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Identification of Glass Powders and Sands from the Crushing of Glass Waste from the City of Lomé in Togo

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Abstract

The sustainability of a city depends on the effective and efficient management of its solid waste. Waste recycling channels mainly process glass bottles for direct reuse. Some of these sectors carry out the crushing and grinding of end-of-life glass waste for use in civil engineering without the identification in terms of building materials being clearly established. The present study therefore aims to determine the physical and chemical characteristics of glass powders and sands resulting from the crushing and grinding of glass waste from Grand Lomé in Togo in order to consider their granular potential. Samples of sand and glass powder from the crushing and grinding of white, brown and green glass were subjected to characterization tests in the laboratory followed by analysis of the granular parameters and their modeling by Weibull's law. The results show that the powder and the glass sand contain a high proportion of silica (SiO_2) ranging from 69.11% to 70.18% and a low proportion of alumina (Al_2O_3) (less than 0.07) and iron (Fe_2O_3) (lower to 1.09). These three materials have tight and male graded grain sizes ($Cu < 5$ and $Cc < 1$) and less homogeneous ($k < 2.89$). The absolute density ($2 < dab < 3$) and the fineness modulus ($Mf < 2.1$) make these materials probable aggregates for plaster and coating mortars. Nevertheless, an in-depth study will be made to determine a suitable formula.

Keywords

Glass Waste, Granular Parameters, Weibull's Law, Construction Materials

1. Introduction

The management of household and similar waste is one of the environmental problems that developing countries are constantly solving by improving collection, treatment, recycling and landfilling processes in order to make their cities cleaner and free from all waste. It is a major concern globally due to the increasing amounts of waste and industrial by-products [1]. It is also an important issue from a technical and organizational point of view [2] because of the increase in populations leading to an increase in the quantity of waste. Thus, developing countries must obey standards in order not to expose themselves to the pollution of their environments [2].

In Greater Lomé and its surroundings, the management of this waste is done through public sector actors represented by the municipalities and prefectures; the private sector by NGOs and the informal sector by individuals gathered in neighborhood associations [3]. They are part of the local authorities whose role is to ensure the disposal of household and similar waste [4]. The latter proceed by direct collection from households to a technical landfill or through transit areas where pre-collection waste and recovery residues have been transported. The waste collected consists of putrescible, paper and cardboard, textiles, glass, metals, plastics, specials, fines (sand), unclassified fuels, unclassified incombustibles [2]. The greatest recovery is done in compost by NGOs but many are solid waste that can be recovered in building construction and public works [5].

In addition, the development of constructions in Greater Lomé leading to intensive exploitation and the exhaustion of silty sand quarries near the city cause an increase in construction costs. A recovery of non-biodegradable waste such as glass consisting mainly of silica such as silty sand seems an interesting recycling drop-off point.

Indeed, the studies of Kolédzi *et al.* (2011) [2], revealed that the situation of recoverable glass waste in the city of Lomé is eight (8) tons per day in the dry season and three (3) to five (5) tons per day in the rainy season. This gives us an average of about two thousand (2000) tons per year. This glass waste of different colors which are largely bottles, is recovered on a small scale in reusing packaging in households or crushed for use as coarse aggregates in mortars for plastering the exterior walls of residential buildings, in the manufacture of interlocking paving stones and works of art.

One of the major solutions for its large-scale use in construction is to characterize them physically and chemically in order to compare the physical and chemical properties with those of the materials used in the formulation of concretes. This will make it possible to know the chemical constituents and the physical parameters of the glass waste produced by households in the city of Lomé.

In this context, Agani C. (2020) [6] worked on the use of laterite and glasses which are non-biodegradable materials, by reducing the proportions of sand. He has developed a formula for the Concrete-Glass-Laterite material corresponding to 30% glass aggregates and 30% laterite allowing for optimum mechanical resistance. Thermal effusivity, thermal conductivity, resistance to temperature, sportsmanship, water absorption by immersion, behavior of concrete (BVL) to wetting-drying, resistance of concrete (BVL) to acid hydrochloric acid are also determined on the produced product. Work has also been done by Amey K. B. [7] [8] on plastic bags in Togo. He determined a mortar formula based on a non-biodegradable "pure water" type plastic bag as a binder. The 18% - 22% binder dosage formula provides a product with optimal strength and zero water absorption. The behavior of the product obtained under the effect of hydrocarbons is also established.

This study aims to solve the environmental problem created by the congestion of waste bottles in the city of Lomé and its surroundings, by considering their use in the construction industry as binder or sand. To do this, it is necessary to determine the physical and mineralogical properties of glass powders and sands resulting from the crushing and grinding of glass waste from Greater Lomé and to assess the particle size distribution of the materials obtained and analyze them with the Weibull model. Thus, this study will identify the possible areas of use of this glass waste in the construction industry.

2. Materials and Methods

2.1. Study Zone

The study area is located in the south of Togo and more mainly in the maritime region. It is the grouping of the thirteen (13) communes of the prefecture of the Gulf and Agoè-nyivé (**Figure 1**). Inside the area is the city of Lomé which is the capital of Togo. All of its municipalities are normally called Grand Lomé and its population is estimated at 1.5 million people in 2010 [9]. Greater Lomé has experienced very significant demographic growth in recent years and its population represents 1/5 of the Togolese population [9]. This growth poses many health problems, including the management of household and similar waste.

The management of household waste (including glass) is carried out by municipalities and private sector actors. In each municipality there are intermediate dumps where the pre-collection waste is transported to be conveyed to the final landfill of Aképé (CET) using trucks. The recycling channels are located through households and intermediate depots. They recover household and similar waste from the municipalities in their area, generate it and send the recovery residues to the landfill area. The recovery of glass waste in this area is largely done for reuse as packaging in households or crushed as ornamental coatings for the facades of residential buildings.

The map in **Figure 1** illustrates the various official municipal depots (intermediate depots) and the technical landfill center (CET) or the final landfill used by Greater Lomé and its surroundings. The glass waste collected and treated as part of this work is the waste from the Gulf 5 and 7 deposit.

2.2. Materials and Materials

Three different colors (white, green and brown) of broken glass (size less than 10 mm) are obtained from a recycling unit in the city of Lomé (Figure 2). A first sieving gives glass sands and a second fine sieving gives glass powders (80 µm).

The silty sand used is locally available sand from a quarry in Gounokope, Togo. The cement is of the CPJ45 type and comes from the CIMTOGO company.

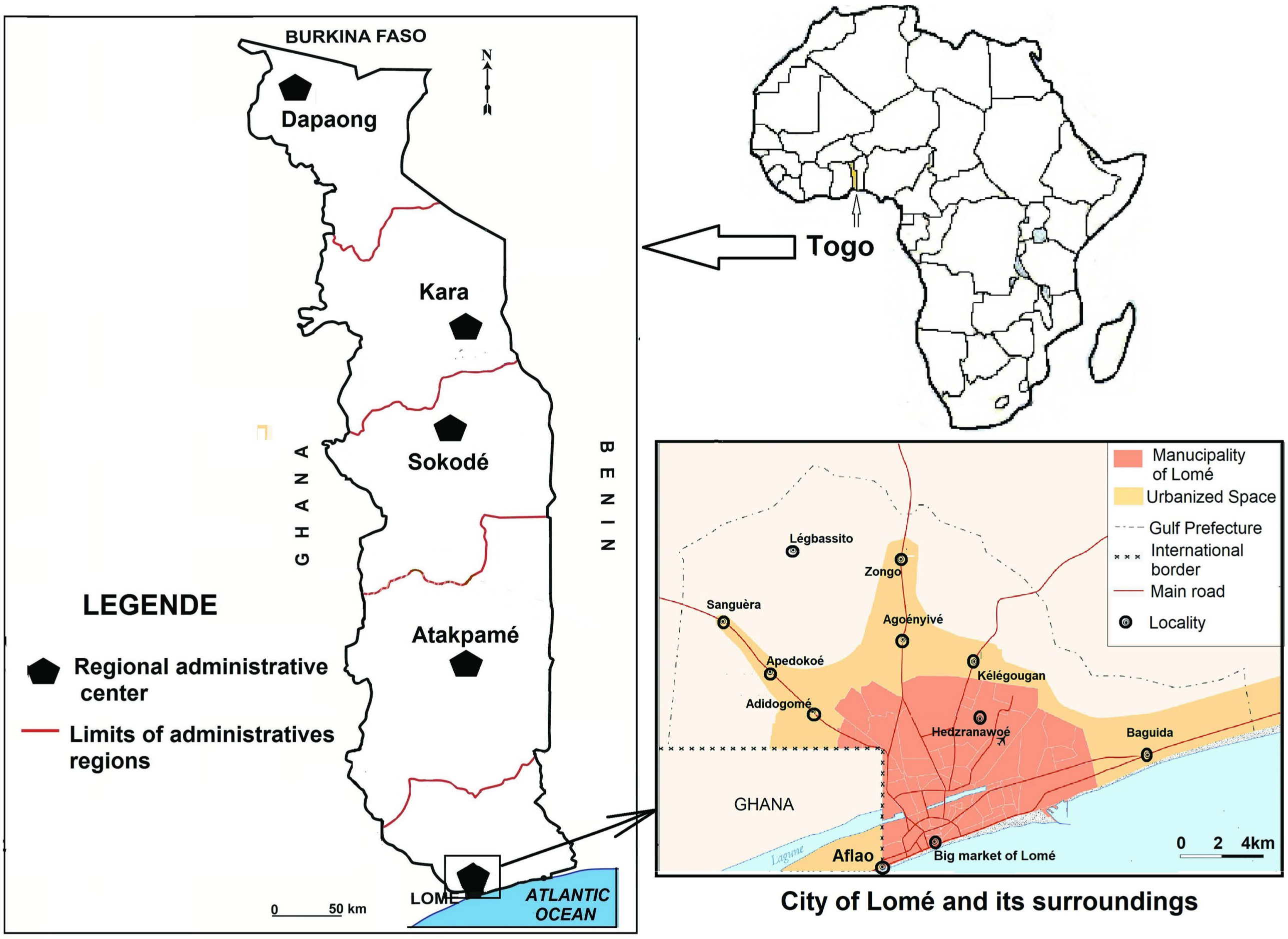

Figure 1. Location of the study area-Lomé and its surroundings.

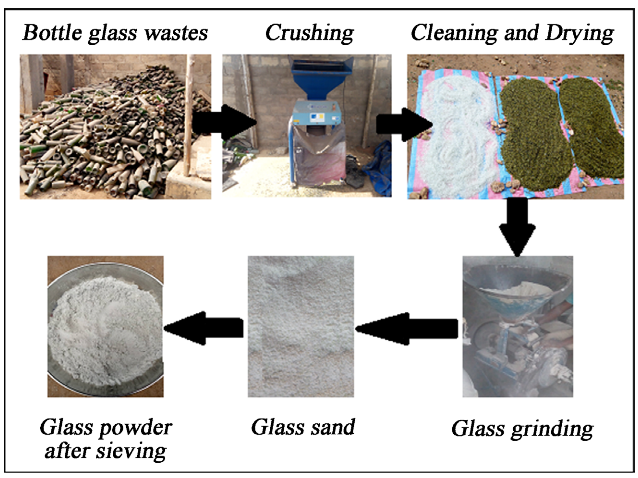

Figure 2. Diagram of transformation of glass waste into glass sands and powders.

The materials used to carry out these tests consist of:

- A CONTROLAB brand oven with an adjustable temperature of more than 200˚C and a precision of 0.1˚C, for drying sand at a temperature of 105˚C;
- A KERN brand electronic scale, with a maximum load of 15,000 g and an accuracy of 0.01 g;
- A set of standard CONTROLAB brand sieves with standard mesh sizes of 0.08 mm, 0.1 mm, 0.125 mm, 0.16 mm, 0.2 mm, 0.25 mm, 0.315 mm, 0.4 mm, 0.5 mm, 0.63 mm, 0.8 mm, 1 mm, 1.25 mm, 1.6 mm, 2 mm, 2.5 mm, 3.15 mm, 4 mm, 5 mm for dry particle size analysis of sand;
- Standard CONTROLAB sieves and 25 µm, 45 µm, 75 µm, 110 µm, 180 µm for the analysis of powders and cement;
- A device complete with CONTROLS brand sand equivalent equipment;
- A pycnometer for absolute density measurements.

2.3. Methods

The approach of this work first consisted in producing glass sands and powders from recycled glass waste. These materials were subjected, in the National Laboratory of Buildings and Public Works (LNBTP), to tests of particle size analysis, sand equivalence, water absorption, determination of apparent and absolute densities [10]-[15]. Analyzes of the mineralogical composition were carried out on cement and glass powders at the Waste Treatment and Valorization Management Laboratory of the Faculty of Sciences of the University of Lomé in Togo.

From the results of the granulometric analysis tests, several granular parameters are determined: the uniformity coefficient Cu (Hazen), the curvature coefficient Cc, the fineness modulus and the parameters of the Weibull law.

1) Granular parameters

The expressions for the granular parameters are given by the following Equation (1), Equation (2) and Equation (3) [16] [17] [18]:

- Coefficient of uniformity (Hazen) Cu

$$Cu = \frac{d_{60}}{d_{10}} \tag{1}$$

- Curvature coefficient Cc

$$Cc = \frac{(d_{30})^2}{d_{10} * d_{60}} \tag{2}$$

Fineness modulus Mf

$$Mf = \frac{r(0.125)+r(0.25)+r(0.5)+r(1)+r(2)+r(4)}{100} \tag{3}$$

With:

$$r(x) = 1 - Q_r(x) \tag{4}$$

The parameters of these equations are given by:

d_{60}: sieve diameter of which 60% are loops

d_{30}: sieve diameter of which 30% are loops

d_{10}: sieve diameter of which 10% are passers-by

$Q_r(x)$: cumulative distribution at sieve x

2) Weibull distribution parameters

Weibull's law which is an exponential law associated with the power function which allows materials science to examine the particle size distribution of a material. It is one of the models proposed to study the distribution of grains within a sandy material [5].

Studying a distribution in a material according to Weibull's law amounts to determining its shape parameter k and scale λ in order to adjust its particle size analysis curve [5] [19].

Indeed, the Weibull law is written in the form given by Equation (5).

$$p(d) = 1 - e^{-\left(\frac{d}{\lambda}\right)^k} \quad (5)$$

To determine the shape k and scale λ parameters, we gradually transform Equation (5) to a straight line. $p(d)$, probability of the model is between 0 and 1; hence the transformation of Equation (5) gives Equation (6).

$$\ln\left(-\ln\left[1 - p(d)\right]\right) = k\ln(d) - k\ln(\lambda) \quad (6)$$

From Equation (6), the curves $\ln\left(-\ln\left[1 - p(d)\right]\right)$ are represented as a function of $\ln(d)$ and the straight lines of slope k and the constant terms $-k\ln(\lambda)$ which made it possible to deduce λ for all the sands. In this study, the parameter d represents the diameter of the sieves and $p(d)$ the percentage of passers-by.

3. Results

3.1. Mineralogical Composition of Glass Powders and Cement

The three types of glass powders analyzed contain a large amount of silica (SiO_2) which varies from 69.11% to 70.18% and a small amount of calcium (CaO) equal to 1.12% (**Figure 3**). This is due to the mineralogical composition of the basic glass manufacturing material, which is sand [5]. They also contain small amounts of minerals which are practically identical for all the colors of glasses studied. The densities of the three types of glasses are also almost identical ($0.69 \le d \le 0.72$). Thus the perception of the color of glasses has a negligible influence on their mineralogical compositions and their density (**Figure 3** and **Figure 4**), while CPJ45 cement is largely composed of CaO (58.80%) with only 16.33% SiO_2 (**Figure 3**).

3.2. Granular Characterization of Materials

The results obtained in **Table 1** show that the densities of the elaborate glass sands are lower than those of the silty sand. They range from about 1.25 to 1.30 for the apparent density against 1.38 for silty sand. The absolute density varies from 2.40 to 2.50 for the elaborate glass sands and 2.63 for the silty sand. The

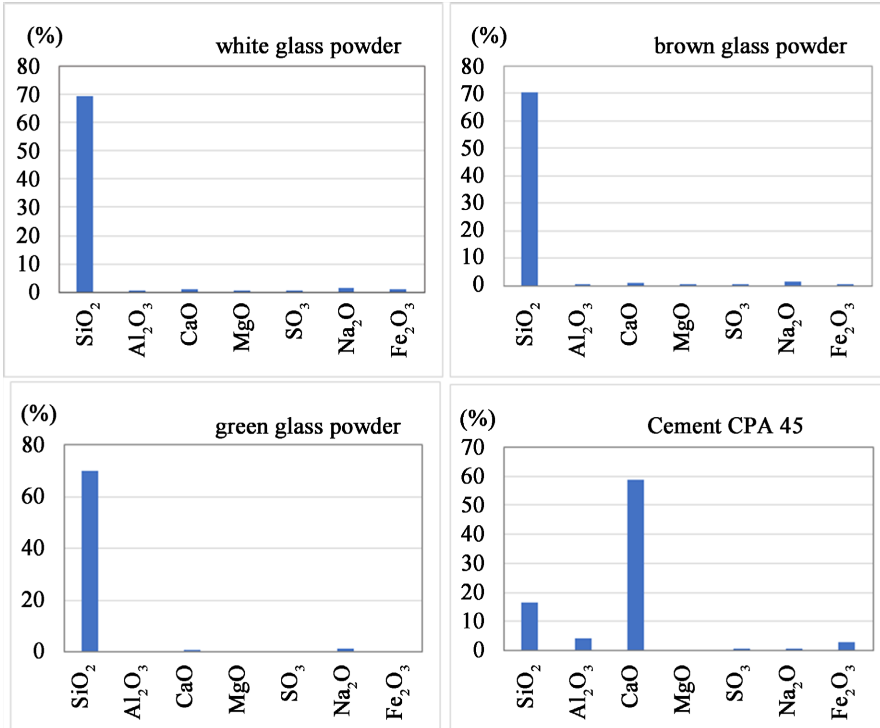

Figure 3. Mineralogical composition of CPJ45 and glass powders.

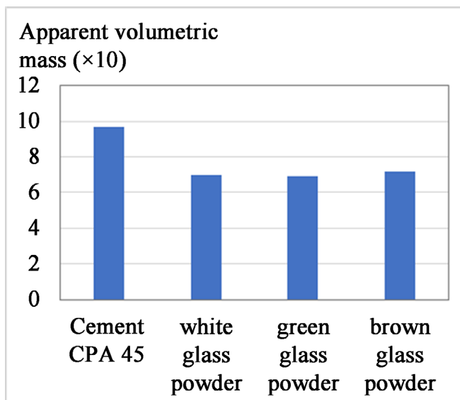

Figure 4. Apparent density of CPJ45 and glass powders.

determination of the water absorption coefficients after 72 h of the sands shows that the white glass sand with 30.14% absorbs more water than the green glass sand (29.11%), brown (23.33%) and silty sand (22.46%). The fineness modules of the glasses are all between 1.40 and 1.8 and that of the silty sand is 1.59. These four materials are in the same fineness category (Materials too fine). On the other hand, glass sand and silty sand are fine sands which have a tight grain size ($2 < Cu < 5$) and poorly graduated ($Cu < 6$ and $Cc < 1$). The cleanliness of the four sands studied (silty sands and white, green and brown glasses) by the Sand Equivalent test is similar with a Sand equivalent test *(ES)* value between 71 and 76. We can also conclude that the colors have no effect on the granular properties of materials.

3.3. Distribution of WEIBULL

For the analysis of the distribution of grains within granular materials with the Weibull model, the parameter *d* is taken as the size of the sieves and *p*(*d*), the percentage of the corresponding passers-by. The graphs in Figure 5 made it

Table 1. Physical characteristics of glass sand and silty sand.

Physical properties	*White glass sand*	*Green glass sand*	*Brown glass sand*	*Silty sand*
Sand equivalent test (ES)	71.00	71.00	71.00	76.00
Absolute density (dab)	2.40	2.50	2.50	2.63
Apparent density (dap)	1.30	1.25	1.25	1.38
Fineness modulus (Mf)	1.59	1.40	1.80	1.79
HAZEN's coefficient (Cu)	2.22	3.17	2.94	2.44
Curvature coefficient (Cc)	0.98	0.97	0.99	0.89
Water absorption coefficient after 72 hours	30.14	29.11	23.33	22.46

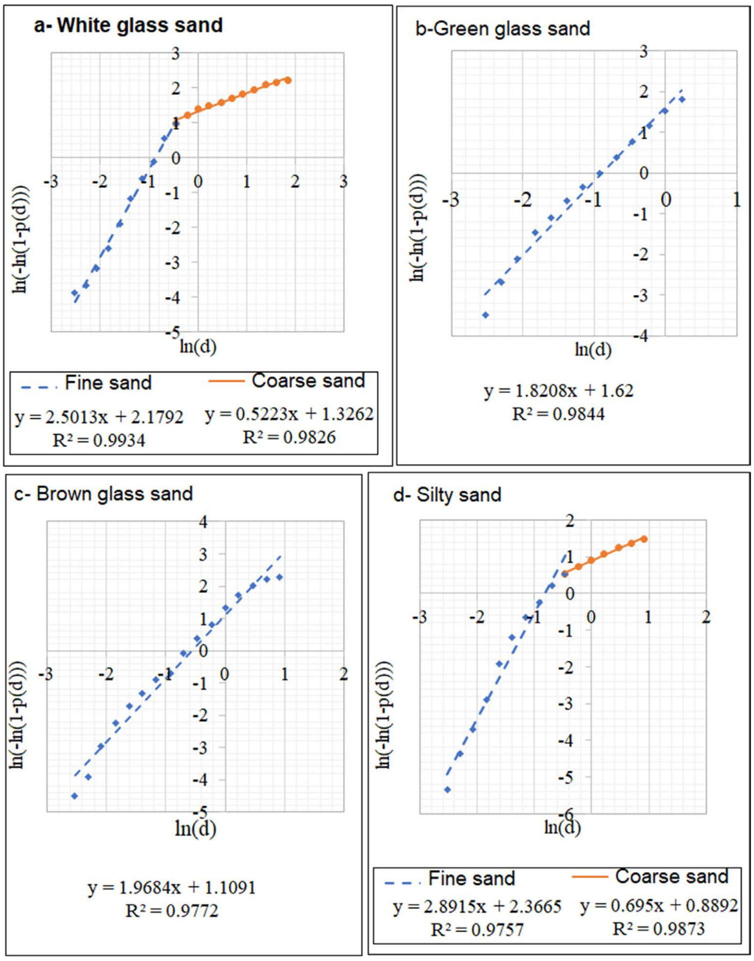

Figure 5. Weibull model applied to the grain size distribution within glass sands and silty sands.

possible to determine the parameters of shape k and scale λ of the Weibull model.

The application of the Weibull model to examine the distribution of grains within the elaborate glass sands made it possible to determine the parameters of shape k, of scale λ and to extract the correlation coefficient R^2 from the linear model (**Table 2**). For silty sand and white glass, a separation into two distinct parts characterized by different straight portions corresponding to the fine fractions of sand with a diameter between 0 and 0.80 mm and the coarse fractions of sand with a diameter between 0.80 mm and 2 mm, is made for a better correlation of the parameters. Thus, a dispersion of grains was observed on white glass sand and silty sand with a predominance of fines. The Weibull model therefore made it possible to separate the granular fractions and to assess the distributions of fines compared to coarse ones. The reliability of the model has been proven by the correlation coefficients of the linear models developed, which vary from 0.98 to 0.99, a value very close to 1 ($R^2 \geq 0.98$).

4. Discussion

While the granular parameters have given the generalized form of the distribution of materials which are of tight and poorly graduated grain sizes, those of the Weibull law have made it possible to explain the distribution of the grains according to the form and the scale of internal distribution (the materials are not homogeneous and have size limits which is the 0.08 mm sieve).

The very high proportion of silica (SiO_2) (>69.11%) and very low proportion of other components (<1.47%) makes it possible to consider the use of glass as aggregates in mortar and concrete.

The four sands studied have an apparent density (dap) between 1.25 and 1.38, and an absolute density (*dab*) of 2.4 to 2.63, which are the densities of common aggregates (2 < *dab* < 3) used in the production of conventional concrete. As for the Modulus of fineness between 1.59 and 1.79, the sands are too fine and therefore they belong to the category of materials not authorized for conventional concrete. Referring to the work of Amey K. B. [18] [20] [21] [22] [23], silty sands and certain silica sands in Togo are generally very fine (*Mf* < 2.1), category f3, granular class 0/1, poorly graded, of tight grain size, very badly classified, of

Table 2. Parameter of the Weibull distribution law of glass and silty sands (parameters of form k and scale λ).

Materials		Shape parameter (k)	Scale parameter (λ)	R^2
silty sand	Fine (<0.80 mm)	2.89	0.44	0.98
	coarse (>0.80 mm)	0.70	0.28	0.99
White glass sand	Fine (<0.80 mm)	2.50	0.42	0.99
	coarse (>0.80 mm)	0.52	0.08	0.98
Green glass sand		1.82	0.41	0.98
Brown glass sand		1.96	0.57	0.98

strong asymmetry towards the small sizes and slightly clayey. These sands are unsuitable for conventional concretes priced globally. These same works have defined areas of use of the different sands according to their properties. Thus, a form of mortar is defined for the areas of use of fine sands ($Mf < 2.1$) in mortar coatings, mortar coatings and smooth-looking areas of building facings.

Glass sands being too fine ($Mf < 2.1$), of tight grain size ($2 < Cu < 5$) and poorly graduated ($Cu < 6$ and $Cc < 1$), it is therefore possible to use them in the same fields, namely: mortar coating, mortar coatings and smooth-looking areas of building facings [18] [20] [21] [22] [23]. These materials having a different mineralogical composition from natural sands (silty and siliceous sands), an in-depth study will therefore be considered to determine a suitable formula.

5. Conclusion

The aim of this work was to contribute to the reduction of pollution in the City of Lomé and its surroundings (Togo) through research into the use of glass waste as building materials in civil engineering and construction. Laboratory tests on glass powders and sands resulting from the grinding of glass waste of the three colors (white, green and brown) made it possible to characterize them and to deduce their granular potential. Glass waste composed largely of silica in a proportion greater than 69.11% can be used as aggregates in mortars and concrete (sands) given the neutral action of silica grains on cement and water. Also their granular characteristics and parameters of the Weibull law, namely the Equivanlent of Sand ($ES > 70\%$), the modulus of fineness ($Mf < 2.1$), the coefficients of Uniformity ($Cu < 6$) and Curvature ($Cc < 1$) and the shape parameter ($k < 5$), make these materials (crushed glass waste) sands that are too fine, of tight grain size, poorly graduated, non-homogeneous. These elaborate glass sands can therefore be used for mortar rendering and building coating work. Given their different mineralogical composition from natural sands (silty and siliceous sands), an in-depth study to find a suitable formulation is necessary for their use in civil engineering works.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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