International Journal of Advanced Materials Research
Vol. 6, No. 1, 2020, pp. 16-22
http://www.aiscience.org/journal/ijamr
ISSN: 2381-6805 (Print); ISSN: 2381-6813 (Online)

Physical and Mechanical Properties of Compacted Concrete Containing Waste Glass and Laterite as Replacements of Sand

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Abstract

In Benin, laterite is abundant and is largely used in housing construction especially in rural areas. Many studies have been conducted on laterized concretes obtained by partially or fully replacing sand by laterite. However, no one has considered the use of laterite in compacted concrete. The present work investigates the possibility of replacing fine aggregate by laterite and waste glass in compacted concrete. The mixtures were produced by partial replacement of sand at dosages of 0%, 30% and 40% by laterite and at dosages of 0%, 20% and 30% by waste glass. The physical properties (fresh and dry densities and water absorption) at 28 days and mechanical properties (flexural and compressive strength) at 7, 14, 28 and 90 days were studied. Results showed that concrete containing 30% laterite and 30% waste glass showed a compressive and flexural strengths higher than that of the control mix. Its compressive strength and flexural strength were 2.4% and 8.4%, respectively, higher than those of the control concrete at 28 days and 10.4% and 29.4 respectively higher at 90 days. Fresh and dry densities decreased as the waste glass and laterite percentage increased. However the water absorption increased with the increasing of waste glass and laterite, but were below 10%, showing that it is a good quality concrete. Therefore, concrete containing waste glass and laterite can be used in construction.

Keywords

Waste Glass, Laterite, Compacted Concrete, Flexural and Compressive Strengths, Density, Water Absorption

Received: December 11, 2019 / Accepted: January 9, 2020 / Published online: February 20, 2020

1. Introduction

With industrial development and people's living standards improvement, the volume of domestic and industrial wastes is increasing. Unfortunately, most of the wastes is not recycled. Moreover, many domestic, industrial and construction wastes are toxic and harmful [1, 2] and waste glass is one of them. The disposal of waste glass in landfills is an important environment challenge that many countries face around the world [3]. According to the U.S. Environmental Protection Agency, more than 10 million tons of waste glass is generated in the USA each year but more than 70% of the waste glass was disposed in landfills [3]. Thus, the recycling of waste glass is a solution for waste reduction and depletion of natural resources. Finding a way to recycle waste glass, one in which great quantities of waste glass can be consumed will be of great value.

Concrete is the most widely used construction material, and huge amounts of natural resources are required to manufacture it [4]. The use of waste glass into construction material seems to be the best choice since it reduces the consumption of natural resources and landfill rate. Because of this, waste glass has been studied by many researchers for use as partial replacement of cement, fine or coarse

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aggregates in concrete. Park and al [5] found in their study that waste glass color has no influence on concrete properties, thus eliminating the need to sort glass by color before using it in concrete. The use of high content glass aggregate (more than 45%) in concrete creates a serious alkali-silica reaction (ASR) which result in a lower strength, lower durability of concrete [6] and deleterious expansions and cracks [7, 8]. However ASR can be mitigate by grinding glasses to particles size less than 300 micrometers [9]. Park and al [5] also reported that the compressive, tensile and flexural strengths of concretes containing waste glass as fine aggregate demonstrated a decreasing tendency with increasing of waste glass ratio. In their study, Shayan and Xu [10] found that when aggregates or cement is replaced at 30% ratio by glass there are no detrimental effects on concrete long-term properties. Malik and Al [11] and Adaway and Wang [12] has found that concrete containing up to 30% replacement of sand by waste glass showed a compressive strength higher than that of the control at 7 and 28 days.

Laterite is a product of tropical or sub-tropical weathering [13]. Laterite is a mixture of clayey iron and aluminum oxides and hydroxides formed as a result of the weathering of basalt under humid, tropical conditions [14]. It is readily available in Benin, especially in the south part. Laterite is used as fine and coarse aggregate in several parts of the world [15]. Adepegba was identified as the first to study the effect of using laterite as fine aggregate in concrete [16]. Many studies have revealed that the incorporation of laterite as sand replacement in concrete or mortar decreases the strength due to the presence of clay. However, Awoyera and Osunade [13, 17] have recommended a replacement ratio of 10 to 30%.

Although many interesting studies regarding the use of laterite soil or waste glass in concrete as sand replacement have been conducted in the past, no one have considered using both laterite and waste glass in concrete. The current study objective is to explore different combinations of laterite and waste glass for natural fine aggregate replacement in compacted concrete and identify the effects associated with such combinations on compacted concrete's mechanical properties such as compressive and flexural strengths and physical properties such as density and water absorption.

Compacted concrete generally called roller compacted concrete is a zero-slump concrete with a dry skeleton that is composed of similar basic ingredients with conventional concrete, but have much less water and cementitious binders compared to concventional portland cement concrete [18].

2. Materials and Methods

2.1. Cement

High Strength Composite Portland Cement of type CEM II / B-LL 42.5 R, manufactured by NOCIBE, a cement company in the Republic of Benin, was used for preparing concrete mixes. The Physical and chemical characteristics of this cement are given in Table 1.

2.2. Gravel

The gravel used in this study comes from Kpoba quarry in the Mono Department in Republic of Benin.

In this work, only aggregates with diameter less than 10 mm were used in the manufacturing of all concrete samples. Figure 1 presents the grading curve of the gravel used. The physical properties of the gravel are presented in Table 2.

2.3. Sand

Locally available sand from natural sources was used for this project. The sand grading curve is showed in Figure 2 and its physical properties are also presented in Table 2.

Table 1. Chemical and physical properties of cement.

Chemical composition (%)											
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Mn_2O_3	TiO_2	P_2O_5	K_2O	Na_2O	SO_3	Cl
16.55	3.65	3.00	61.45	1.51	0.11	0.30	0.19	0.18	0.16	1.9	0.01

Physical properties						
Specific density	Blaine (cm^2/g)	Initial setting time (min)	Final setting time (min)	Compressive strength (MPa)		
				2 days	7 days	28 days
3.15	4600	228	306	21	33.6	48

Table 2. Physical properties of aggregates.

Properties	Sand	Laterite	Waste glass	Gravel
Bulk density	1.51	1.30	1.23	1.50
Specific gravity (g/cm^3)	2.6	2.53	2.5	2.64
Fineness modulus	1.72	1.86	1.22	-

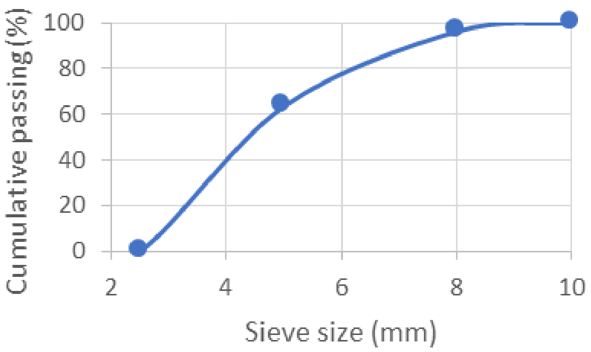

Figure 1. Grading curve of gravel.

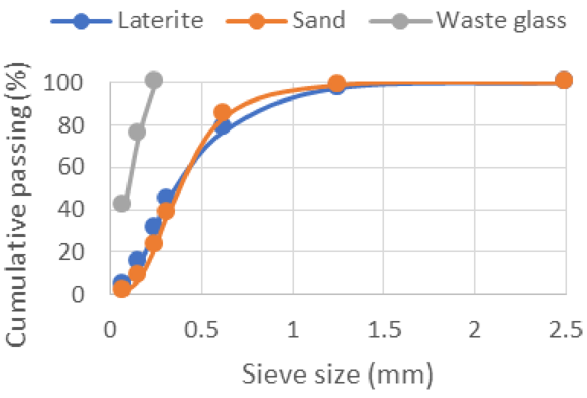

Figure 2. Grading curve of fine aggregates.

2.4. Laterite

The laterite used in this study and presented in Figure 3, was taken at a depth of about 2 m at Tanzoun district in Porto-Novo, a city in Republic of Benin. Figure 2 shows the grading curve of the laterite and Table 2 its physical properties.

Figure 3. Laterite.

2.5. Waste glass

The waste glass used in this study were obtained from glass bottles, mainly empty beverages bottles, collected from the nature. To avoid contamination of manufactured concrete, the collected bottles were first soaked in water in order to get rid of their labels before being cleaned properly to remove impurities such as oils, salts, etc. Finally, the waste glass was finely crushed in a grinder. To reduce the alkali-silicate reaction, only aggregates with diameter less than 250 μm were used in the making of test samples. Figure 4 shows the appearance of waste glass after grinding.

Figure 4. Waste glass.

The chemical composition of the waste glass aggregates used in this work is shown in Table 3.

2.6. Water

The water used to produce the samples comes from the drinking water supply network of the University of Abomey-Calavi in Republic of Benin. This water, which has a pH of 4.7 [19], complies with the current water quality standard for concrete manufacturing.

Table 3. Chemical composition of waste glass.

Chemical composition	Percentage (%)
SiO_2	70.45
Al_2O_3	2.75
Fe_2O_3	0.92
CaO	15.25
MgO	0.78
K_2O	0.76
Na_2O	9.39
SO_3	0.1

3. Experimental Procedure

3.1. Mixture Proportioning

To study the effect of sand substitution by waste glass and laterite in compacted concrete, a total of nine mixes were made and their detailed mix proportions are presented in Table 4.

These mixes included one control mix, which consisted of sand, gravel, cement and water, and eight other mixes made by replacing sand by 0%, 20% and 30% of waste glass and/or by 0%, 30% and 40% of laterite.

For all the mixes, the amount of cement was kept at 450 kg/m^3, fine aggregate and gravel were maintained at 505 kg/m^3 and 757.5 kg/m^3 respectively.

The water/cement (w/c) ratio was 0.5 for all mixes.

Table 4. Concrete mix proportion by weight for a constant w/c ratio (0.5).

Concrete type	Cement	Sand	Waste glass	Laterite	Gravel
0-0	1	2.02 (100%)	0 (0%)	0 (0%)	3.03
0-20	1	1.62 (80%)	0.40 (20%)	0 (0%)	3.03
0-30	1	1.41 (70%)	0.61 (30%)	0 (0%)	3.03
30-0	1	1.41 (70%)	0 (0%)	0.61 (30%)	3.03
30-20	1	1.01 (50%)	0.40 (20%)	0.61 (30%)	3.03
30-30	1	0.81 (40%)	0.61 (30%)	0.61 (30%)	3.03
40-0	1	1.21 (60%)	0 (0%)	0.81 (40%)	3.03
40-20	1	0.81 (40%)	0.40 (20%)	0.81 (40%)	3.03
40-30	1	0.61 (30%)	0.61 (30%)	0.81 (40%)	3.03

3.2. Casting and Curing of Samples

Before mixing, each concrete constituent was first dried in an oven at a temperature of 105°C for 72 hours. For each mix, materials quantity were weighted and then mixed in a dry state in a standard concrete mixer for 2 min. Then, water were added and, all materials were again mixed for another 2 minutes to obtain an homogeneous mix.

Concrete samples were cast in prismatic molds of dimensions 40 mm×40 mm×160 mm. Before pouring the mixture in the mold, the internal faces of the mold were coated with a thin layer of vegetable oil in order to facilitate the demolding. Each mold was filled in three successive layers. Each layer was first manualy compacted with a cylindrical steel rod of 5 mm diameter before going through vibration during 10 seconds on a vibrating table to achieve maximum compaction. The last layer, after manual compaction, were covered with a steel plate before going through vibration in order to make flat the top plane of the sample. Samples were demolded 3 hours later and allowed to air-cure for 24 hours before being immersed in a 27°C water until the age of testing. For each mix, six specimens were manufactured.

4. Test Method

In this study flexural strength, compressive strength, water absorption, fresh and hardened concrete density of compacted concrete containing waste glass and laterite were investigated.

4.1. Fresh and Dry Density

Fresh density were measured for all mixes after moulding. The fresh density of each mix represents the mean value of fresh densities of the six samples. The dry density was measured at 28 days just before the flexural strength test.

4.2. Water Absorption

The water absorption of the concrete was measured in order to investigate the effect of waste glass and laterite substitution on permeability resistance. Water absorption was measured on prismatic 40 mm x 40 mm x 160 mm specimens according to NF P 18-555. At 28 days of age, the specimens were oven-dried at 105°C for 48 h and allowed to cool down at room temperature before being immersed in water. After 24 hours of immersion, samples were removed from water, and their surfaces were cleaned with a soft dry cloth before taking their weight. Water absorption was calculated by using the following equation:

$$W_a = \frac{W_w - W_d}{W_d} \text{x}100 \quad (1)$$

W_a = Percentage of water absorbed

W_w = Weight of wet specimen

W_d = Weight of dry specimen

4.3. Flexural Strength

Flexural strength test was performed on 40 mm x 40 mm x 160 mm prismatic specimens at ages of 7, 14, 28 and 90 days. The flexural strength test was carried out on a Toni Technick compression testing machine of capacity 25 kN in bending with a loading rate of 0.05 kN, according to NF EN 12390-5.

The value of flexural strength of each concrete mix is the average of six measurements.

4.4. Compressive Strength

Half samples from flexural strength test were used for compressive strength test. The compressive test was conducted on a Toni Technick machine of capacity 250 kN on compression with a load rate of 2.4 kN/s according to NF EN 12390-3. The value of flexural strength of each concrete mix is the average of twelve measurements.

5. Results and Discussion

5.1. Fresh and Dry Density

Table 5 shows the fresh and dry density of all the concrete mixes. The control concrete showed the highest fresh density. It can be seen that fresh density decrease with increase in waste glass and laterite. The fresh density of concrete containing waste glass and/or laterite is 1 to 5.88%

lower than that of the control mix. The decrease in fresh density can be attributed to the lower specific density of laterite and waste glass compared to sand.

Table 5. Fresh and dry density.

Mix type	Fresh density (kg/m^3)		Dry density (kg/m^3)	
	Value	Reduction ratio (%)	Value	Reduction ratio (%)
0-0	2483.1	-	2444	-
0-20	2458.3	1	2408.7	1.44
0-30	2414.1	2.78	2364.2	3.27
30-0	2429.7	2.15	2419.1	1.02
30-20	2408.9	2.99	2390.2	2.20
30-30	2375	4.35	2373	2.91
40-0	2406	3.10	2399.6	1.82
40-20	2365.9	4.72	2355.3	3.63
40-30	2337.2	5.87	2318.5	5.14

Dry density trends are similar to fresh density. The same trend were reported by topçu and Canbaz on conventional concrete [20]. Concrete containing 40% laterite and 30% waste glass showed the lowest fresh and dry density which are respectively 5.87 and 5.14 lower than that of the control concrete.

5.2. Water Absorption

Figure 5 shows the water absorption of all mixes. Water absorption increased with the percentage of waste glass.

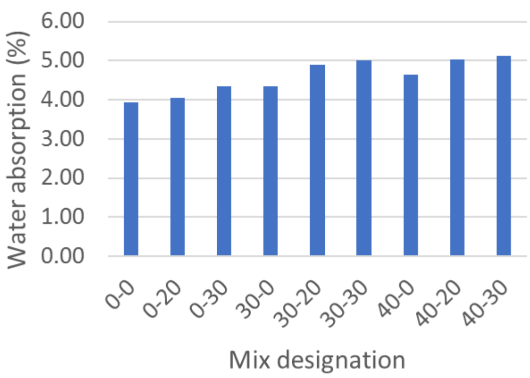

Figure 5. Water absorption by immersion.

The increase in water absorption may be due to the reduction of the adhesive strength between waste glass and cement because of the shape and smooth texture of waste glass which result in internal crack, therefore allowing water to penetrate the concrete. Similar findings have been reported by Sara de Castro et al [21]. Water absorption of concrete containing 20% and 30% waste glass are 10 to 16% higher than the control one. The water absorbed by the concrete also increases with increasing percentage of laterite.

5.3. Compressive Strength

Figure 6 shows the compressive strength development for all concretes at different ages up to 90 days. From the results, it can be seen that compressive strength increased with age. Compressive strength of concrete containing waste glass is lower at 7 days than that without waste glass, but this tendency is reversed at later ages (14, 28 and 90 days). This could be explained by the pozzolanic effect of waste glass which may be low at early curing days but became significant after 7 days. The compressive strength decreased with the increase of laterite. However, among concrete containing laterite, concrete containing 30% laterite and 30% waste glass showed the highest strengths, strengths which are 2.9% and 10.4% higher than the control one at 28 and 90 days respectively.

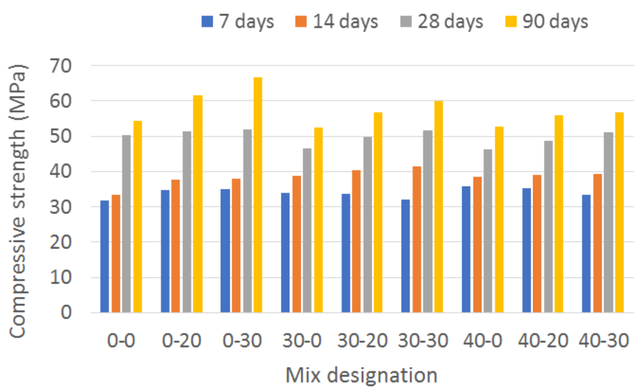

Figure 6. Compressive strength.

5.4. Flexural Strength

The flexural strengths test results are presented in Figure 7. The flexural strengths were observed to follow the same trend with the compressive strength. The flexural strength increased with the waste glass percentage but decreased with the laterite percentage. At 28 days, the mix containing 30% laterite and 30% waste glass showed a flexural strength which is 8.4% higher than that of the control mix. At 90 days, the same mix showed the highest flexural strength of all, which were 29.4% higher than that of the control one. The big gap (from 8.4% at 28 days to 29.4% at 90 days) showed that pozzolanic reaction has increased with days and became more significant.

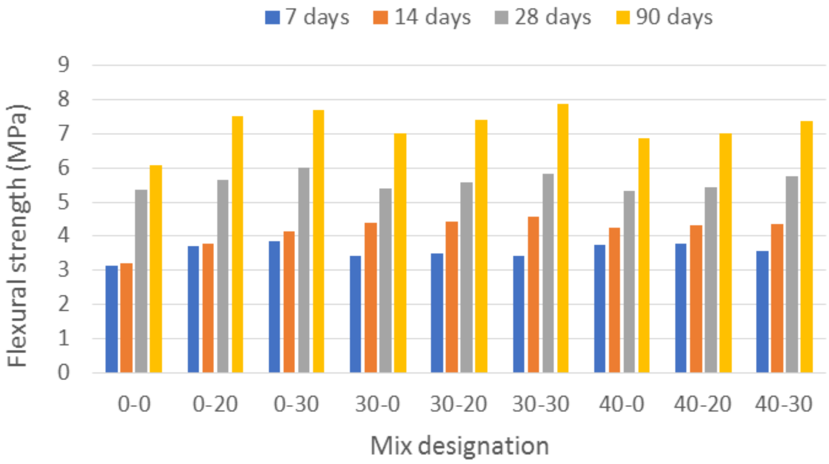

Figure 7. Flexural strength.

6. Conclusion

This work has studied the possibility of using waste glass and laterite as a partial replacement for fine aggregates.

Based on the results obtained from the experimental tests, the following conclusions can be presented:

1. The compressive strength and flexural strength increased with an increase in waste glass content but decreased with the increase in laterite content. At 28 days and 90 days of age, concrete containing 30% waste glass and 30% laterite gave higher compressive and flexural strengths compare to the control mix.
2. The density decreased with the increase in the content of waste glass and laterite. This could be due to the low specific gravity of waste glass and laterite compare to sand.
3. Compared to the control mix, mixes containing either waste glass or laterite have given higher water absorption values. Water absorption increased with the percentage of waste glass and also with the percentage of laterite. However, each mix showed a water absorption value lower than 10%, showing that they can be classified as good quality concrete.

Based on the materials used in this study, the results suggested that it is technically feasible to utilize waste glass and laterite in the production of compacted concrete.

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