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Evaluation of the Properties of Local Sands Used in a Cement Mortar and in the Formulation of a Standard Sand to Test the Class of Cements

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Abstract: The aim of this work was to provide a better alternative to the problems of importing standardized sand and to make good use of local sand to produce a quality mortar. Sand samples taken from various locations in the city of Brazzaville were subjected to a number of laboratory tests and to two types of mortar formulation. The results obtained show that local sands (S1-S8) in their natural state are finer and cannot be used as standard sand for cement quality control. However, some local sands can be used in the manufacture of masonry mortar. The mechanical properties of mortars made with these sands are lower than those of mortars made with standard sand, but are strongly correlated with the latter. The reformulation of local sands (S1-S8) mixed with crushed sand S9 considerably improves the mechanical properties of the mortar, which are identical to those of standard sand. The mechanical strength of mortar based on local S3 sand enriched with crusher sand (0/5) is greater than that obtained with standard sand. Reformulated sand can be used as standard sand for cement quality control. The relationship in formulation 2 between the mechanical strength of mortar based on improved local S3 sand and that of standard sand can be used to test cements. Several studies show that it is sometimes difficult to obtain the expected compressive strength of a given cement with standard sand. For the 32.5R cement used, the sands (S1-S3, S5, S6) improved to crushed sand with formulation 2, produce standardized sands for testing cements.

Keywords: Standard Sand, Mortar, Crushed Sand, Normative Zones, Particle Seize Analysis, Sand Equivalent

1. Introduction

The ever-increasing need to build basic infrastructure as part of the accelerated urbanization of cities in developing countries is leading to considerable consumption of construction materials (cement, sand). Existing resources are being depleted at an increasing rate and, in some cases, populations are settling on material deposits, prompting researchers to look for alternative materials. These materials, consumed at a rate of 5% per year [1] for cement and 5.5% [2] for sand, require quality or categorization tests before being used to guarantee the safety of the works. The main concern is the current situation in the city of Brazzaville, which is plagued by erosion, leading to silting up of neighborhoods and waterways. The depletion of natural sandpits can be compensated for by sand from erosion, watercourses and the crushing of rock materials. Sustainable urban development is not only the future of the construction industry, but also the savior of the environment. However, in order to preserve natural resources and reduce the sand produced by erosion and rock crushing, more precautions need to be taken. Over the past two decades, demand for cement in sub-Saharan Africa has grown by 5-12% per year [1, 2]. However, to test cement, African countries import standardized sand, specified at regional level by EN 196-1 [3] for Europe, ASTM C778-21 [4] for the Americas and ISO 650 [5] for India. The total use of foreign standards does not enhance the value of local materials and does not take into account the specific features of the local environment [6]. In other words, the use of standards requires equipment and chemicals for laboratory testing, or material such as standardized sand used for cement testing. Standard sand is often very expensive and sometimes unavailable on the local market, so compliance tests are not always carried out. The lack of qualified technicians to carry out laboratory tests before using cement can have an impact on the quality assurance of the work. Most African countries use the NF EN 196-1 standard [3] and imported standard sands to determine cement quality. These imports not only pose an economic problem in terms of cost, but also sometimes lead to a shortage of foreign currency. Added to this is the fact that the Republic of Congo, for example, does not have its own standards, unlike countries such as South Africa, France, America, etc... To reduce the cost and environmental impact of quality cement construction, the use of non-conventional local sands (recycled or natural) can be an advantage if it is preceded by the necessary studies [7-9]. In fact, some studies have shown that certain local materials, although they do not meet the specifications of European or American standards, have proved to be good in use, whereas some constructions that comply with these same standards have deteriorated prematurely [3, 7-11]. These standards have been designed to take into account the behavior of materials in the local environment. Standardized natural sand from France has round grains, a silica content of at least 98% and standardized granularity [3]. The Republic of Congo, like many African countries, has huge sand deposits [7] that could be used to formulate standardized sand. Local production of standardized sand would make it possible to make the most of local sands, reduce the cost of laboratory testing and create jobs. Several studies on the formulation of standard sand have been carried out. M. Diop et al., 2002 [12] obtained a local standard sand by mixing three types of sand so that the mixture fell within the particle size range of the European standard [3] and offered the same strength as imported standard sand [13]. On the other hand, R. G. Elenga et al., 2019 [6] used mathematical models to compare the strength of local sand with that of imported standard sand. Studies on standard sand are rare in Africa and the subject remains open.

The aim of this study is to characterize the sands commonly used in construction and to find, among them or their mixtures, a substitute for standard imported sand. To do this, the properties of the sand, the strength class of the cement and mortar and the relationships between the intrinsic properties of the mortars will be determined.

2. Materials and Method

2.1. Materials

The local sands used were collected from various locations, as shown in Table 1 below. In what follows, the sand collection sites will be designated by the letter S representing the sand, followed by a number, as shown in Table 1. They are among the sands most commonly used for construction in the city of Brazzaville, capital of the Republic of Congo. Three sands (S2, S3, S7) were extracted from the Congo River and (S2, S3) the S7 quarry (S7) respectively. Three sands (S5, S6, S8) came from erosion in three districts of the city of Brazzaville and two sands (S1, S4) were taken from natural sandpits. The sand (S9) is obtained after crushing the S9 sandstone, taken from the south of the city of Brazzaville.

***Table 1.** Geographical location of sampling sites.*

Site	Sample	Localization
Matéssama	S1	15°16.05'E; 04°06.04'S
Fleuve	S2	15°22.56'E; 04°17.35'S
Yoro	S3	15°22.56'E; 04°17.24'S
Académie	S4	15°18.24'E; 04°08.14'S
Nkombo	S5	15°20.49'E; 04°17.38'S
Mfilou	S6	15°19.74'E; 04°20.15'S
Djoué	S7	15°17.35'E; 04°19.21'S
Mboualé	S8	15°17.46'E; 04°12.21'S
Concassé	S9	15°30.43'E; 04°29.36'S

The cement used is class 32.5R type CEMII, whose physic chemical characteristics are presented in table 2.

***Table 2.** Physic chemical characteristics of the cement.*

Properties	AV	LV	Standards
Start of plug	140 min	$\geq 75\ min$	NF EN 196-3
Mixing water	26.56%	----	NF EN 196-3
Chatelier	2.31mm	$< 10mm$	NF EN 196-3
SSB (Finesse)	4159	----	NF EN 196-6
Content SO_3	2.1	≤ 3.5	NF EN 196-2
Fire loss	8.4	----	NF EN 196-2
Chloride content	0.05%	≤ 0.10	NF EN 196-2

(AV - average values; LV - limit values)

2.2. Methods

The particle size analysis of the various sands was carried out in accordance with standard NE 933-1 [14]. For each sample, 200 g, previously steamed for 24 h at 105°C, were passed through a series of mechanized 0.08, 0.125, 0.16, 0.25, 0.5, 1, 1.6 and 2-mm sieves. Sand equivalent is an indicator used in geotechnical engineering to characterize the cleanliness of sand. It indicates the content of fines (elements with a diameter of less than 0.5 mm), essentially of clay, vegetable or organic origin on the surface of the grains, defined in accordance with standard NF EN 933-8 [15].

The blue value of the soil (BVS) test characterizes the activity of the clays contained in the soil and also assesses the fine particles of clay origin contained in the sands. It reports the surface activity of the clays, organic matter and iron hydroxides contained in the fines, in accordance with standard NF P 94-068 [16].

Density is used to match masses and volumes. It can also be used to determine the weight of the material in accordance with ISO/TS 17892-4 [17].

Absolute density is the ratio between the mass of the material and its actual volume, minus the volume of the pores (open and closed). It is equal to the real density in the case of non-porous materials and is defined in accordance with standard P18-558 [18].

The absorption coefficient, defined as the ratio between the mass of water absorbed by the sample after soaking in water and the dry mass of the sample. This soaking is obtained by immersing the sample in water for 24 hours at 20°C, measured in accordance with standard NF P 18-555 [19]. The mass organic matter content of a natural soil sample is measured in accordance with standard NF P94-055 [20]. The modulus of fineness and their permissible ranges, uniformity coefficients and curvature coefficients are defined in accordance with the respective standards EN 196-1 [3] and NF P18-540 [21]. The uniformity coefficients Cu and curvature coefficients Cc were used to characterize the grain size of the sands, according to the following formulae:

$$C_U = \frac{D_{60}}{D_{10}} \quad (1)$$

$$CC = \frac{D_{30}}{D_{10} * D_{60}} \quad (2)$$

where Dx is the particle size corresponding to x% by weight of the sieve. The specific surface area of sand refers to the actual surface area of a soil particle, as opposed to its apparent surface area. It is of great importance for phenomena involving surfaces, such as the adsorption and absorption of water. The specific surface area of a soil is controlled in part by the particle size distribution. This parameter has been used to interpret the physical properties of sands. In addition, by knowing the blue value of soil BVS (g/100g) of the sand, it is possible to determine the specific surface area using the following formula:

$$SSA\left(\frac{m^2}{g}\right) = 20.93 * BVS \quad (3)$$

with the SSA (m^2/g) - specific surface area, and *BVS* (g/100g) - the blue value of soil.

The cation exchange capacity is the number of cations in the double layer that can be easily replaced or exchanged by other cations per 100 g of soil. It can be determined from the blue value of soil (BVS) using the following formula:

$$CEC\left(\frac{meq}{100g}\right) = BVS * \frac{1000}{374} \quad (4)$$

with CEC (meq/100g) - cation exchange capacity. Specific surface area (SSA) and cation exchange capacity (CEC) do not change in the presence of water content.

EN 196-1 [3], ASTM C778 [4], ISO 650 [5] are used to select local sands that match the standard sand range. EN 196-1 [3], ASTM C144 [22, 23], SABS 1090 [23], BS 1200 [24] are used to select local sands that correspond to the range of sands used in the manufacture of cement mortars.

Origin Pro 2019b software was used in the process of implementing the relationships between standard sand and local natural sands. The mathematical model selected is the one with the highest coefficient of determination R^2 and the lowest Chi - sqr (χ^2). The Chi - sqr (χ^2) - is used to test the independence between two random variables.

The mortars were formulated in two ways:

Formulation 1:

Sand/Cement ratio = 3 and Water/Cement = 0.5

Formulation 2:

Sand/Cement ratio = 2.25 and Water/Cement = 0.5

Formulation 1 is the one generally used to formulate standard mortars. However, as the results were not satisfactory, formulation 1 was modified by reducing the mass of sand by 25%, leading to formulation 2. Samples of each of the two formulas were kept in water for 7, 14, 21 and 28 days before being crushed.

3. Results and Discussion

3.1. Granulometry

With the exception of the S9 sand, all the other sands examined have predominantly broken matte round grains, indicating aeolian transport. Giresse et al., (1990) [25] explain this broken grain morphology by the fact that the sands of the "Bateke" series have already undergone reworking. However, to assess sand quality, several standards rely on particle size analysis EN 196-1 [3], ASTM C778-21 [4].

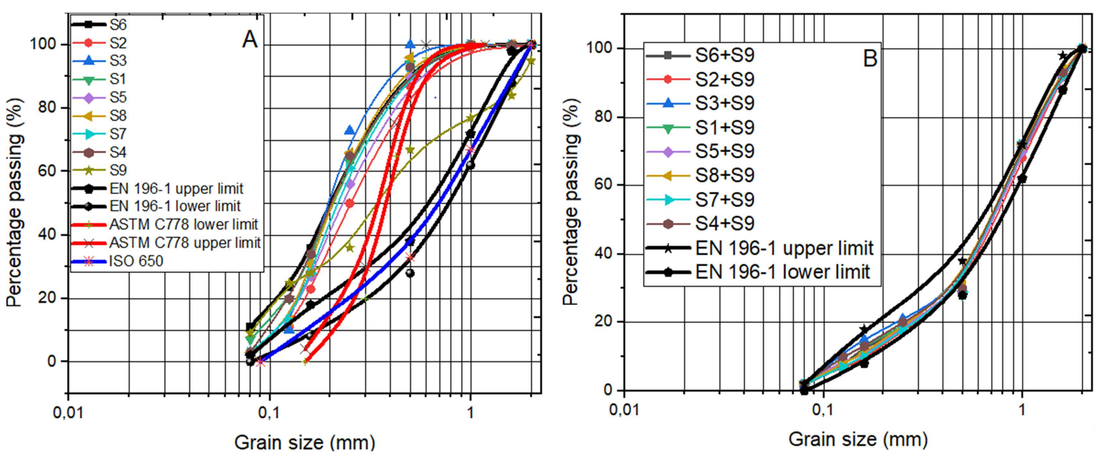

Figure 1. *Sieve size curves for local sands and normative curves for standard sands.*

Figure 1A shows the sieve-size curves of the nine (9) raw sands studied and the reference curves of European standard EN 196-1 [3], American standard ASTM C778 [4]. All the grading curves for the nine natural sands used do not incorporate any normative range. In other words, the particle size curves of the EN 196-1 [3], ASTM C778-21 [4] standards are not compatible with the local sands studied. These curves show concavities pointing downwards, suggesting that these sands are finer than standard sands. With the exception of sand S9, which contains 5 mm grains, the other eight sands have only 1 mm grains. These sands all have more or less the same appearance, which can be explained by the fact that the sands (S1-S8) have the same eolian origin [26, 27]. Figure 1B, on the other hand, shows that the local sands improve with the addition of crushed sandstone (S9), thus entering the particle size range of standard EN 196-1 [3]. This time, the concavity is oriented upwards, reflecting the presence of coarse elements in the sands of the mixture.

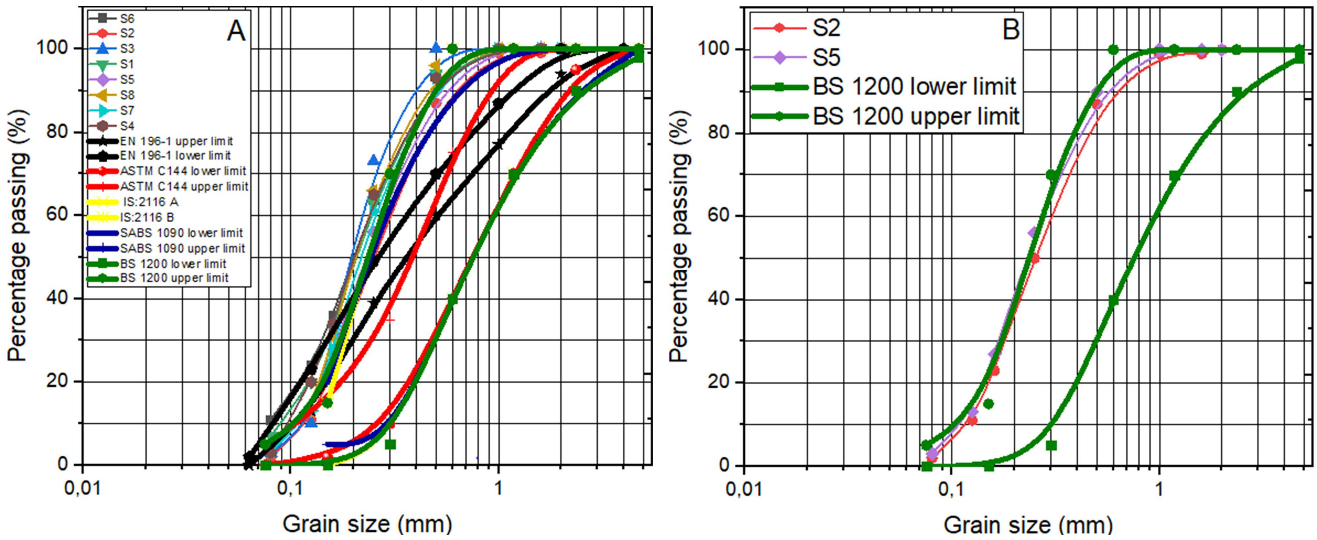

Figure 2. *Grading curves for local sands and normative ranges for the manufacture of masonry mortars.*

In Figure 2A, the local sands studied do not incorporate the normative spindles, whereas the S2 and S5 sands in Figure 2B comply with British Standard BS 1200 [22] for mortar manufacture [13].

In Figures 1A and 2A, sands S2 and S3 are close to sand S8 located upstream on the right bank of the Congo River. In other words, dredged sands S2 and S3 are largely the result of sand erosion in the hills north of the city of Brazzaville due to the destruction of vegetation cover by human activity. The particle size analysis of the three sands corresponds to that of podzol-type sands for some and to that of eolian origin for the cover sands S5, S6 and S8 [6]. The physical characteristics of the local sands are presented in Table 3.

Table 3. *Physical characteristics of local sands.*

Sand	D	P	SE	BVS	OM	WA	BD	AD	SSA	CEC
S1	0.23	7	90.32	0.025	0.32	0.19	1.77	2.60	0.52	0.67
S2	0.28	3	96.23	0.025	0.08	0.33	1.57	2.63	0.52	0.67
S3	0.21	3	96.44	0.025	0.09	0.16	1.5	2.62	0.52	0.67
S4	0.24	3	88.93	0.050	0.35	0.22	1.78	2.61	1.05	0.13
S5	0.25	3	91.24	0.025	0.14	0.42	1.76	2.61	0.52	0.67
S6	0.23	11	78.45	0.075	0.38	0.38	1.48	2.61	1.57	0.2
S7	0.24	3	95.22	0.025	0.09	0.27	1.58	2.58	0.52	0.67
S8	0.24	3	84.01	0.050	0.47	0.56	1.65	2.61	1.05	0.13
S9	0.57	9	65	0.1	0.02	3.42	1.48	2.61	2.09	0.27

D (mm) – average diameter; P (%) – passing through the sieve 0.08; SE (%) – sand equivalent; BVS (g/100g) - blue value of soil; OM (%) - organic matter; WA (%) - water absorption; BD (T/m^3) - bulk density; AD (T/m^3) - absolute density; SSA (m^2/g) - Specific surface area; CEC (meq/100g) - Cation exchange capacity.

With the exception of sand S9, which has the BVS (0.1), the local sands (S1-S8) studied are insensitive to water, (the blue value soil is less than 0.1) i.e., the sands are devoid of clay. Sands S9 and S6 are clean with respective sand equivalents SE (65-78.45%), higher than the minimum of 60%, but lower than the maximum of 80%. S6 and S9 sands are ideal for high quality concrete. Local sands S1-S5, S7 and S8 are very clean, with SE sand equivalents (84.01-96.44%) of over 80%. The almost total absence of clay or silt fines can lead to a lack of plasticity in the concrete, which can be remedied by adding water or plasticizers. However, the addition of water reduces the short-term strength of the concrete. The results of the sand equivalents are in line with those of the BVS, i.e., these sands are free of fine particles. Crusher sand S9 has the highest water absorption WA (3.42%) compared to the fines content of sand P (11%), but is not clayey. Their bulk densities BD (1.48-1.8 T/m^3) show that the soils present are indeed sands that do not fall within the permitted range AD (2.63-267 T/m^3) [26]. The absolute densities are very close, meaning that the mineralogy and chemical composition of these local raw sands may be similar. However, the bulk densities of sands S3, S6 and S9 are similar to those reported for dune sands [26, 28]. Sands S1-S3, S5, S7 have specific surface area SSA (0.52 m^2/g) and cation exchange capacity CEC (0.67 meq/100g). Sands S4, S6, S8, S9 have higher specific surface areas (1.05-2.09 m^2/g) and cation exchange capacities of CEC (0,13-0,27 meq/100g).

Table 4. *Properties of natural local sands.*

Sand	FM	UC	CC	GR
S1	1.23	2.67	1.04	3.72
S2	1.53	2.5	0.9	3.5
S3	1.17	1.69	0.8	2.62
S4	1.22	2.3	0.98	3.72
S5	1.43	2.45	0.97	3.46
S6	1.18	3.29	1.28	4.44
S7	1.33	2.27	0.93	3.23
S8	1.25	2.09	1.01	3.0
S9	1.8	6.0	0.6	17,7
lower limit	2.61	7.18	1.18	9.07
upper limit	2.73	5.33	1.56	6.33

(FM - fineness module; UC - uniformity coefficient; CC - curvature coefficient; GR – granularity ratio)

According to Table 4, the fineness modulus FM (1.17 - 1.53) of the natural local sands are less than 2 and do not fall within the recommended range FM (2.61-2.73) [29], i e., the sands studied are fine [26]. Furthermore, the characteristics of the local natural sands studied differ from those of standard sand [3]. The uniformity coefficients UC (2.09-3.29) are greater than 2, i.e., the grain size of the local natural sands is spread or varied. The coefficient of curvature CC (0.6-0.97) for sands S2-S5, S7 and S9 is less than 1 [3]. In other words, the grain size of S2-S5, S7 and S9 sands is poorly calibrated, indicating the absence of certain diameters corresponding to D10 and D60 [30]. These poorly graded sands are difficult to compact and produce mortars with poor mechanical properties [26, 27, 31]. On the other hand, sands S1, S6 and S8 have coefficients of curvature CC (1.01-1.28) which fall within the range CC (1-3), i e., the three natural local sands are well graded [31]. In other words, local sands in their natural state have a grain size that varies from one sampling site to another.

S9 crusher sand (corrective sand for local natural sands) has a uniformity coefficient of the same order of magnitude as standard sand. Its average diameter is small in relation to its fine content P (11%), which is higher than the permitted content P (10%). Table 5 shows the properties of local natural sands improved with S9 sand grading 0/5.

Table 5. *Properties of local sands improved with S9 crusher sand.*

Sand	FM	UC	CC	GR
S1+S9	2.71	6.38	2.5	7.16
S2+S9	2.75	5.12	1.43	6,09
S3+S9	2.66	6.83	2.54	8.5
S4+S9	2.68	6.31	2.35	7.44
S5+S9	2.73	5.31	1.91	6.32
S6+S9	2.68	6.38	2.41	7.21
S7+S9	2.70	5.19	1.96	6.18
S8+S9	2.69	5.47	1.8	6.65
lower limit	2.61	7.18	1.18	9.07
upper limit	2.73	5.33	1.56	6.33

(FM - fineness module; UC - uniformity coefficient; CC - curvature coefficient; GR - granularity ratio)

Table 5 shows that the parameters deduced from the improved local sands have fineness moduli FM (2.66-2.75), uniformity coefficients UC (5.12-7.18) and curvature coefficients CC (1.43-2.5). In other words, improved sands have a spread and well-calibrated grain size.

3.2. Compressive Strength

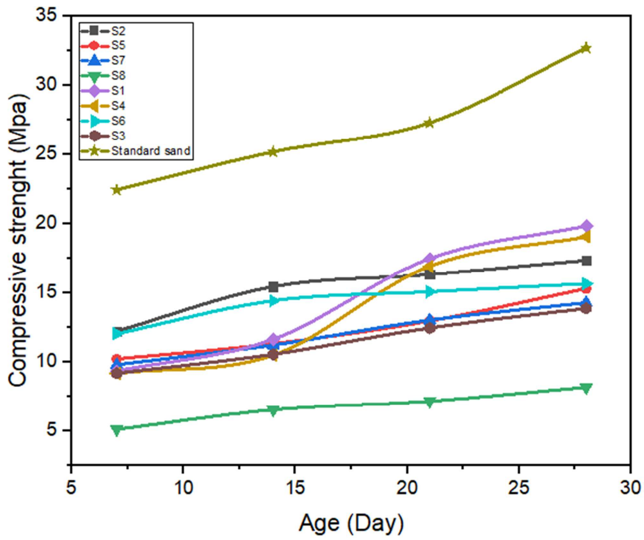

Figure 3. *Compressive strength of raw sand mortars as a function of maturation.*

Figure 3 shows the evolution of the compressive strengths of mortars formulated with local raw sand and those formulated with standard sand as a function of age. The result obtained with CEM II 32.5R cement shows that the compressive strength with standard sand at 28 days is CS (32.72 MPa). The compressive strength with standard sand is higher than that obtained with local raw sand CS (8.16-19.84 MPa). Local raw sands have fine grains according to their fineness modulus. This result shows the role played by grain size in the compressive strength of mortars (B. V. Vendatarama Reddy et al 2008 [31]). These natural local sands cannot be used for cement quality control. The compressive strengths of local sand and standard sand are correlated. In addition, local sands S1, S2 and S4 comply with ASTM C270 [32] and NF EN 1015-11 [30] for the manufacture of type M masonry mortar.

***Table 6.** Correlation between the properties of standard sand and local natural sands.*

Sand	CC	Relationship	R^2	χ^2
S1	0.946	Y = 0.68X + 16.4	0.932	1.24
S2	0.936	Y = 1.47X + 3.85	0.877	2.24
S3	0.989	Y = 1.66X + 7.2	0.979	0.37
S4	0.946	Y = 0.68X + 16.9	0.896	1.89
S5	0.992	Y =1.55X + 7.02	0.984	0.27
S6	0.922	Y = 2.01X - 2.45	0.850	2.71
S7	0.988	Y = 1.74X + 5.39	0.976	0.42
S8	0.988	Y = 2.69X + 8.30	0.974	0.46

(CC - correlation coefficient; R^2 - Determination coefficient; χ^2 - Chi-sqr)

The best correlations obtained between the compressive strength of the standard sand and those of the local sands (S3, S5, S7, S8) have the coefficients of determination R^2 (0.974-0.984) and the χ^2 (0.27-0.43).

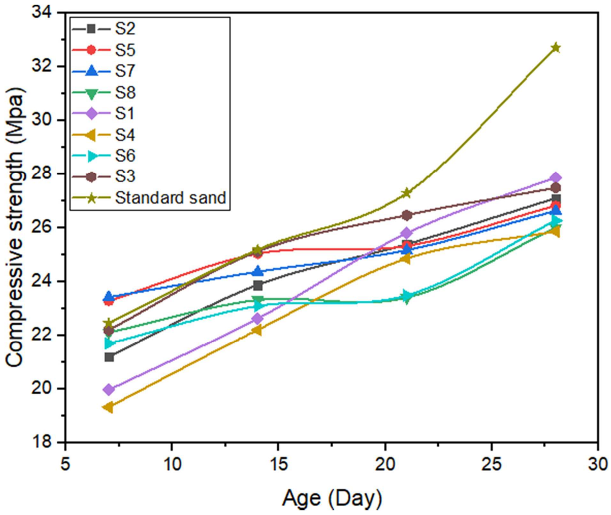

***Figure 4.** Compressive strength of mortars based on local raw sands improved with S9 sand as a function of age (Formulation 1).*

Figure 4 shows the compressive strength values of local raw sands upgraded with S9 crusher sand at different ages compared with formulation 1. The 28-day compressive strengths of the improved local raw sands are lower than those obtained with standard sand. The low compressive strengths of local raw sands can be explained by the fact that standard sand is 98.05% quartz [3], a very strong mineral. In other words, improved local raw sands can be composed of several minerals less resistant than quartz, such as feldspars and micas obtained mainly from crushed sandstones [4] and dune sands.

***Table 7.** Relationship between the compressive strength of local sands and that of standard sand (formulation 1).*

Sand	CC	Relationship	R^2	χ^2
S1+S9	0.985	Y = 0.99X + 2.7	0.971	0.52
S2+S9	0.986	Y = 1.37X - 7.07	0.971	0.52
S3+S9	0.956	Y = 1.45X - 10.32	0.913	1.58
S4+S9	0.961	Y = 1.14X + 0.08	0.924	1.37
S5+S9	0.980	Y = 2.35X - 32.85	0.960	0.71
S6+S9	0.975	Y = 1.78X - 15.57	0.951	0.88
S7+S9	0.998	Y = 2.57X - 37.54	0.997	0.50
S8+S9	0.958	Y = 2.03X - 21.91	0.917	1.53

(CC - correlation coefficient; R^2 - Determination coefficient; χ^2 - Chi-sqr)

Formulation 1 gives the results shown in Table 7. Natural local raw sands (S1, S2, S5, S6, S7) upgraded with crusher sand S9 have coefficients of determination R^2 (0.951-0.997) and χ^2 (0.5-0.88). In other words, by improving the sands (S1, S2, S5, S6, S7) with crusher sand (S9), it is possible to deduce the strength of the mortar with the standard sand. The best correlation is the one with the highest coefficient of determination R^2 (0.997) and the smallest Chi-sqr χ^2 (0.50).

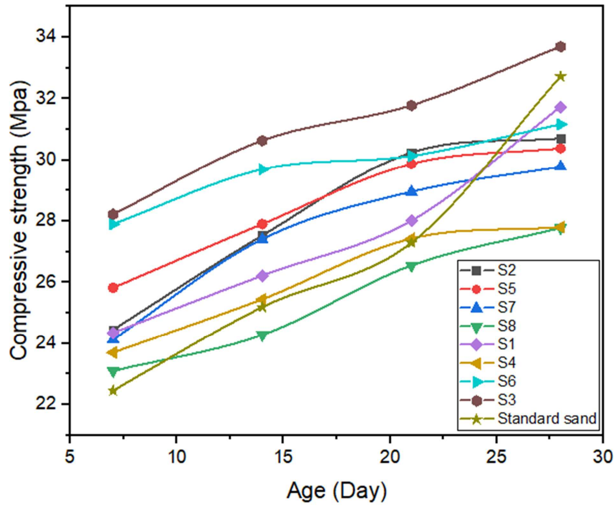

***Figure 5.** Compressive strength of mortars based on local sands improved with S9 sand as a function of age (Formulation 2).*

Figure 5 shows the evolution of the compressive strengths of local raw sand mortars (S1-S8) improved with crushed sand (S9) at different ages of 7, 14, 21 and 28 days. The sands (S1, S2, S3, S6) fall within the particle size range of standard EN 196-1 [3] often used by most African countries. Only the compressive strength CS (33.69 MPa) of the improved S3 sand is higher than that of the standard sand CS (32.72 MPa). The mixture of improved S3 sand and crushed sand can be considered as standard sand for cement quality control. In other words, the local raw sands (S1, S2, S3, S6) have grain size parameters close to those of standard sand. However, the 28-day compressive strengths of the sands (S1, S2, S4-S8) are lower than those obtained with standard CS sand (32.72 MPa). Improved local sands contain angular grains which make it possible to obtain high compressive strengths [5, 22], whereas standard sand contains fewer angular grains. In this case, mineralogy takes precedence over grain shape and compressive strength depends on this. However, there is a strong correlation between improved local sand S3 and standard sand, so it can be used as a substitute for standard sand.

In Figure 5, the mechanical strength CS (33.69 MPa) of the mortar made with local sand S3 improved with crushed sand is higher than CS (32.76 MPa) obtained with standard sand. The increase in mechanical strength obtained with formulation 2 compared to formulation 1 can be explained by the fact that formulation 2 contains more water due to the reduction in sand mass. Improved local sands have an angular shape that requires more water for better particle cohesion [23]. The highest compressive strength is obtained by mixing local sand S3 with crushed sand S9. The fines play an important role in the cementitious matrix and thus contribute to improving the compressive strength of mortars and concretes [24]. The compressive strengths of local sands improved using formulation 2 are correlated with those of standard sand (Table 8).

Table 8. *Relationship between the compressive strength of local sands and that of standard sand (formulation 2).*

Sand	CC	Relationship	R^2	χ^2
S1+S9	0.993	Y = 1.10X - 3.94	0.987	0.23
S2+S9	0.936	Y = 1.13X - 5.52	0.877	2.24
S3+S9	0.992	Y = 1.51X - 20.57	0.984	0.29
S4+S9	0.944	Y = 1.73X - 18.77	0.892	1.97
S5+S9	0.949	Y = 1.59X - 18.85	0.901	1.80
S6+S9	0.969	Y = 2.48X - 47.37	0.940	1.10
S7+S9	0.940	Y = 1.13X - 9.80	0.884	2.11
S8+S9	0.978	Y = 1.61X - 14.41	09.57	0.78

(CC - correlation coefficient; R^2 - Determination coefficient; χ^2 - Chi-sqr)

Local sand (S3) improved with crushed sand S9, produced a substitute for standard sand with a 28-day compressive strength of CS (33.69 MPa). The cement used is class 32.5R and the compressive strength CS (33.69 MPa) of the improved S3 sand is higher than that of the standard sand CS (32.72 MPa). The relationships obtained with the sands (S1, S2, S4-S8) should be excluded as their compressive strengths are lower than that of the cement CS (32.5 MPa). According to Table 8, the relationship obtained between standard sand and improved sand S3 is better because its R^2 (0.987) is the highest and the χ^2 (0.23) the lowest.

4. Conclusion

The aim of this study was to characterize nine sands used in construction and to find a substitute for standard sand among them or their mixtures. The in-situ production of standard sand is an alternative to the problem of importing it. Standardizing local sand will reduce the cost of laboratory testing, create jobs and add value to local sand. Raw local sands are fine, clean and, in some cases, conform to ASTM C270 and EN 1015-11 standards for the manufacture of masonry mortar. However, natural local sands cannot be used for cement quality control unless they are improved with 0/5 crushed sand. The correlation of formulation 2 between standard sand and improved local sand S3 is a linear fit (Y = 1.51X - 20.57) with coefficient of determination R^2 (0.984), coefficient of curvature CC (0.992) and χ^2 (0.29). Using formulation 2, a substitute for standard sand was determined with local sand S3 improved with crusher sand S9. The compressive strength CS (33.69 MPa) of the improved local sand S3 is higher than that obtained with the standard sand CS (32.76 MPa). Sands S1, S2, S5, and S6 have CS compressive strengths (30.38-31.73 MPa). These sands can be used as normalized sand to test cements. In fact, several studies show that it is sometimes difficult to obtain the expected compressive strength of a given cement with standard sand, and often a strength of 30 MPa is accepted by experience.

Conflict of Interest

The authors declare no competing interests.

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