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Sustainable utilization of crushed waste glass as sand replacement for production of eco-friendly interlocking paving stones

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Abstract. In an attempt to ensure sustainability of construction materials, efforts were being made to reuse some non-biodegradable waste materials as substitute materials in mortar production. Sand is a major constituents in the production of mortar, however, using waste materials such as glass as partial or complete substitute for sand in mortar production will ensure the reduction on the needs to dredge for it, thereby preserving the very valuable natural sand resources within the environment. Furthermore, the use of crushed waste glass as a replacement for sand in the production paving stones will ensure that the paving stones are eco-friendly thereby eliminating the challenges of discriminate dumping of glass wastes in landfill. This research investigates the utilization of crushed waste glass as partial and complete replacement for natural sand in cement mortar for the production of interlocking paving stones (IPS). The waste glass was varied at various percentage proportions by weight to replace the fine aggregate in the cement mortar mixes. Laboratory tests which includes chemical composition, particle size distribution, specific gravity, and compressive strength were carried out on the crushed glass materials, sand and paving stone samples respectively. The obtained results show that the both the load and non-load bearing interlocking paving stones containing 20% crushed waste glass exhibited better performance in strength development than the control and other paving stone mixes containing various content of waste glass materials. This study demonstrates clearly that waste glass can be adopted to produce eco-friendly interlocking paving stones, and this will help both in the sustainable management of glass wastes and greening of the environment.

1. Introduction

Annually, over a million tons of glass wastes are being produced all over the world. Report by the International Energy Agency (IEA) [1] stated that as of 2005, the total amounts of waste glass generated was about 130 metric tons. Furthermore, from the report, European Union (EU), China and the United States of America (USA) were reported to be generating approximately 33 metric tons, 32 metric tons and 20 metric tons of the waste glass respectively [1, 2]. However, waste glass being a non-biodegradable waste material, constitute a major nuisance to effective landfill or dump sites management and operations [3]. It was reported by [2 – 6] that glass is an amorphous material, with large percentage of silica compounds used for producing different forms, types, and colours of glass



products. Meanwhile, as generated waste materials, due to its nature occupy huge portions of spaces in landfill/dump sites, often triggering serious environmental pollutions [2]. Consequently, in view of rising scarcity of valuable spaces for locating landfill/dumping sites and the need to lower generated wastes, eradicate pollution and protect the environment, finding alternate solution to indiscriminate disposal of waste glass in dumping sites has become necessary. In addition, studies by Olofinnade et al. [3, 6], [7] mentioned that one of the best alternatives of solving the menace glass wastes on the environment is to reuse and recycle them as alternative construction material. In addition, recently there has being a rising demand for high performing sustainable materials in the construction industry, which constitutes a move towards eco-friendly and sustainable practices [8 – 10]. Around the world today, there is a general awareness that the construction industry depends so much on conventional materials such as granite, sand and cement, for concrete and mortar production. However, it was emphasized by researchers that continued exploitation of these resources raises huge environmental and economic costs especially in developing nations, and also contributing heavily to continued depletion of natural resources and greenhouse gases emission (GHG) [8-10]. However, studies by [9], [11 – 13] mentioned that the inception of sustainable development and renewable materials prompted mainly through regulations, landfill shortages, environmental concerns, limited availability of natural aggregates, innovations and cost reduction, the construction industry is now committed to the use of supplementary cementitious materials (SCM) from environmental wastes in concrete and mortar production. According to [13], [14 – 15], utilization of waste materials such as waste glass will helps achieving green concrete production, contributes to reduction of GHG emission and have been observed to be effective in both structural and non-structural engineering applications. Waste glass provides equal alternative options as a substitute material for traditional aggregate in concrete. Using crushed waste glass materials as aggregate and SCM in concrete and mortar benefits the environment and helps in reducing the needs for extracting raw resources. A study by Ismail et al. [16] mentioned that waste glass and sand have almost similar physical and chemical properties. In addition, several studies have been carried out on reusing waste glass as aggregate and cement replacement in cement mortar and concrete by examining the influence and optimum percentage content of waste glass that can be used as aggregate and cement substitute in the production of mortar and concrete [2 – 7], [10], [15 – 17]. Moreover, reusing wastes such as waste glass in concrete and mortar works for structural and non-structural engineering structures such as road pavements and buildings contributes to achieving sustainable construction [15, 18]. Therefore, this present study investigates the suitability of crushed waste glass (WGS) as sand replacement in cement mortar for the production of eco-friendly interlocking paving stone units that can be used for paving walkways and sidewalks for pedestrians and landscapes. The option of interlocking paving stones has over time proved effective for roadways in areas of high water table without losing its strength and durability.

2. Methodology

2.1. Cement

The cement used in this study was Ordinary Portland Cement (OPC) of grade 42.5 which was sourced commercially within the local market in Ota, Ogun state, Nigeria. The grain size distribution of the Portland cement is shown in Figure 1, while its physical properties is shown in Table 3. The chemical compositions of the cement was analysed using the X-ray fluorescence (XRF) is presented in Figure 3.

2.2. Sand

The natural sand (fine aggregate) material was sourced commercially. The grain size distribution analysed through sieve analysis is also depicted in Figure 1. Moreso, the physical attributes of the sand are shown in Table 3. The oxide compositions of the natural sand materials was analysed using the X-ray fluorescence (XRF) is presented in Figure 3.

2.3. Crushed waste glass aggregate (WGS)

The crushed waste glass employed as substitute for the natural sand (fine aggregate), was obtained as disposed mixed coloured glass wastes from dump sites and waste collection points within Sango-Ota, Ogun state, Nigeria. The glass wastes comprises mainly bottle and container glasses and flat glasses.

The collected waste glass materials were thoroughly washed with water to remove contaminants and impurities, then air-dried before crushing to required particle sizes using the milling machine. The particle size distribution of the milled glass sand material (WGS) is presented in Figure 2. Moreover, Figure 1 show samples of the crushed glass material and the natural sand. Table 3 depicts the physical properties of the waste glass materials, while the chemical compositions of the WGS materials are shown in Figure 3.

2.4. Water

Portable water obtained from the Structures and Materials laboratory in Covenant University was used for mixing the various constituents to produce the mortar for moulding the interlocking paving stone (IPS) samples.

2.5. Materials proportioning, Mixing and Testing

The cement, sand, waste glass sand (WGS) and water used in this research were all weighed using a digital weighing balance. The mortar constituents were batched by weight in compliance to ACI Standard [19]. Two (2) mix ratios (cement: fine aggregate: water) adopted for this study are in the range of 1:2.75 for load bearing IPS and 1:5 for non-load bearing IPS with corresponding water-cement ratios of 0.485 and 0.50 respectively. The mixing process was carried out manually to ensure good mixing of the mortar components. Crushed waste glass sand (WGS) was used to partially and completely replace the natural sand in percentage proportions of 0, 5, 10, 20, 30, 40, 50 and 100%. The required batching quantities of the various mortar constituents for the production of the interlocking paving stone (IPS) are presented in Table 1 and 2 for the load bearing paving stones and non-load bearing paving stones respectively. Before, pouring the mortar in the plastic moulds, the moulds were thoroughly greased with oil for easy demoulding of the IPS units after hardening. Each layers of the freshly prepared mortar was manually compacted twenty-five times with a 25 mm tapping rod during the process of casting.

Table 1. Proportioning of mortar material for load bearing paving unit

Percentage substitute of sand with waste glass, %	Mortar constituents (kg)			
	Cement	Sand	Waste glass	water
0	25	68.75	-	12.13
5	25	65.31	3.44	12.13
10	25	61.88	6.88	12.13
20	25	51.56	17.19	12.13
30	25	48.13	20.63	12.13
40	25	41.25	27.50	12.13
50	25	34.38	34.38	12.13
100	25	-	68.75	12.13

Table 2. Proportioning of mortar material for non-load bearing paving unit

Percentage substitute of sand with waste glass, %	Mortar constituents (kg)			
	Cement	Sand	Waste glass	water
0	25	125	-	12.50
5	25	118.75	6.25	12.50
10	25	112.50	12.50	12.50
20	25	100.00	25.00	12.50
30	25	87.50	37.50	12.50
40	25	75.00	50.00	12.50
50	25	62.50	62.50	12.50
100	25	-	125	12.50

The IPS's were demoulded after 2 days to ensure some level of curing and strength gain before curing in water by total immersion. The IPS moulds used are of the H type having a surface cross-sectional area of 0.032 m² and thickness of 0.06 m. After the IPS were cured in water for 7 and 28 days, they were further openly dried and compressive strength test was carried out on the IPS samples. Three specimens were tested for each tests.

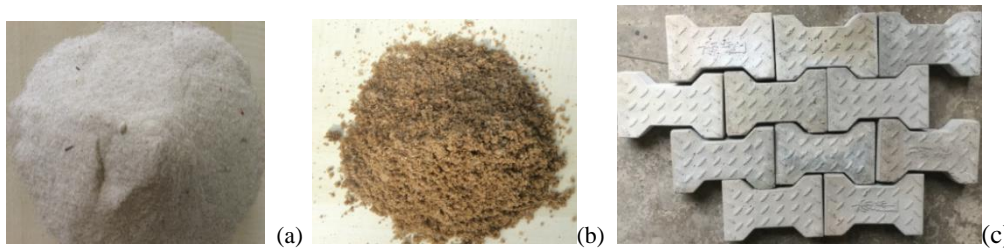


Figure 1. Specimen materials (a) Crushed glass sand; (b) Natural sand; (c) IPS with glass sand

3. Results and Discussion

Waste glass sand exhibited a very low water absorption of 0.40% and compare favourably well with the recorded water absorption of 0.42% for the natural sand as shown in Table 3. The particle size grading of the fine aggregates; that is for both natural sand and waste glass sand (WGS) are closely similar as presented in Figure 2. Similarly, the estimated specific gravity and fineness modulus for both materials are close (Table 3). The obtained results on the physical properties for the natural sand and glass sand (WGS) clearly shows that both materials have similar physical properties as also mentioned in the study of Ismail et al. [16].

Table 3. Physical properties of materials

Properties	Portland cement	Sand	Waste glass sand (WGS)
Fineness Modulus	0.60	2.69	2.99
Specific gravity	3.15	2.62	2.50
Water absorption		0.42	0.40

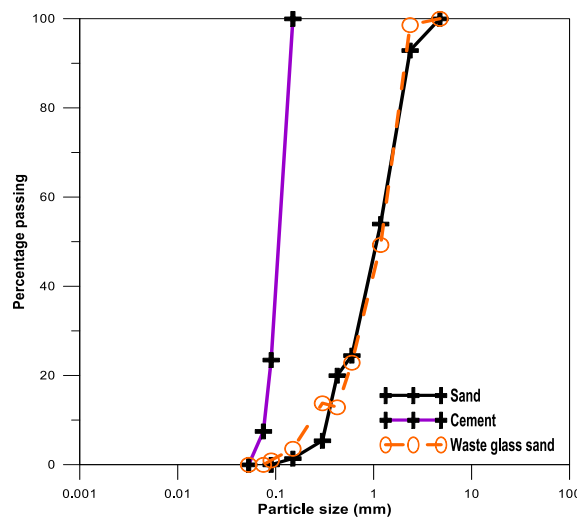


Figure 2. Particle size distribution for cement, sand and WGS

The oxide compositions of the Portland cement as displayed in Figure 3 shows the alkali compound of the Portland cement was 0.18%, using $Na_2O_{eq} = Na_2O + 0.658K_2O$, indicating a low-alkali cement content. Moreover, the chemical composition clearly shows the cement material having a high percentage of CaO content, while the crushed waste glass (WGS) particles indicate the WGS has a high percentage of silica (SiO_2) content as the natural sand, while the sodium compound content indicate the waste glass material to be soda-lime (Figure 3).

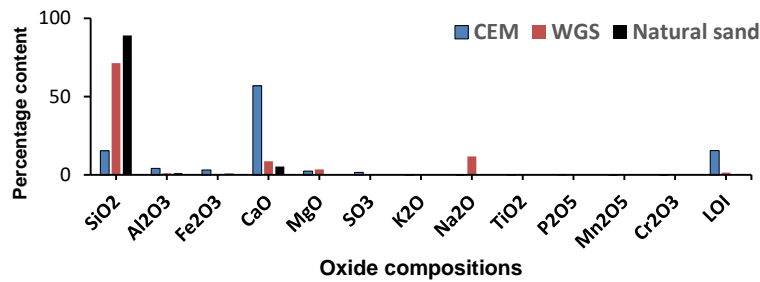


Figure 3. Chemical compositions for cement, sand and crushed glass materials

Figure 1(c) shows the picture of the interlocking paving stone (IPS) containing waste glass sand (WGS) as replacement for natural sand. The obtained results as displayed in Figures 4 and 5 indicated a declining trends in the compressive strength of the interlocking paving stone units as the percentages of glass content increases for both the load bearing paving stones and non-load paving stone units. This implies a loss in the strength of the paving units with increasing replacement dosages of glass content irrespective of the mix ratio. Moreover, a more significant increase in the compressive strength for the IPS was observed as the curing ages increases from 7 to 28 days curing age. This can be attributed to the pozzolanic effect of the glass at prolong curing. However, an appreciable increase in compressive strength was observed at 20% replacement level compare with the control paving stones as indicated in Figure 4 and 5 for both paving stones produced at different mix ratio.

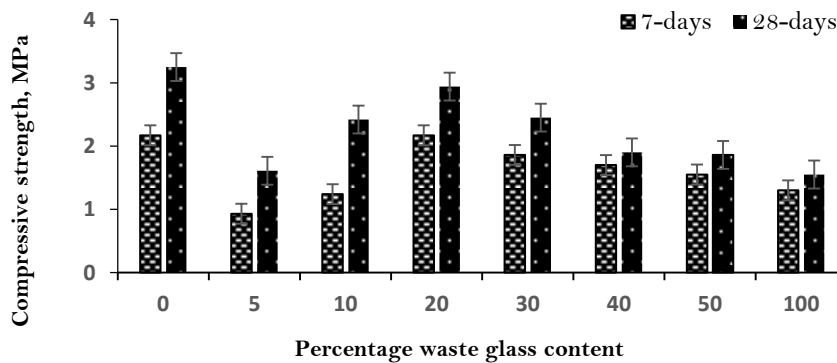


Figure 4. Compressive strength for load bearing interlocking stones with glass content

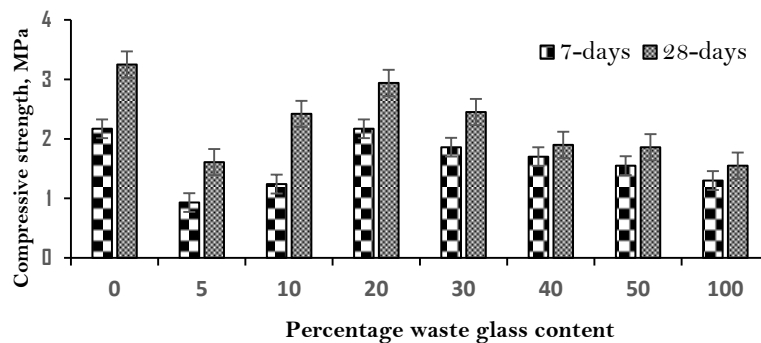


Figure 5. Compressive strength for non-load bearing interlocking stones with glass content

In addition, the obtained results at 20% replacement level agree with the standard requirements suggested by NBRI [20] on compressive strength of interlocking paving stone units.

4. Conclusion

This study investigates the strength performance of interlocking paving stones produced with waste glass sand as substitute for natural sand. The following conclusions can be deduced from this study:

- i. The physical properties and chemical compositions for the natural sand and glass sand (WGS) shows close similarity.
- ii. The strength of the interlocking paving stones were significantly improved with the incorporation of waste glass sand at 20% level.
- iii. The interlocking paving stones containing WGS meet the standard requirements specified for compressive strength of interlocking paving stone units that can be adopted for constructing pedestrian/non-traffic paving and light roadways route such as landscape, building environments and premises, public and car parks, low-traffic pedestrian sidewalks and stabilizing sloppy terrain. This study demonstrates clearly that waste glass can be adopted to produce eco-friendly interlocking paving stone, and this will help both in the sustainable management of glass wastes and greening of the environment. In addition, it is recommended that further studies be carried out on the long term performance and durability of IPS produced with cement mortar containing crushed glass particles.

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