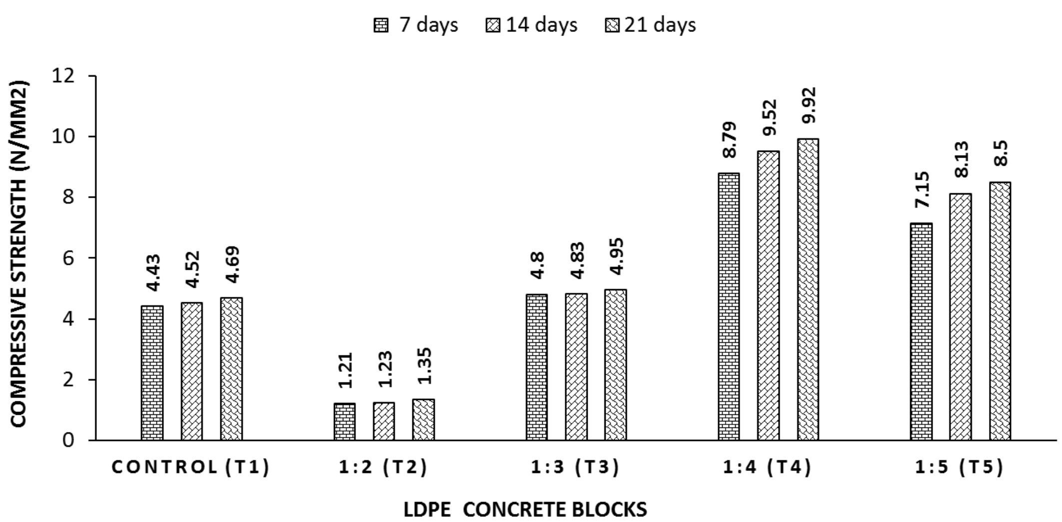

Figure 1. Mean Compressive strength at 7 days, 14 days, 21 days.

In all the treatments, including the control, the compressive strength of the LDPE-bonded load bearing concrete blocks increased with an increase in the curing period. The control developed a compressive strength of 4.43 N/mm^2 after 7 days of curing, ending up with a compressive strength of 4.69 N/mm^2 after 21 days of specimen aging. Although it had the least compressive strength, treatment T_2 (mix 1:2) also reflected an increase in compressive strength over the curing periods. It started at 1.21 N/mm^2 to 1.35 N/mm^2, which was higher than the initial compressive strength.

3.3. Water Absorption of the LDPE-Bonded Concrete Block Results

The results indicated that the LDPE-bonded concrete blocks had lower mean water absorption (3.5%) than that of the control, which had mean water absorption of 6.8% (Table 4).

Table 4. Water absorption test results for the various treatments.

Treatment	Mix Ratio	Water absorption (%)
T_1	1:5 (w/c 0.5)	6.80
T_2	1:2	1.68
T_3	1:3	2.35
T_4	1:4	4.57
T_5	1:5	5.65

The results reflected that there was an increase in the water absorption with a decrease in the LDPE content of the LDPE-bonded concrete block treatments. Treatment T_5 had the highest water absorption of 5.6%, while T_2 had the lowest water absorption of 1.67%. This may be attributed to the porous nature of sand, whose water absorption increased as the amount of plastic in the ratio decreased. This meant that the polyethylene bonding properties reduced the water absorption rate. Treatment 2 (1:2) had the lowest water absorption (1.67%) because of the higher LDPE content in the mix ratio. The control had absorbed the highest amount of water (6.8%) because it had no LDPE content in it. Water absorption was found to be 1.68%, 2.35%, 4.57% and 5.65% for T_2, T_3, T_4 and T_5, respectively. The water absorption for these treatments was less than that of the control which was 6.8%.

4. Conclusions

The results indicated that the control (without LDPE) specimen had a lower compressive strength than that of the optimum LDPE-bonded concrete blocks with a mix of 1:4. The optimum compressive strength attained for the LDPE-bonded load bearing concrete blocks was 9.92 N/mm^2 after 21 days of specimen aging. Reducing the amount of plastic in the LDPE:sand mix had a positive effect on the compressive strength of the LDPE-bonded load bearing concrete blocks until an optimum LDPE:sand mix of 1:4 was achieved. The compressive strength of 1.35 N/mm^2, 4.95 N/mm^2 and 8.50 N/mm^2 for 1:2, 1:3 and 1:5 LDPE-bonded load bearing concrete blocks, respectively were lower than those of the 1:4 LDPE-bonded concrete blocks (9.92 N/mm^2) after 21 days of curing.

There was an increase in the compressive strength of all LDPE-bonded concrete blocks with an increase in the curing period. The control developed a compressive strength of 4.43 N/mm^2 after 7 days of curing, ending up with a compressive strength of 4.69 N/mm^2 after 21 days of curing. Although it had the least compressive strength, treatment 2 (mix. 1:2) also reflected an increase in the compressive strength over the curing periods. It started with a compressive strength of 1.21 N/mm^2 and ended up with a compressive strength of 1.35 N/mm^2, which was higher than the initial compressive strength.

The LDPE-bonded load bearing concrete blocks were found to have lower water absorption than the standard concrete blocks (control). The water absorption range was between 1-6%, which was lower than the standard 7% concrete blocks are limited to. Water absorption was found to be 6.8%, 1.68%, 2.35%, 4.57%, and 5.65% for T_1, T_2, T_3, T_4 and T_5, respectively.

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