Research Article

Comparative Study of Mortars Made with Sands of Different Geological Origin

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The present work is a comparative study of sand mortars from various geological origins to highlight their influence on mortar qualities. Five different sands and the cement CEM II/B−P 42.5R were used to produce mortars with similar water/cement ratios (W/C). These are the "Sanaga" sand from the Sanaga River, the "Wouri" sand from the Wouri River, the Nyambaka basalt sand, the Meiganga granite sand, and the Leboudi gneiss sand. The physical, chemical, and mineralogical features of these sands were used to characterize and classify them. They were then used to formulate mortars, which were analyzed and compared. According to the results of the mortar setting time tests, the initial setting time ranges from 195 minutes for Sanaga sand mortar (MS04) to 210 minutes for gneiss sand mortar (MGN03), passing Wouri sand mortar (MW05) with 200 minutes, basalt sand mortar (MB01) with 198 minutes, and granite sand mortar (MGR02) with 196 minutes. The final setting time ranged from 496 minutes (MGR02) to 510 minutes (MGN03), with an average of 300 minutes added to the initial setting time. The flexural strength tests of the mortars reveal that crushed sands outperform alluvial sands. They range from 1.64 to 2.18 MPa after 2 days, 3 to 3.90 MPa after 7 days, and 7 to 14.84 MPa after 28 days. The results of the compressive strength tests show that quarry sand mortars have greater average compressive strengths than alluvial sand mortars, with basalt sand providing the greatest performance. These strengths range from 6.35 to 10.83 MPa after 2 days, 7.55 to 18.96 MPa after 7 days, and 22.81 to 34.58 MPa after 28 days, with the MB01 being the best sand. These findings reveal that the geological origin of sands, which specifies certain of their physicochemical and mineralogical attributes, has an impact on the properties of mortars. This impact is also influenced by granulometry and organic matter concentration.

1. Introduction

The world is in full demographic expansion, and this expansion generates many challenges because it is accompanied by increased demand for goods and services. Therefore, the construction of sustainable infrastructure is essential for the well-being of the population, and to achieve this, the production of aggregates is essential. With the realization of more and more gigantic works, the requirements for the intrinsic properties of the materials are growing. With a diversified offer, natural aggregates are obtained by the exploitation of quarries in different geological contexts which could influence the quality of the produced materials.

The mortar is made up of an assembly of materials of a generally mineral nature (cement, sand); its setting and hardening are mainly due to the formation of the various hydrates of the cement caused by the hydration of the various mineral phases in presence as well as the intrinsic properties of the sand used [1, 2].
One of the essential properties of mortar is its ability to conform to the shape into which it is poured while still in a fresh state. Its implementation depends on the setting time, which is the time it takes for the cement matrix in general and the mortar in particular to support the loads induced by its weight without deformation [3]. The mechanical behavior of mortars depends strongly on their microstructure, the quality of the matrix-aggregate interface, and the size, orientation, and density of the elements that constitute them [4–6].

Despite numerous research works carried out on mortars [7–10], questions remain unanswered concerning the interaction between cement and aggregates, especially those concerning the influence of the nature of the aggregates on the hydration phenomenon. From this point of view, works [11] have shown that the mechanical properties of mortars based on quarry sand were close to each other and that mortars based on alluvial sands presented weaker mechanical properties than the latter. This finding stimulates interest in the intrinsic qualities of sands which influence these properties. Thus, to further investigate this line of research, especially concerning the causes of the disparities observed in the mechanical strength, it is important to identify the relevant parameters influencing mortar’s hydrate formation, starting from the geological origin of sand, through the characterization of the aggregates sampled from various rock nature. Following that, it will be necessary to evaluate the impact of these aggregates on mortar setting by investigating setting time, and ultimately to identify the impact of each on the mechanical strength of the mortars produced.

To do this, we will be interested in the chemical, physical, and mineralogical characterization of the sands, the determination of setting times, flexural strengths, compressive strengths, and mineralogical properties of mortars in the fresh and hardened state as appropriate.

2. Location of the Sampling Sites

The geographical location of the sand collection sites used in this study is presented here. Figures 1 and 2 present maps of the locations of the study areas in different regions of Cameroon. Table 1 summarizes the coordinates of the sampling sites. Once determined, sampling sites refer to geological settings that may influence the chemistry and mineralogy of sand samples. As a result, it is critical to present them.

3. Geology of the Sampling Sites

3.1. The Basalt. The basalt was collected at Nyambaka, a commune at coordinates (N6°30′55″ E14°17′29″) in the Adamaoua region, Vina department.

The Nyambaka area is covered essentially by volcanic rocks. These volcanic rocks are mainly an ancient series of basalt-andesite [12]. According to Toteu et al. [13], the Nyambaka area is essentially made up of rocks of Cenozoic volcanic-plutonic origin.

3.2. The Granite. The granite block used in our study was taken from the abandoned quarry of a road project. It is located in Dana, Meiganga which is a town located at coordinates (N6°30′55″ E14°17′29″) in the Adamaoua region and the chief town of the Mbéré department.

The Meiganga area is made up of magmatic rocks, metamorphic rocks, and sedimentary rocks [14, 15]. According to the geological reconnaissance map of Cameroon [12], the southern part of Meiganga in which the study site is located, is covered mainly by two types of geological formations: metamorphic and plutonic formations. The metamorphic formations are represented by the rocks of the Lom series, the base complex, and the gneisses. The magmatic or plutonic formations constitute the dominant geological formation [12, 13]. They are syntectonic concordant granites constituted among others by calc-alkaline granites with biotite, biotite, amphibole, and pyroxene. The Dana area (sample site) is mainly composed of undifferentiated granites with porphyritic textures. These granites are cut by intrusions represented by SW-NE-oriented quartz veins and SE-NW-oriented microgranite veins [12].

3.3. The Gneiss. The gneiss sand is produced by CHINA MEILAN CAMEROON COMPANY SARL (CMCC), whose exploited massif is located at the coordinates (N3°53′51″ E11°26′57″) in the central region, department of lekié, in the district of Okola, more precisely in the locality of Leboudi.

In the area of southern Cameroon where the study area is located, studies highlight a bedrock consisting mainly of metamorphic and plutonic rocks belonging to the Precambrian base complex [16–18]. The basement of southern Cameroon is composed of two major petrostructural groups: the Ntem Group and the Yaoundé Group. The Yaoundé Group is a very homogeneous group resulting from the high-pressure metamorphism of a geological material of volcanic-sedimentary origin. It consists of the Yaoundé and Mbalmayo-Bengbis series [18].

The Yaoundé series is a unit that outcrops essentially in the Yaoundé region. It is made up of formations of the Pan-African chain of age 540–600 Ma. These formations belong to the ancient metamorphic basement of the Cameroon base complex [16], consisting of paraderivious and orthoderivious formations. The latter are intrusive in the paraderivative formations. The paraderivative metamorphites are composed of various paragneisses, mica-schists, and simple quartzite and diasthene in low proportions while the orthoderivative formations which were sampled are formed of pyroclasts (pyroxene and plagioclase gneiss) to which are associated pyroxene and amphibole gneiss, pyroxenites, and biotites [19].

3.4. Sanaga Sand. The sand of the Sanaga River is collected on a site of artisanal extraction in Ebebda at the coordinates [N4°22′00″ E11°16′03″], which is a commune of Cameroon located in the region of the center and the department of the lekié.
The geology of the Sanaga watershed is constituted by a basic complex formed by a large set of crystalline shales made up of ektinites, migmatics, and concordant ancient eruptive rocks represented essentially by syntectonic granites. We also note the formation of lower mica-schists and quartzites with constant facies; we also note the same folding
directions without forgetting the presence of the upper and lower gneiss towards the banks of the river [20].

3.5. Wouri Sand. The sand from the Wouri River used in this study was taken from an artisanal extraction site in Bonamoussadi in the littoral region, Wouri department, Douala 5th district. The sand was extracted from the Bonamoussadi beach quarry at coordinates (N4°06'55" E9°44'05"").

The part of the Wouri River sampled has a geological cover constituted by the formations of the basement, essentially represented by gneiss-emblechists with biotite and secondarily by anatexis, syntectonic granites not circumscribed and circumscribed [21].

### Table 1: Sand sample collection points.

<table>
<thead>
<tr>
<th>Sand</th>
<th>Sampling locations</th>
<th>Latitude</th>
<th>Longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gneiss</td>
<td>Leboudi, Yaoundé</td>
<td>3°53'51&quot;</td>
<td>11°26'57&quot;</td>
</tr>
<tr>
<td>Granite</td>
<td>Dana, Meiganga</td>
<td>6°30'55&quot;</td>
<td>14°17'29&quot;</td>
</tr>
<tr>
<td>Basalt</td>
<td>Nyambaka</td>
<td>6°53'29&quot;</td>
<td>14°05'43&quot;</td>
</tr>
<tr>
<td>Wouri</td>
<td>Bonamoussadi beach, Douala</td>
<td>4°06'15&quot;</td>
<td>9°44'05&quot;</td>
</tr>
<tr>
<td>Sanaga</td>
<td>Ebebda</td>
<td>4°22'00&quot;</td>
<td>11°16'03&quot;</td>
</tr>
</tbody>
</table>

4. Materials and Methods

4.1. Materials

4.1.1. Sands. The sampling of sands was carried out following the NF EN 932-1 [22] standard. During this stage, three (03) samples of sand were taken in the granular state, namely the alluvial sand of the Sanaga River at Ebebda-Monatélé (SS04), the alluvial sand of the Wouri River at Bonamoussadi-Douala (SW05), and the gneiss sand coming from the quarry of Leboudi in Yaoundé (SGN03). Two (02) additional sand samples were taken from granite blocks collected in Meiganga (SGR02) and basalt blocks collected in Nyambaka (SB01). These were crushed with a sledgehammer and then ground and sieved in the laboratory to retain the 0.08/2mm particle size class.

4.1.2. Cement. The choice of cement to be used was the ROBUST 42.5R type NC CEM II/B–P 42.5R of the company CIMENCAM SARL in Fiquli because it is the most used in Cameroon. It complies with the standard NF EN 197-1 [23]. The characteristics of the cement are summarized in Table 2:

4.2. Methods

4.2.1. Sand Preparation. The preparation of the mortar specimens was subject to the preparation of the sands in the laboratory in the following steps: The blocks of rocks taken from the field were crushed with a sledgehammer and an anvil; the rock fragments were passed through a ball mill; the products of the crushing and the alluvial sands were dried and then passed through a 2mm sieve, and the bypasses were kept; these by-passes were then washed with a 0.080mm sieve to eliminate the fine clayey materials and plant materials and thus avoid the agglomeration of the grains, which could distort the results of the analysis. The final step consisted of drying each sand sample in an oven at 105°C for 24 hours.

4.2.2. Particle Size Analysis by Sieving. The granulometric analysis allows for determining the size and the respective weight percentages of the different families of grains constituting the sand sample. This test is defined by the standards EN 933-1 [24] and EN 933-2 [25]. The following formulas were used in the context of the realization of this test:

(i) Percentage of cumulative sieves P (%):
\[ P(\%) = 100 - r(\%) \]  

(ii) The percentage of cumulative refusals for each sample type is denoted r (%) and is determined as follows:
\[ r(\%) = \left( \frac{R}{M} \right) \times 100 \]

where R is the mass of accumulated refusals in grams. M is the mass of the test sample for each sample

4.2.3. Sand Equivalent According to the NF EN 933-8 [26] Standard. This test measures the cleanliness of the sand. It gives an overall account of the quantity and quality of the fine elements by expressing a conventional volumetric ratio between the sandy elements that sediment and the fine elements that flocculate. The visual sand equivalent (ESV) is defined by the formula:
\[ ESV = \frac{h}{h_1} \times 100 \]

The sand equivalent (ES) is defined by formula:
\[ ES = \frac{h_2}{h_1} \times 100 \]

where h1 is the height of the upper level of the flocculate about the bottom of the test tube. h2 is the height of the top level of the sedimented portion relative to the bottom of the specimen. h is the height of the sediment at the level of the upper face of the sleeve.

4.2.4. Densities

(1) The Absolute Density According to the ASTM C128–7a [27] Standard. The purpose of this test is to determine the mass per unit volume of the material that constitutes the aggregate without taking into account the voids that may exist between the grains.

The absolute density is determined by the following formula:
\[ \rho = \frac{v_2 - v_1}{M} \]

where \( \rho \) is the absolute density. M represents mass of solid grains (about 300 g). \( v_1 \) is the volume of water. \( v_2 \) is the total volume (solid grains + water).
The compressive strength test is carried out on each half specimen section in mm² (b = 40 mm) and the “fitting coefficient” $R^2$ (correlation coefficients) was determined. Afterward, a classification was made according to the quality of the regression line and the distribution of the data. XRF was performed on the different sands.

4.2.7. Production of Mortar Samples. The mortar samples were made according to EN 196-1 [28] with dimensions of $4 \times 4 \times 16$ cm. From the formulation of the normal mortar, at water/cement (w/c) = 0.5, the sand used was basalt sand (SB01), granite sand (SGR02), gneiss sand (SGN03), Sanaga sand (SS04), and wouri sand (SW05). The different mortar formulations were carried out, namely, MB01, MGR02, MGN03, MS04, and MW05, respectively, for each sand used. Three samples of each formulation were used for both the flexural strength test and the compressive strength test. A total of 45 prismatic mortar specimens were produced. The quantities used are found in Table 3.

4.2.8. Setting Time. The setting time test is performed with the Vicat apparatus on the cement paste at normal consistency. The initial setting time is the time from the beginning of mixing the cement paste until the Vicat needle stopped at a distance $d$ from the bottom of the mold filled with 500 g of paste and such that $d = 4 \pm 1$ mm. The final setting time is the time after which the Vicat needle only sinks by 0.5 mm. This test is carried out following Standard NF EN 196-3 [29].

4.2.9. Mechanical Tests. The flexural strength test was carried out on three $4 \times 4 \times 16$ cm prismatic mortar specimens, for each formulation, at 2, 7, and 28 days of cure. In the end, the strength allowed is the average of the three values obtained. This test is performed according to EN 196-1 [28] using the formula:

$$R_f = \frac{1, 5 \times F_f \times L}{b^3}$$

where $R_f$ is flexural strength MPa, $L$ = distance between the lower support in mm, $F_f$ = breaking load in N, and $b$ = thickness of the specimen ($b = 40$ mm).

The setup used for this test is shown in Figure 3. The compressive strength test is carried out on each half of the specimen used for the flexural test on the same dates. The compressive strength is calculated using the formula:

$$R_c = \frac{F_c}{S}$$

where $R_c$ = compressive strength MPa, $F_c$ = breaking load N, and $S$ = specimen section in mm² ($S = 1600$ mm²).

The setup used for this test is shown in Figure 4.

4.2.10. X-Ray Diffraction (XRD). XRD measurements were performed using a D8 Brucker-AXS diffractometer equipped with a Lynx eye position-sensitive detector, with Cu Ka $\lambda$Cu = 1.54056 Å radiation operated at 40 kV and 40 mA, increment 0.013° 2Θ, and a measuring time per step of 30 s. The diffraction patterns were collected in the 2 theta range from 7.5 to 90°. Qualitative analysis of the phase composition of the powder samples was conducted using the PDF-2 2007 release software and X’Pert High Score Plus. XRD was performed on the raw materials (sands) at first and on the mortars, after 2, 7, and 28 curing days, to identify the hydrated products.
5. Results and Discussions

5.1. Granulometric Analysis by Sieving and Sand Equivalent.
The results of the particle size analysis of the different sands studied are presented by the particle size curves in Figure 5. These results have been reduced to the granular class 0/2.

At the end of this test, it emerges that the sands that have undergone grinding in the laboratory such as granite and basalt present a uniform granulometry with percentages of fine (<0.2 mm) included between 20 and 25% higher than that of the standardized sand. This is due to the grinding process used which mobilized a ceramic ball mill and an identical grinding time, thus conferring continuous granulometry with a majority of coarse sands (≥0.2 mm) which are nevertheless close to the normalized sand. It should be noted, however, that the basalt shows slightly better resistance to grinding, which suggests a better hardness of the material.

The gneiss quarry sand has a proportion of fines of around 30%. The curve which has a more or less rectilinear aspect from 400 μm, has a continuous granulometry in the whole but presents a granularity with a majority of average grains (between 0.3 and 1 mm). This sand contains more fine materials than the standardized sand up to the mesh size of 1.52 mm.

<table>
<thead>
<tr>
<th>Table 3: Composition of mortar-tested samples.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement type</td>
</tr>
<tr>
<td>Cement (g)</td>
</tr>
<tr>
<td>Sand (g)</td>
</tr>
<tr>
<td>Water/cement (w/c)</td>
</tr>
</tbody>
</table>

**Figure 3:** Set-up for flexural strength test (three-point bend test).

**Figure 4:** Set-up for compressive strength test.

**Figure 5:** Sand grading curves.
Alluvial sands have overall finer grain sizes than quarry sands and standard sand (in the 0.4 and 2 mm classes). However, the fine fraction (<0.2 mm) represents less than 5% of these sands. Their curves are the most distended of the standard sand.

The determination of the modulus of fineness and the equivalent sand ES of each sand is reported in Table 4.

All the sands studied have a modulus of fineness within the range of permissible values (i.e., between 1.8 and 3.2) according to NF EN 12620 [30]. According to this standard, the basalt (SB01), granite (SGR02), and gneiss (SGN03) sands are said to be a little too fine, while the Sanaga and Wouri sands are classified as coarse sands. These lower fine contents are probably due to the transport of the grains by water, resulting in a gravimetric separation that is to the advantage of the medium to coarse grains during formation in the river beds, but they may also be because they are mainly composed of quartz (hard and unalterable mineral).

The values of the equivalent of the sands of all the sands respect the specifications of the sands to be used in the confection of the quality concrete, according to the standard NF EN 933 8 [26] which must be higher than 65%. Also, according to this criterion, they are all considered as very clean sands.

5.2. Absolute Density and Bulk Density. Table 5 summarizes the densities of the rock samples in the natural state.

These results show that the absolute density of quarry sands is higher than that of alluvial sands. The same is true for bulk density. Basalt has the highest absolute density of 2.87 g/cm³ followed by granite (2.71 g/cm³) and gneiss (2.63 g/cm³). The Sanaga sand (2.68 g/cm³) is denser than the Wouri sand (2.55 g/cm³). Except for the Wouri sand, the density of all the sands is higher than the minimum threshold of 2.6 g/cm³ prescribed by the ASTM C118 standard [31]. These results are similar to those of Luc Leroy et al. [4] who used Basalt sands of 2.87 g/cm³ and river sands of 2.60 g/cm³. However, they diverge from those of Gupta and Vyas [7] who used river sands denser (2.65 g/cm³) than granite powder (2.46 g/cm³) probably due to the granularity. The results obtained depend on the minerals present in the materials. The denser sands suggest a high content of minerals such as quartz (2.65 g/cm³), muscovite (2.8 g/cm³), albite (2.6 g/cm³), anorthite (2.5–2.8 g/cm³), and olivine (3.2–3.6 g/cm³) among other minerals commonly present in granites, basalts, and gneisses.

5.3. Petrography of Rock Samples

5.3.1. Basalt. Two basalt facies (LAME B and LAME C1) were identified among the basalts used (Figure 6).

For sample LAME B, this rock has a microlitic porphyritic texture with 80% of the rock mass made up of microlites of constitutive minerals to form the matrix. The rock is made up of phenocrysts, microphenocrysts, and microlites of olivine, clinopyroxenes, and plagioclases. There is also an abundance of oxides which add up to the constitutive minerals to form the matrix. Olivine crystals in the rock exist as subautomorphic to xenomorphic phenocrysts, microphenocrysts, and microlites. They are pleochroic; the phenocrysts show cracks. Clinopyroxenes are found as microphenocrysts and microlites in the matrix. They are xenomorphic and measure less than 0.1 mm in diameter. They also present an advanced state of alteration. Plagioclases are the most abundant mineral phases in this matrix and are found as needle-like microphenocrysts and microlites. Most of the crystals show the Carlsbad twin and are pleochroic between the grey and white shades of the first order. Oxides are present in the rock as opaque minerals and are also relatively abundant. They are found in the matrix as well as in some mineral phases, indicating the impact of alteration.

Regarding the LAME C1 sample, this rock is mesocratic (dark in color). It has a microlitic porphyritic texture and contains more volcanic glass than developed mineral phases. It contains very little olivine and clinopyroxene but is rich in plagioclases, volcanic glass, and oxides. Plagioclases are abundant in the rock and are found as phenocrysts in the form of elongated baguettes and also as needle-like microphenocrystals. The phenocrysts present several cracks through them and have undergone a little bit of alteration. Most of the plagioclases show Carlsbad twins. Clinopyroxenes are less abundant in the rock and are found in phenocrysts and microlites. The phenocryst is subautomorphic and shows signs of alteration. Olivine in this rock is found as microlites in the groundmass. The oxides here are large and abundant. They are found both in the groundmass and in some phenocrysts.

5.3.2. Granite. Regarding the granite, 3 thin sections (LAME A, LAME I, and LAME H) taken from various granite facies were observed (Figure 7).

Sample LAME A shows that this granitic rock is leuocratic, with more than 70% white minerals. It has a porphyritic texture with large xenomorphic crystal phases. The rock is made up of plagioclase feldspars, potassic feldspars (orthoclase), quartz, and biotite. Plagioclase is abundant in the rock and is found as xenomorphic phenocrysts. Most crystal phases are pleochroic. The potassic feldspar which is
orthoclase is xenomorphic. Quartz is not as abundant as the feldspars and it is also xenomorphic. The biotite crystals are found in clusters.

Sample LAME I has a porphyritic texture. The mineral phases identified are plagioclase, quartz, biotite, and pyroxene. Plagioclase is the most abundant, occurring as xenomorphic crystals with a majority of these crystals exhibiting polysynthetic twins. Quartz is found to show a little bit of alteration, and some crystals have oxide inclusions. The biotite crystals are found in clusters. Pyroxene is found dotted in the rock with crystal sizes ranging between 1 and 5 mm long.

The sample LAME H presents the same characteristics as the other granitic rock except that it is dominated by light minerals and has muscovite which presents itself as a phenocryst.

5.3.3. Gneiss. The LAME F and LAME G samples observed in Figure 8 for the gneiss show that the rock is foliated and dominated by light minerals while the other rocks do not show any distinctive direction of mineral orientation. All rocks contain quartz, plagioclase, biotite, and muscovite; this rock has the highest proportion of muscovite and biotite. Plagioclases in all rocks exhibit polysynthetic twins with rock F having other plagioclases exhibiting the Carlsbad twin.

5.4. Results of Chemical Analysis by X-Ray Fluorescence. Table 6 shows the chemical composition of the sands studied.

The loss on ignition (LOI) varies from 1.12 to 1.87. Concerning alluvial sands, it ranges from 1.55 for Sanaga sand to 1.87 for Wouri sand. Quarry sands have losses of 1.65 for basalt, 1.37 for granite, and 1.12 for gneiss. These values correspond to the presence of organic matter in the various materials and can be considered to meet the ASTM C40 standard.

The different materials are characterized by high silica contents that vary between 41.27 and 63.19% with an arithmetic average of 52.75%. The highest contents are found among the alluvial sands whose values vary from 61.78% for the Wouri sand to 63.19% for the Sanaga sand. These high silica contents are justified because the basement of the Sanaga basin is constituted by a basic complex formed by crystalline schists made up of ectsinite, magmatic and syntectonic granites, lower mica-schists, and quartzites with constant facies [20]. The basement of the Wouri basin is essentially represented by biotite gneiss-embrechists and secondarily by anatexis, uncircumscribed, and circumscribed syntectonic granites [21]. These rocks have the main constituent quartz which is a mineral of hardness 7, according to the scale of Mohs, and this last one will thus resist the alteration during the transport. The quarry sands have silica contents that vary from 41.27 to 55.18%. The highest content is that of granitic sand, usually rich in quartz; its silica content is 55.18%.

For the other major oxides, the alumina content varies between 5.4 and 11.96%. Quarry sands show an alumina concentration between 9.68 and 11.96%, with the highest
value being in granite. The alluvial sands show contents that oscillate around 5.4 to 5.83%, the highest value being that of the Sanaga sand. These values are due to the presence of feldspars and potentially kaolinite in the materials. Iron oxide contents vary from 3.01 to 12.68%; they could be contributed by olivine and amphiboles. The content of calcium oxide varies from 1.45 to 9.66% probably from calcite; the content of magnesium oxide varies between 0.33 and 17.54% brought by illite and olivine. The other major elements, namely potassium oxide, phosphorus oxide, and sodium oxide, show low concentrations, sometimes less than 1%. These results are similar to those of Elat et al. [8] for gneiss and alluvial sands, those of Unčík and Kmecova [32] for basalt, and those of Gupta and Vyas [7] for granite.

5.5. Results of X-Ray Diffraction (XRD) on Sands. The X-ray diffraction (XRD) performed on each sand sample studied has been compiled in Figure 9.

5.6. Setting Time Results. The results of the setting test are shown in Figure 10.

The mineralogical composition of the sands thus presented, combined with chemical analysis, are key elements in determining the influence of the minerals’ intrinsic properties, in particular their strength, on mortar strengths and also the influence of the chemical elements that make up these minerals in cement reactions. Once these characteristics have been determined, the properties of ready-mixed mortars can be investigated.
≤500 µm (Figure 5). Numerous works [41–44] report that particle size plays a central role in the setting time of mortars, provided that the sands used do not contain chemical elements that may accelerate or retard the setting. Indeed, the incorporation of recycled fine aggregate into the mortar increases the initial setting time from 20% to 63% depending upon the size fraction of recycled fine aggregate, whereas the final setting time of the mix varies from low to high depending upon the presence of organic matter, clay, etc [41, 42]. Resende et al. [43] reported that copper slag-based mortar shows delayed setting time, i.e., initial and final setting time are increased by 2, 5, 10 h, and 3, 8, and 18 h for 25, 50, and 75% substitution, respectively. The studies in [44] studied the variation in setting time of mortar using natural water, sulfuric acid solution, and hydrochloric acid solution treated with recycled fine aggregate. They found that initial, as well as final setting time decreases due to acid treatment. This reduction in setting time is due to the presence of...
calcium chloride residue and calcium sulfate residue on the surface of acid-treated recycled fine aggregate which reacts with cement, induces a reduction in calcium silicate hydrates, and promotes the setting of mortar cement. The mortars studied can be used for bonding mortars, as the setting time value is higher than 120 min, which is the minimum value for mortars of this utility [45].

The bonding that takes place during hydration between the cement paste and the aggregates results in a particular paste zone called the “transition aureole” or paste/aggregate interface, so the interaction between the matrix and the aggregates in this zone will depend on the physical parameters and the chemical composition of the sands.

5.7. Mechanical Test

5.7.1. Flexural Strength Results. Figure 11 shows the evolution of the average flexural strengths at 2, 7, and 28 days measured at room temperature.

It was found that they vary from 1.64 to 2.18 MPa at 2 days, from 3 to 3.90 MPa at 7 days, and from 7 to 14.84 MPa at 28 days. It can be seen that quarry sand mortars have higher average flexural strengths than alluvial sand mortars at 28 days, although at 2 days these strengths tend to equalize. In fact, at an early age, as the cementing process is not completed, the cementitious materials tend to show the same mechanical behavior, whereas at 28 days, they show an almost stable behavior over time [46]. The flexural strength performance of quarry sands is due to the angular nature of the sand grains, which favors mortars subjected to flexure compared to alluvial sand mortars, whose sand grains are generally round in shape. Similar results were obtained in the work of Gupta and Vyas [7], where the replacement of alluvial sand with granite powder resulted in flexural tensile strengths increasing by 23–39%, depending on the case.

It seems clear that the response of mortars to bending stresses is strongly dependent on the shape of the sand grains, with an angular shape favoring strength over a rounded shape. The divergence of strengths in materials of the same shape would depend on the intrinsic properties of the materials, which can be elucidated by studying the compressive strengths.

5.7.2. Compressive Strength Results. The test was carried out at ages 2, 7, and 28 days of curing following the EN 196-1 [28] standard. The evolution of the compressive strengths of the different mortars is given in Figure 12.

The results show that the average compressive strengths vary between 6.35 and 10.83 MPa at 2 days, 7.55 to 18.96 MPa at 7 days, and 22.81 to 34.58 MPa at 28 days. The highest values are for basalt mortar (31.28 MPa), followed by granite mortar (30.58 MPa), gneiss mortar (28.68 MPa), and alluvial sand mortars. Similar work [4] confirms that the mechanical properties of mortars with basalt aggregate have the best mechanical performance at 28 days (34 MPa), followed by alluvial sand aggregates (24 MPa), and mortars with gneiss aggregate (22 MPa). This is because basalt is a compact rock, hard and tough and also consists of hard minerals such as olivine, plagioclase, and clinopyroxene.

Regarding the alluvial sand mortars (MS04, MW05), the MS04 mortar has higher values at 2, 7, and 28 days, respectively, of 8.43 MPa, 16.66 MPa, and 24.37 MPa than the MW05 with 6.35 MPa, 7.55 MPa, and 22.81 MPa. This slight difference in favor of MS04 is due to a higher percentage of silica contributed by quartz and other hard minerals such as plagioclases (see XRF and XRD results). SW05 also has a higher organic matter content (LOI = 1.87) than SS04 (LOI = 1.55), which harms the cementitious matrix [47]. Overall, these results support the claim that the quarry sand mortars studied have higher average compressive strengths than the alluvial sand mortars. In addition, sands of volcanic origin provide better strengths than sands of metamorphic origin, with basalt providing the best performance. The quality of alluvial sands depends on their constituent minerals, their degree of weathering, and their organic matter content.
5.8. X-Ray Diffraction (XRD) Results on Mortars. The 28-day XRD results for the mortars studied (MB01, MGR02, MGN03, MS04, and MW05) are shown in Figure 13. These results allowed the identification of all the minerals present in the raw materials. In addition to these, the nonhydrated cementitious minerals such as halite, tricalcium aluminate, tetracalcium alumino ferrite, and calcium oxide [46, 48, 49] were also detected. The hydrates identified are ettringite, portlandite, monosulfoaluminate, katoite, and to a lesser extent stratlingite [46, 50–53]. There is an absence of transformation of the sand minerals, and the hydrates formed are those found in Portland cement independently in sands. The result is that the chemical constituents of the sands do not seem to react with those of the cement, certainly because they are mostly in a crystalline state. Indeed, amorphous materials have been shown in numerous studies [54, 55] to influence the mechanical properties of cementitious matrix. For other researchers [9, 32], crushed basalt on the one hand and crushed granite on the other hand, mainly influence the physical behavior of mortars. Crushing rocks to make quarry sand would therefore not have a sufficient effect on degrading the minerals that would then react with the cement.

6. Conclusion

The objective of this work is to carry out a comparative study of the physicochemical and mineralogical properties of sands of different geological natures in mortars. For this purpose, we used Sanaga sand and Wouri sand as alluvial sands. For quarry sands, basalt, gneiss, and granite sands were used. The particle size classification of these sands showed that the granite and basalt sands had curves closest to the standard sand; the others had a greater amount of fines, with a predominance of fines in the gneiss sand. Chemical analysis indicated the presence of minerals that were confirmed by petrography and mineralogy. This included muscovite, olivine, plagioclase, amphibole, biotite, quartz, kaolinite, orthoclase, vermiculite, augite, and microcline, among others. These minerals corresponded to the minerals commonly found in the geological areas from which the materials used for the study were derived. The presence of hard minerals such as quartz and plagioclase was responsible for the strength of the rocks and hence, the grain sizes obtained after grinding. The analysis of the setting time of mortars showed that the presence of fine particles influenced the setting time. The higher the fine content, the...
longer the setting time. The initial setting time varied from 195 min for MS04 to 210 min for MGN03, via MW05 (200 min), MB01 (198 min), and MGR02 (196 min). The final setting time varied from 496 min (MGR01) to 510 min (MGN03) with an average of 300 min over and above the initial setting time to reach the final setting time. The flexural strength tests of the mortars showed that the crushed sands had better properties than the alluvial sands. They varied from 1.64 to 2.18 MPa at 2 days, from 3 to 3.90 MPa at 7 days, and from 7 to 14.84 MPa at 28 days. In the compressive strength tests, the results showed that the quarry sand mortars studied have higher average compressive strengths than the alluvial sand mortars, with basalt sand performing best. The strengths ranged from 6.35 to 10.83 MPa at 2 days, 7.55 to 18.96 MPa at 7 days, and 22.81 to 34.58 MPa at 28 days, with 34.58 MPa for the basalt mortar. These results were due to a more abundant presence of hard minerals. The mineralogical analysis of the mortars revealed the presence of cement hydrates and nonhydrated phases in all the mortars. It was also noted that there were no minerals in the sands that could chemically interfere with the setting process. The results thus obtained could be completed by studying the transition interface between the sand grains and the cement through scanning electron microscopy on the mortars. This investigation will be the subject of a future study.

Data Availability
All data generated or analyzed during this study are included in this article and available as a preprint.

Disclosure
A preprint is available at the following URL: DOI: https://doi.org/10.21203/rs.3.rs-1508892/v1 [56]. This manuscript has not been published elsewhere in any form or language and has not been submitted to more than one journal for simultaneous consideration.

Conflicts of Interest
The authors declare that they have no conflicts of interest.

Authors’ Contributions
Yannick Tchedele Langollo validated the study, proposed a methodology, wrote, reviewed and edited the study, performed visualization, and created the original draft. Bilkissou Alim conceptualized the study, proposed a methodology, investigated the study, and wrote the original draft. Njoya Mfokou Abdou Nasser performed validation, wrote, reviewed, and edited the study, and performed visualization. Oumar Ali Taïga proposed a methodology, wrote, reviewed, and edited the study, and created the original draft. Njoya Moussa Jalil proposed a methodology, performed investigation, and reviewed and edited the study. Belinga Essama Boum Raphael supervised the study, proposed a methodology, and was responsible for the resources. Mache Jacques Richard supervised the study, proposed a methodology, and was responsible for the resources.

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