

Investigation on the Use of Local Sand in Burkina Faso as Standard Sand for Testing Compressive Strength of Cement

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How to cite this paper: Savadogo, N., Traore, Y.B., Nshimiyimana, P. and Ouedraogo, M. (2024) Investigation on the Use of Local Sand in Burkina Faso as Standard Sand for Testing Compressive Strength of Cement. *Open Journal of Applied Sciences*, **14**, 3545-3555.

<https://doi.org/10.4236/ojapps.2024.1412231>

Received: October 2, 2024

Accepted: November 10, 2024

Published: December 17, 2024

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Abstract

The aim of this work is to identify a substitute for imported standardized sand for determining the strength class of cements using local sands. To this end, three (03) local sands (Manga, Kaya and Dori) were characterized and then used to formulate sand mixtures fitting into the granular spindle of standardized sand noted SM1, SM2 and SM3. SM1 is composed of 80% Manga sand plus 20% Dori sand. SM2 is a mixture of 80% of the refusal and 20% of the passing through the 0.25 mm sieve of the Manga sand. SM3 is composed of 77% Manga sand 0.25 mm sieve refusals plus 23% Kaya sand. These sands were used to characterize a CEM II/B-M (P-L) 42.5 R cement by comparing it with the results of a standardized sand noted SS. Characterization of the local sand showed them to be less dense and more absorbent than the standardized sand. Mortars made with SM1, SM2 and SM3 thus have lower workability and bulk densities in the fresh and hardened states than the SS-based mortar, with higher porosities accessible to water after 28 days of curing. Mechanical characterization of the cement gave lower compressive strength values with local sands at 2 and 28 days cure. At 2 days cure, local sands gave 17.42 MPa, 14.68 MPa and 17.13 MPa respectively for SM1, SM2 and SM3, compared with 21.12 MPa for standard sand. At 28 days, mortars based on SM1 and SM3 sands give higher strength values than the 42.5 MPa required by standard NF EN 197-1, with 44.21 MPa and 43.17 MPa respectively, compared with 49.84 MPa for standardized sand. On this basis, correction factors have been proposed for the use of local sands in cement characterization. They nevertheless require repeatability studies before validation.

Keywords

Cements, Standardized Sand, Strength Class, Particle Size Distribution, Water Absorption Coefficient

1. Introduction

In the construction sector, cement concrete is the most widely used material in the world. Today, the world is experiencing galloping urbanization. According to the United Nations Population Division, more than half the world's population lives in cities, and this figure is set to rise to 68% by 2050. In Burkina Faso, the latest 2019 General Census of Population and Housing (RGPH) shows a population of 20,505,155, with an urbanization rate of 26.1%. By comparison, the population stood at 14,017,262 in 2006, with an urbanization rate of 22.7%. According to projections, the country's population could reach 43,432,000 by 2050 [1]. This population growth, combined with rapid urbanization, is creating a strong demand for housing, transportation networks and other essential infrastructure, leading to an increase in construction projects. These needs call for increased consumption of building materials, particularly cement concrete, which is the most widely used material. As a result, the quantities of cement required are enormous. To meet this demand, Burkina Faso currently has six cement plants, producing around 6.7 million tons of cement every year.

One of the essential characteristics of cement is its compressive strength. It is used to classify cements produced in accordance with standard EN 197-1 [2], which categorizes them into three (03) so-called strength classes. This parameter is continuously determined in cement production plants, where the number of tests per volume of cement produced is also prescribed by the standard. Determined on prismatic mortar specimens, the test method for determining the compressive strength of cements is described in standard EN 196-1 [3]. This standard requires the use of standardized sand for making mortar. In Burkina Faso, the standardized sand used for cement characterization is imported entirely from outside the country. Given the large number of tests that have to be carried out, importing this standardized sand has a major impact on cement production costs and the frequency of internal checks, as well as on the carbon footprint of these plants. Like Burkina Faso, several African countries face this problem, and work has already been carried out to find local sand to replace standardized sand [4]-[7]. By definition, standardized sand is natural, siliceous sand, particularly in its finest fractions. It is clean, the grains are generally isometric and rounded in shape, and must comply with normative requirements such as EN 196-1 [3]. Sime [8] worked on the formulation of standardized sand from local Ethiopian sands. She selected three local sands (Dire Dawa, Aleltu and Alage), washed, dried, sieved and separated them into fractions of different sizes, which she then mixed in a predetermined proportion so that they had the granular distribution of stand-

ardized sand. The compressive and flexural strengths of mortar cubes and prisms made with the local sand samples gave lower values than those of standard imported sand. The 2-day results were 18.00 MPa, 14.80 MPa and 5.70 MPa respectively for the Dire Dawa, Aleltu and Alage sands, compared with 19.60 MPa for the standard sand. Thus, two of the three sand samples show a relatively uniform trend in compression test results and could constitute sources of sand that could replace imported standard sand after some processing. Elenga *et al.* [5] characterized the mechanical properties of mortars made from five (05) local sands from Congo Brazzaville. They gave values that were lower than those of standardized sand mortar, but strongly correlated with the latter. The authors then defined simple analytical relationships between the mechanical strengths of mortars made from local sands and those of standardized sand, which would enable them to be used to test cements. In the same line, Diop *et al.* [6] analyzed the possibility of using local Senegalese sands as standardized sands in the mechanical characterization of cements. In the first phase of their study, based on orientation tests, they developed a ternary mixture of two rolled sands and a crushed sand that fulfilled the criteria required for a standardized sand. Their work showed that mortars made with the formulated sand offer strengths equal to those of normal sand. Tests carried out with three (03) different types of cement and in two (02) different laboratories show identical dispersions, which are very low ($CV < 5\%$). Sand formulated in this way enables cements to be classified according to mechanical strength criteria in the same way as standard sand. All these studies have shown that it is possible to find locally sand that can replace standardized sand for the mechanical characterization of cements. However, depending on the local sand studied, granular corrections are often necessary, and correlations must also be defined between the local sand and the standardized sand to enable its use. These adjustments are specific to each local sand and depend on the physico-chemical and mechanical characteristics of the local sands used.

Burkina Faso is also rich in sand resources that could be used to formulate a standardized sand. Local production of this sand would make it possible to promote local materials, reduce the cost of imports and the carbon impact of cementitious products on the environment. Thus, the general objective of this study is to formulate a sand meeting the characteristics of standardized sand based on local sands for the characterization of the strength class of cements according to standard NF EN 196-1 [3]. Specifically, the aim is to characterize local sands in comparison with standardized sand, to formulate sands from mixtures of local sands meeting the characteristics of standardized sand, or to determine correlations between the mechanical strength of cements determined with processed sands and that with standardized sand.

2. Materials and Methods

2.1. Materials

For this study we selected three (03) types of local sand to formulate the standard-

ized sand. The sands studied come from different localities in Burkina Faso, namely Manga in the Centre-South, Dori in the North and Kaya in the Centre-North. The sand from Manga and Kaya was natural river sand, while that from Dori was dune sand. Manga sand is the local sand most widely used in construction in Burkina Faso. After on-site sampling, the sands were oven-dried at 105°C to constant mass. The dry sand obtained was passed through a 2 mm sieve to collect the by-product for further study. Standardized sands formulated from a mixture of these sands were used to characterize a CEM II/B-M (P-L) 42.5 R cement from CIMBURKINA. The water used is potable tap water maintained at a temperature of 20°C.

2.2. Methods

After sampling, the local sands were individually characterized from a physical point of view. Granular distribution was determined by particle size analysis in accordance with EN 933-3 [9], bulk density in accordance with EN 1097-3 [10], specific density and water absorption coefficient in accordance with EN 1097-6 [11], and cleanliness by sand equivalent test in accordance with EN 933-8+A1 [12].

The preparation of normal sand from these local sands was based essentially on the correction of local sand particle size distribution. Different mixtures were prepared to obtain sands with a particle size curve in accordance with standard EN 196-1 [3]. Three (03) mixes were selected: two (02) are different sand mixes and one (01) is obtained by mixing precise proportions of different rejections of the same sand after sieving. It should be noted that Manga sand was used as the base sand in all the mixes selected.

The sands thus formulated were used to make normal mortars in accordance with standard EN 196-1 [3], whose characteristics in the fresh (physical) and hardened (physical and mechanical) states were analyzed. In the hardened state, tests were carried out on $4 \times 4 \times 16 \text{ cm}^3$ prismatic specimens made to standard EN 196-1 [3] and kept in a water basin in a room regulated at $20^\circ\text{C} \pm 1^\circ\text{C}$ until the age of the test. Specimens are tested after 2 and 28 days of curing in accordance with EN 197-1 [2].

3. Results

3.1. Sand Characteristics

Table 1 shows the results of the physical characterization of the selected sands compared with imported standardized sand. The standard sand has a bulk and absolute density of 1.70 g/cm^3 and 2.63 g/cm^3 respectively. Its absorption coefficient is 0.2%. It is a clean sand with a sand equivalent of 93%. In terms of bulk and absolute density, Manga sand is close to standardized sand, with values of 1.59 g/cm^3 and 2.63 g/cm^3 for bulk and absolute density respectively. The water absorption coefficient of 2.97%, on the other hand, is higher than that of standardized sand. In its natural state, Manga sand is less clean than standardized sand,

with a sand equivalent of 81.64%. It was then washed and dried before use. The apparent and absolute densities of Dori sand are 1.35 g/cm³ and 2.63 g/cm³ respectively. It therefore has a lower bulk density than standardized sand, but the same absolute density. It is as clean as standardized sand, with a sand equivalent of 94.16%. Its absorption coefficient, however, is higher than that of standardized sand, at 1.92%. Kaya sand has a bulk density of 1.47 g/cm³ and an absolute density of 2.56 g/cm³. It is the sand with the highest clay content of the three (03) sands studied, with a sand equivalent of 71.91%. It was also washed before use. Its absorption coefficient is 2.30%. Based on the absorption coefficients of local sands, they appear to have a rather high level of intragranular porosity compared with standard sand.

Table 1. Physical characteristics of sand.

Sand	Manga	Dori	Kaya	Standard
Bulk density (g/cm³)	1.59 ± 0.020	1.35 ± 0.011	1.47 ± 0.0226	1.70
Absolute density (g/cm³)	2.63 ± 0.013	2.63 ± 0.004	2.56 ± 0.006	2.63
Absorption coefficient (%)	2.97 ± 0.764	1.92 ± 0.855	2.30 ± 0.715	0.2
Sand equivalent (%)	81.64 ± 0.54	94.16 ± 0.421	71.91 ± 0.518	93

The particle size distribution curves for the different sands are shown in **Figure 1**. It can be seen that the curve for imported standardized sand fits perfectly into the grading range of standard NF EN 196-1 [3]. Its fineness modulus is 2.63, its grain size uniform and well graded, with a Cu uniformity coefficient of 0.47 and a Cc curvature coefficient of 1.37. Grain size analysis of the Manga sand shows that the coarse part of the sand between 0.8mm and 2mm fits into the spindle, but the fine part below 0.8mm lies above the upper limit of the spindle. Manga sand has a lower percentage of fine elements below 0.8mm than standard sand. It is therefore coarser than standardized sand, with a fineness modulus of 3.01. Its grain size is also uniform and well graded, with a Cu uniformity coefficient of 0.5 and a Cc curvature coefficient of 1.02. Dori sand is a dune sand, and the particle size distribution curve shows that it is a very fine sand with a grain size of 0/0.5, which does not at all fit into the spindle of standardized sand. Its modulus of fineness is 1.59 and its grain size is uniform and poorly graded, with uniformity coefficients Cu of 1.74 and curvature coefficients Cc of 0.98. Kaya sand has a grain size similar to that of Dori sand, except that its curve fits more or less well into the spindle between grain sizes 0.1 and 0.2mm, unlike that of Dori. Its modulus of fineness is 1.59, with a uniform, poorly graded grain size whose coefficient of uniformity Cu is 0.71 and that of curvature Cc is 0.99.

None of the local sands therefore have the characteristics of a standardized sand. Based on the results of the particle size analyses, we have made corrections to obtain sand mixtures whose curves fit within the particle size range of standardized sand.

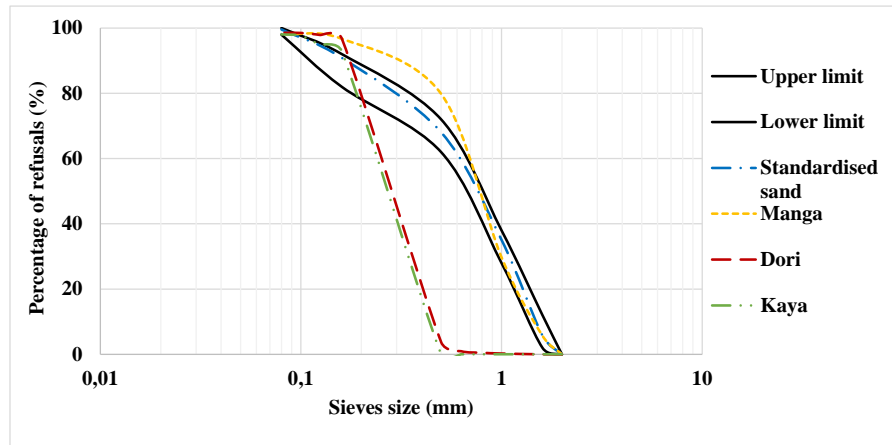


Figure 1. Granulometric curves for Manga, Dori and Kaya sand compared with sand standardized in the EN 196-1 range.

3.2. Correction of Local Sand Particle Size Distribution

Grain size correction is carried out experimentally by mixing Manga sand (coarse) with fine sand in increasing proportions, in order to obtain a grain size within the range specified in standard NF EN 196-1 [3]. After washing and drying the sand from Manga and Kaya, we were able to identify three sand mixtures, SM1, SM2 and SM3, whose particle size curves fall within the standardized sand spindle (Figure 2). The SM1 mixture is made up of 80% Manga sand and 20% Dori sand. SM1 has a fineness modulus of 2.67 and uniformity and curvature coefficients of 0.34 and 1.20 respectively. The SM2 mixture is made up of 80% refusal and 20% passing through a 0.25 mm sieve of Manga sand. It has a fineness modulus of 2.72 and uniformity and curvature coefficients of 0.39 and 1.10 respectively. The SM3

Table 2. Identification code and composition of formulated sands.

SS	SM1	SM2	SM3
Standard sand	80 % Manga + 20 % Dori	80% refusal on the 0.25 mm sieve of Manga + 20% passing the 0.25 mm sieve of Manga	77% refusal on the 0.25 mm sieve of Manga + 23% Kaya

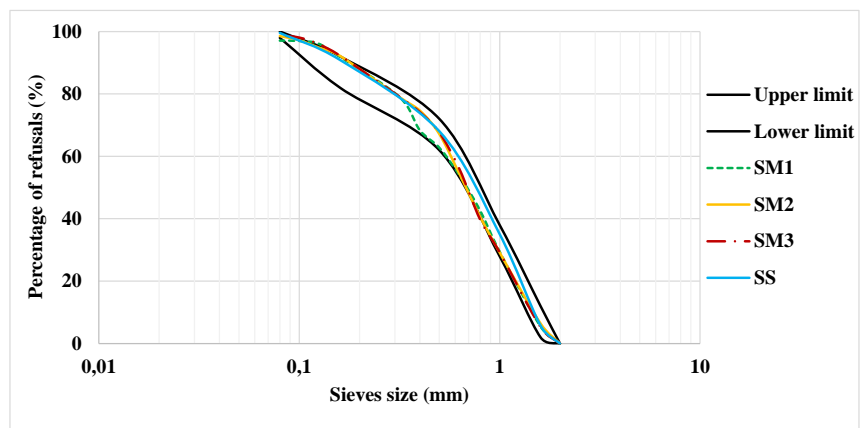


Figure 2. Particle size distribution of sand mixes produced in the EN 196-1 range.

mixture is made up of 77% Manga sand 0.25mm sieve refusal and 23% Kaya sand. It has a fineness modulus of 2.78 and uniformity and curvature coefficients of 0.42 and 1.21 respectively. All the sand mixes produced have a coarser particle size than standard sand. Their percentage of particle sizes between 0.5 and 2mm is higher than that of standardized sand. This is due to the fact that all the mixtures contain a majority of Manga sand, which is much coarser than standardized sand. **Table 2** shows the composition of the various sand mixes.

3.3. Mortar Characteristics

3.3.1. Slump and Fresh Density

The slump and fresh density results for the different mortars are shown in **Figure 3**. Slump measurements show that mortars based on local sands have a much lower slump than the reference mortar based on standardized sand. From a value of 32.6 mm with standardized sand, SM1, SM2 and SM3 have values of 6.6 mm, 2.3 mm and 5.3 mm respectively. The low workability of mortars based on local sands is explained by their water absorption capacity, which is very high compared to that of standard sand. As a result, much of the mixing water is absorbed by these sands and can no longer be mobilized to fluidize the mix. According to Ruan *et al.* [13], this low workability can also be explained by the fact that the local Manga sand used in all mixes is coarser than standardized sand. In their study, they showed that increasing the number of coarse particles in a sand increases water consumption. This explains why the SM2 sand, which consists solely of Manga sand, has the lowest slump.

We also note that mortars based on processed sands have lower densities than mortar with standardized sand. The values obtained are 1.57 g/cm³, 1.39 g/cm³, 1.31 g/cm³ and 1.51 g/cm³ respectively for SS, SM1, SM2 and SM3 sand. This drop in density could be explained on the one hand by the low bulk density of local sands, and on the other by the low workability of these mortars compared with

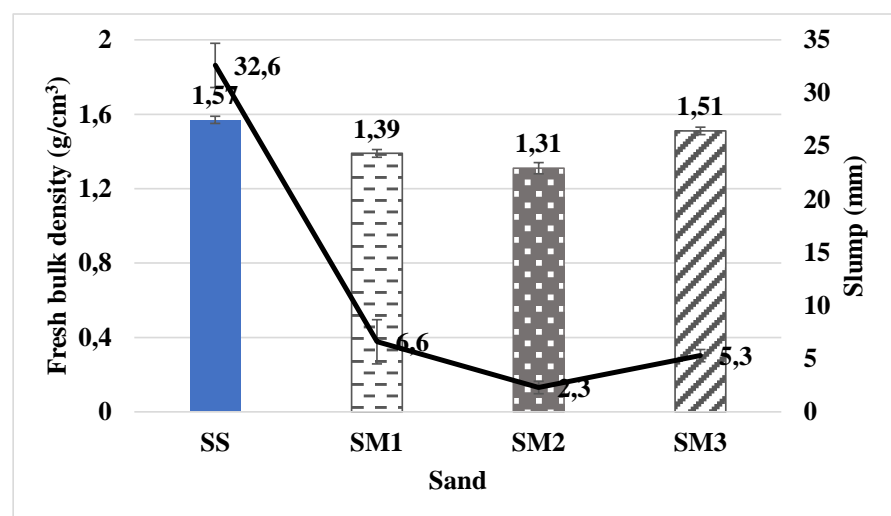


Figure 3. Slump and fresh bulk density of mortars based on formulated sands compared with standardized sand.

standardized sand mortar. This lower workability affects mortar placement in molds and reduces the compactness of cast mortars. The fact that local sands are coarser than standard sand could also explain this drop in density. Indeed, the fineness modulus of the sands are 2.63, 2.67, 2.72 and 2.78 respectively for SS, SM1, SM2 and SM3. Local sands would lack the fine particles needed for better grain stacking to achieve higher density.

3.3.2. Hardened Density and Water-Accessible Porosity

The densities of the various mortars in the hardened state were determined after drying the specimens at 2 and 28 days of curing. The results are shown in **Figure 4**. There was a slight increase in density of around 7% on average between 2 and 28 days for all mortars, attributable to further hydration of the cement between the two times [14]. The results also show that curing time has no influence on the density evolution of mortars with local sands compared to standardized sand. Indeed, mortar with standardized sand is always slightly denser than other mortars with local sand. Mortar density rises from 2.3 g/cm³, 2.2 g/cm³, 2.17 g/cm³ and 2.26 g/cm³ for 2 days' curing to 2.37 g/cm³, 2.28 g/cm³, 2.26 g/cm³ and 2.3 g/cm³ for 28 days' curing for SS, SM1, SM2 and SM3 sands respectively. The local sand mortars SM1, SM2 and SM3 have water-accessible porosities of 9.65%, 10.28% and 10% respectively, and are therefore higher than the reference mortar based on SS standard sand, which has a porosity of 9.59%. This may be explained by the fact that local sand mixtures are coarser than standard sand. Indeed, the literature shows that a better granular distribution favors mortar compaction in the fresh state, thus reducing porosity in the hardened state [13]. The difference in porosity could justify the slight drop in density observed between local sand mortars and the control mortar in **Figure 4**.

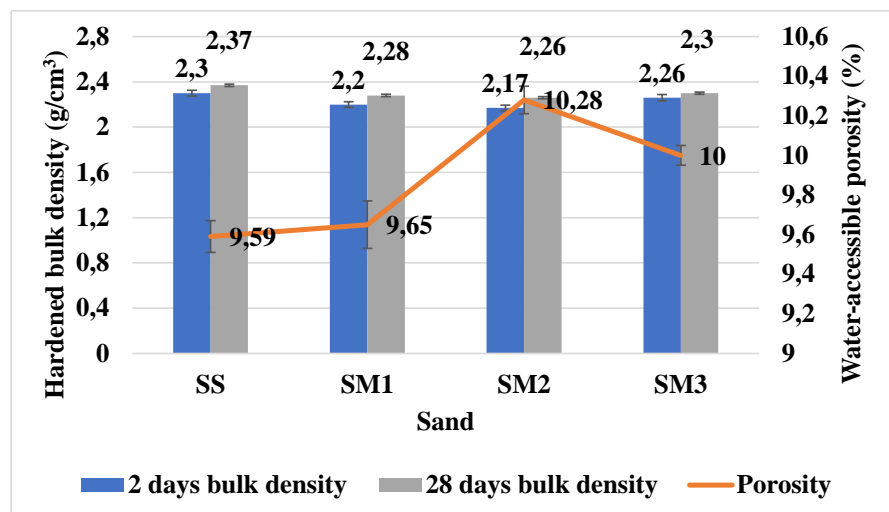


Figure 4. 2-day and 28-day hardened bulk density and water-accessible porosity of mortars.

3.3.3. Compressive Strength

The compressive strengths of mortar specimens at 2 and 28 days are shown in

Figure 5. Local sand-based mortars show lower compressive strengths than standardized sand mortar at 2 and 28 days curing. This may be explained by the higher porosity of these mortars compared to standard sand mortar [4] [15]. Indeed, the higher the porosity, the lower the compressive strength of the mortar. Mortar based on SM2 sand thus has the highest porosity and the lowest compressive strength.

At 2 days, the compressive strengths of SM1, SM2 and SM3 were 17.42 MPa, 14.68 MPa and 17.13 MPa respectively, compared with 21.12 MPa for standard sand. The low 2-day mechanical strength values achieved with local sands could be explained by the absorption of much of the mixing water by the grains of these sands, which can no longer be mobilized for cement hydration at a young age. At 28 days, the compressive strength of the mortars maintains the same trend as at 2 days, where the best value is obtained by the mortar based on SS standardized sand with 49.84 MPa. With local sand mixes SM1, SM2 and SM3, the compressive strengths obtained are 44.21 MPa, 37.32 MPa and 43.17 MPa respectively. The SM1 and SM3 mixes achieved the expected strength for the type of cement used. Continued hydration between 2 and 28 days enabled M1 and M3 mortars to achieve sufficient densification and consequent improvement in strength. The SM2 sand-based mortar, on the other hand, gave a strength of 37.32 MPa, which is below the expected value. The coarse grading of the local sand used in this mix may explain this trend [13].

The ratios between the compressive strengths of mortars based on local sands and those of standardized sand were determined (see **Table 3**). It can be seen that the SM1 and SM3 sand mixes give the best results, with ratios of over 80% of the strength obtained with standard sand. These ratios could be used as a correction factor, when SM1 and SM3 mixes are used to characterize cements. However, a repeatability test should be carried out to validate these correction factors, taking into account other cements.

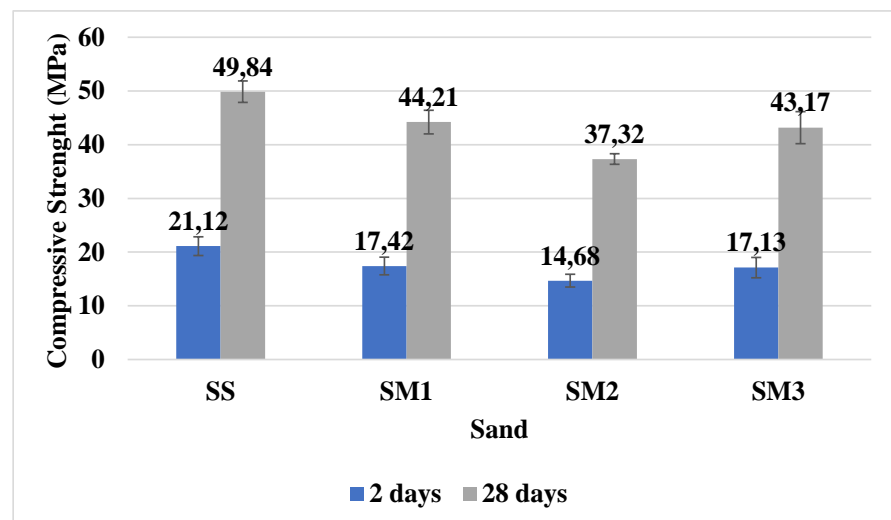


Figure 5. Compressive strength of mortar at 2 and 28 days.

Table 3. Percentage deviation from the standard sand.

Sand	2 days	28 days
SS	100%	100%
SM1	82%	88%
SM2	69%	74%
SM3	81%	86%

4. Conclusions

The aim of this preliminary study was to formulate a sand meeting the characteristics of standardized sand from local sands that could be used to characterize the strength class of cements. The results obtained were as follows:

- The local sands studied have high water absorption coefficients compared with standard sand, and this has an impact on the workability of mortars in the fresh state.
- The apparent densities of local sands are low compared with standard sand, resulting in mortars with lower densities in the fresh and hardened states.
- The water-accessible porosity of mortars based on local sands is higher than that of those based on standardized sand, due to the low workability obtained with these mortars.
- For best mechanical results, fine sand should be mixed with Manga sand. In fact, of the three mixes studied, SM1 and SM3, made up of Manga sand and Dori and Kaya fine sand respectively, give values of over 80% of the strength given by standardized sand for 2 and 28 days of curing.
- Used to assess the mechanical strength of cements, these sands give lower values than those obtained with standardized sand.
- The ratios between the compressive strengths of mortars based on local sands and those of standardized sand have been determined. However, a repeatability study is required to validate these ratios and enable local sands to be used for the mechanical characterization of cements.

Ultimately, the results of this study show that local sand from Manga has the potential to be used as a standardized sand. Before use, it should be amended with around 20% fine sand with a fineness modulus of around 1.6. To validate this potential, the work should continue with a repeatability study by characterizing various cements with this sand, and a reproducibility study by repeating the characterizations in various laboratories.

Conflicts of Interest

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

References

- [1] National Institute of Statistics and Demography (2022) 5th General Population and Housing Census 2019. National Census Committee, National Institute of Statistics

and Demography.

- [2] Standard NF EN 197-1 (2012) Cement—Part 1: Composition, Specifications and Conformity Criteria for Common Cements. French Association for Standardization (AFNOR).
- [3] Standard EN 196-1 (2016) Methods of Testing Cement—Part 1: Determination of Strengths. French Association for Standardization (AFNOR).
- [4] Pantazopoulou, S.J. and Mills, R.H. (1995) Microstructural Aspects of the Mechanical Response of Plain Concrete. *Materials Journal*, **92**, 605-616.
- [5] Elenga, R.G., Ahouet, L., Itoua, N., Konda, S. and Mouengue, G.R. (2018) Propriétés des sables utilisés dans la construction au Congo et formulation d'un sable normalisé local. *Revue RAMReS—Sciences Appliquées et de l'Ingénieur*, **3**, 7-13.
- [6] Diop, M.B., Esteoule, J., Bouguerra, A. and Lo, P.G. (2001) Essais systématiques de validation de formulations de sable sénégalais pour l'élaboration d'un sable normalisé. *Bulletin of Engineering Geology and the Environment*, **61**, 79-86.
<https://doi.org/10.1007/s100640100136>
- [7] Pratiwi, W., Karim, G.A. and Rachmawati, T. (2020) Local Silica Sand as a Substitute for Standard Ottawa Sand in Testing of Cement Mortar. *Materials Science Forum*, **1000**, 220-226. <https://doi.org/10.4028/www.scientific.net/msf.1000.220>
- [8] Girma Sime, L. (2020) Study on the Compressive Strength of Hydraulic Cement Mortars about Sand Deposits in Ethiopia. *International Journal of Research Publications*, **60**, 51-61. <https://doi.org/10.47119/ijrp100601920201431>
- [9] Standard EN 933-3 (2012) Tests to Determine the Geometric Characteristics of Aggregates—Part 3: Determination of the Shape of Aggregates—Flattening Coefficient. Association Française de Normalisation (AFNOR).
- [10] Standard EN 1097-3 (1998) Tests to Determine the Mechanical and Physical Characteristics of Aggregates—Part 3: Method for Determining Bulk Density and Intergranular Porosity. French Association for Standardization (AFNOR).
- [11] Standard EN 1097-6 (2022) Tests to Determine the Mechanical and Physical Characteristics of Aggregates—Part 6: Determination of Density and Water Absorption Coefficient. French Association for Standardization (AFNOR).
- [12] Standard EN 933-8+A1 (2015) Tests to Determine the Geometrical Characteristics of Aggregates—Part 8: Evaluation of Fines-Sand Equivalent. French Association for Standardization (AFNOR).
- [13] Ferreira, R.L.S., Medeiros, M., Pereira, J.E.S., Henriques, G.F., Tavares, J.C., Marvila, M.T., *et al.* (2023) Effects of Particle Size Distribution of Standard Sands on the Physical-Mechanical Properties of Mortars. *Materials*, **16**, Article No. 844.
<https://doi.org/10.3390/ma16020844>
- [14] Savadogo, N., Messan, A., Hannawi, K., Prince Agbodjan, W. and Tsobnang, F. (2020) Durability of Mortar Containing Coal Bottom Ash as a Partial Cementitious Resource. *Sustainability*, **12**, Article No. 8089. <https://doi.org/10.3390/su12198089>
- [15] Chen, X., Wu, S. and Zhou, J. (2013) Influence of Porosity on Compressive and Tensile Strength of Cement Mortar. *Construction and Building Materials*, **40**, 869-874.
<https://doi.org/10.1016/j.conbuildmat.2012.11.072>