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Study of Sands from Bamendou-West Cameroon: Valorization for Concrete Mix Design

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Abstract

Bamendou (West Cameroon), has a huge potential in natural resources, especially sands. However, the use of these materials in civil engineering works leads to the appearance of numerous pathologies which in some cases lead to the total ruin of the works. In order to overcome these infrastructural problems, the main objective of this study is set at the improvement of the service life of structures built in Cameroon using local materials formed under climatic, geological and geotechnical conditions similar to those of materials in Bamendou. Eight sand samples were taken from the most representative and exploited quarries. The identification and classification of the sand taken from the most representative quarries in the study area show that they are mainly clayey, with an average sand equivalent of 57.54. In terms of granulometry, the curves of several sand samples do not fall within the granular range of sands used in the formulation of concrete. The modulus of fineness obtained by particle size analysis varies from 2.91 to 3.92 with an average of 3.31.

Keywords

Residual Sand, Formulation of Concrete, Sand Equivalent, Fitness Modulus, Particle Size, Bamendou

1. Introduction

The use of rocks and derived weathering products in civil engineering has gone on since time immemorial. Meanwhile, the requirement and their use in building projects has significantly increased in recent years due to population growth (Diop et al., 2014; Tatiana et al., 2016; Guetsa et al., 2019; Lee & Yeh, 2008). In the mean-time, these materials are widely distributed on the Earth's surface and the current development projects promote the optimal use of local materials (Bouaziz et al., 2010; Ilalie et al., 2015; Adeline Pons, 2007) that provide two advantages: they are not expensive and easily accessible. However, one of the prerequisites for the use of these materials is the knowledge of their geological, physical and mechanical properties (Ngon Ngon et al., 2012). Among these natural resources, sands are residual materials formed by the degradation of primary granitic rocks, mainly in tropical and subtropical regions. Due to their availability and operability, they are commonly used in civil engineering works and their world demand like other aggregate is getting higher and higher during the last decade.

The economic context of some poor and developing countries only allows a certain class of people to have access to decent housing. However, the construction of infrastructures is very important in these countries (Katte et al., 2019), amongst, one of which is the lack of knowledge about the properties of these sands. This results in poor performance of cladding plasters on walls, cracking and spalling of beams, lintels, posts and even ruin of structures (Tatiana et al., 2016). In the world in general and in Cameroon in particular, geotechnical characterization of construction materials has increased considerably (Aboubakar et al., 2021). Similarly, residual sands have been studied in some areas of the country and their geotechnical characteristics have been highlighted (Ngapgue et al., 2009; Tchouata et al., 2020; Nguefack Ymefack et al., 2020). This has improved the durability of some structures at the local and regional levels. According to the national development strategy (2020), it is a question of substantially improving the rate of access to infrastructure through generating a supply that anticipates demand.

In Cameroon, sands are found associated to residual granitic soil or alluvial materials in the stream beds. Their occurrence and their geotechnical properties have been extensively studied by many researchers. However, the diversity of the obtained results is globally influenced by the type of rock. Bamendou is a locality in Menoua division situated on the Highlands of Western Cameroon. It rests in places on volcanic rock such as basalt, on metamorphic rock such as gneiss and mainly on granitic bedrock (Nono et al., 2009). The alteration of these granites by agents such as temperature, rainfall, topography and the nature of the parent rock have led to the formation of a granitic arena that is exploited by the local population as a sand pit. However, as a result of the use of its sands in civil engineering works, structural failures were noticed later on. Considering the immensity of this deposit exploited in many quarries and the quantity of sand that comes out of it, it is of great importance to characterize these materials. The present study focuses on the physical characterisation of Bamendou (Dschang) sands.

2. General Setting of the Study Area

The study area is a part of the Western Cameroon Highlands (**Figure 1**) between latitudes 5˚23'N and 5˚28'N, longitudes 10˚08'E and 10˚13'E. with a sub-equatorial, characterized by high altitudes, with annual average rainfall varying between 1600 and 2000 mm; and annual average temperature fluctuating between 18˚C and 20˚C (Momo et al., 2016).

According to geological setting, we have two types of rocks in this area:

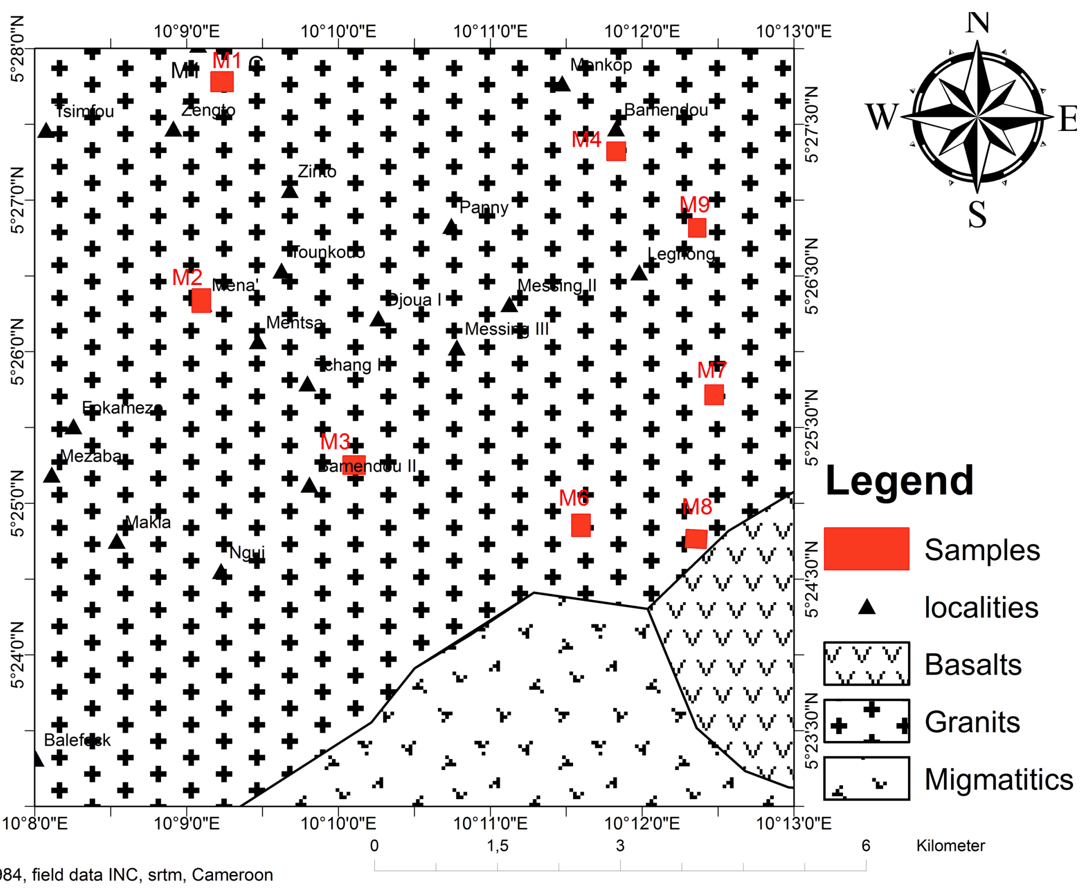
- The volcanic rocks which consist of aphyric basalts, tuffs, sub-aphyric basalts, porphyritic basalts, trachyte (Fosso et al., 2005; Kwékam et al., 2010);
- the plutonic rock which consist of Granito-gneissic basemen (Fosso et al., 2005).

3. Methods of Study

In the Bamendou group, 12 sand quarries are opened by the population. An inventory of these quarries during several field trips permitted us to make a selection for the study. Eight quarries amongst the twelve available were selected because of the abundance of materials they provide.

3.1. Field Investigation

The field work consisted of locating the various study sites and taking samples



SRC GCS WGS 1984, field data INC, srtm, Cameroon

Figure 1. Location (A and B) and geological settings (C) of the study area.

for laboratory testing. Samples from the various quarries were taken from large, market-ready piles. Samples were taken in a representative manner from the top, middle and bottom of each pile, then packed in polystyrene bags, labeled and sent to the civil engineering laboratory of FOTSO Victor University Institute of Technology in Bandjoun for certain tests and to the civil engineering laboratory of the University Institute of Coast in Douala.

3.2. Analytical Methods

The water content was determined in accordance with standard NF P 94-050 (1995). The particle size analysis was carried out by dry method according to NF P 94-056 (1996). The sand equivalent was determined according to the requirements of standard NF P18-598 (1979). The absolute density was determined by measuring the solid grains with a pycnometer and by successive weighing according to the recommendations of standard NF P 94-054 (1991). The void index (e), porosity (η) and saturation (s_r) were determined by calculation using the following relationships:

$$e = \frac{d_r - d_d}{d_d} \quad (1)$$

$$n = \frac{e}{1+e} \quad (2)$$

$$s_r = \frac{w \cdot d_r}{e \cdot \gamma \cdot w} \quad (3)$$

where: d_r is real density, d_d is dry density, ω is Water content, γ is Volume weight.

In order to know with certainty whether the sand is mostly made up of fine or coarse grains, the modulus of fineness (MF) was determined according to the French standard NF P 18-540 (1997) and NF P 18-545 (2011). Thus, the modulus of fineness is equal to 1/100th of the sum of the cumulative refusals, expressed in percentage on the sieves of the following series: 0.16 - 0.315 - 0.63 - 1.25 - 2.5 - 5 mm:

$$\text{Mf} = \frac{\%R_5 + \%R_{2.5} + \%R_{1.25} + \%R_{0.63} + \%R_{0.315}\%R_{0.160}}{100} \quad (4)$$

Cumulative rejects in % of sieves (0.16 - 0.315 - 0.63 -1.25 - 2.5 - 5 mm).

The Hazen uniformity coefficient (C_u) was obtained according to the French standard NF P 18-540 (1997), by the following formula:

$$C_u = D_{60}/D_{10} \quad (5)$$

D_{10} and D_{60} are the abscissa values for the points on the grading curve that correspond to 10% and 60% ordinates. From this standard, the following reference is used to determine the uniformity of the curve:

- $C_u < 3$, then the grain size is uniform or tight;
- $C_u > 3$, then the grain size is varied or spread out.

The curvature coefficient (C_c) allows the shape of the particle size curve to be described thanks to the effective diameter of the particles corresponding to 10%, 30% and 60% of passing. The formula for this coefficient is as follows:

$$C_c = \left(D_{30}\right)^2 \big/ D_{10} * D_{60} \tag{6}$$

Therefore, for a well graded soil, a wide variety of diameters are present. When $1 < C_c < 3$, the grading curve thus indicates the presence of a large variety of diameters. On the other hand, when the coefficient of curvature is too large or too small it indicates the absence of certain diameters between the effective diameters D_{10} and D_{60}, and the grading is then said to be badly graded.

4. Results and Discussions

4.1. Water Content, Absolute Density and Sand Equivalent

The values for natural water content, absolute density and sand equivalent of the different materials are given in **Table 1**.

From **Table 1**, it can be seen that the natural water contents of the different materials vary from 9.47% to 21.70%, with an average of 15.61%. However, the results of the absolute densities range from 2.42 to 2.55 with an average of 2.51. These absolute densities values are almost similar to those found by Tchouata et al. (2020) on the characterization of sands from Batié and Djione (West Cameroon), for use in civil engineering. The almost similar characteristics of these materials in terms of density could be due to the fact that they both originate from a granitic weathering complex. However, these values are slightly lower than those obtained by Tatiana et al. (2016) on the characterisation of the Santchou-West Cameroon sands, with a mean density value of 2.6. This variation in absolute density from one material to another could be due to a variation in the level of weathering of the granitic arena respectively for each sample point.

Table 1. Water content, absolute density and sand equivalent of the studied materials.

Location	Materials	Water content (%)	absolute density	Sand equivalent (%)
Menah	S1	12.32	2.55	85.77
LB2	S2	18.47	2.51	64.04
LTB	S3	16.11	2.53	32.04
Leghong	S4	21.70	2.42	52.80
Troukwet	S5	19.34	2.55	81.86
Nkounny 2	S6	10.57	2.55	64.17
Nkounny	S7	9.47	2.47	30.54
Lèh	S8	1.90	2.46	49.17
Maximum		21,70	2.55	85.77
Minimum		9.47	2.42	30.54
Average		15.61	2.51	57.54

NB: LB2: Bamendou High School 2; LBT: Technical High School Bamendou.

Dreux (1985) qualifies concretes according to the degree of cleanliness of the sands used. The sand equivalent of the studied materials ranges from 30.54 to 85.77% with an average of 57.86%. This result is close to that obtained by Ngapgue et al. (2009) in Batié Cameroon (ES = 71.16), indicate that this is a slightly clayey sand with respect to the recommendations indicated by NF P18-598 (1979) standard. However, the value of 57.86% is far from that obtained by Tatiana et al. (2016) in Santchou Cameroon (ES = 87.76) during a study on the characterisation of alluvial sands from Santchou (West Cameroon) for use in civil engineering. In view of the above, this difference is sufficient proof for the difference in cleanliness between alluvial and eluvial sands from the West Cameroon highlands. The low value of sand equivalent for some materials is not surprising. These sands are associated with clays, which are derived from the alteration of feldspars (orthose or plagioclase) and micas in a dry and humid tropical climate. In addition, the method of extraction and washing of these construction materials also contributes to an increase in the fine particle content of these sands, rendering some samples with a sand equivalent of less than 70 unusable for the production of better quality concrete. Overall, Bamendou sand is not recommended for concrete production, as its cleanliness is too low. If used, this sand could contribute to the premature deterioration of structures.

The summary of void index, porosity and other identification parameters such as water content, absolute density and dry density are presented in **Table 2**.

4.2. Particle Size Composition of Materials

The particle size composition of the natural and corrected materials is shown as a curve in **Figure 2**.

Table 2. Geotechnical parameters of the Bamendou sand.

Sand	ρs (g/cm^3)	ρd (g/cm^3)	e	n	Gs	Sr (%)
S1	2.55	1.40	0.81	0.44	2.55	38.53
S2	2.51	1.19	1.10	0.52	2.51	42.05
S3	2.53	1.22	1.06	0.51	2.53	43.04
S4	2.42	1.14	1.11	0.52	2.42	46.98
S5	2.55	1.28	0.98	0.49	2.55	51.25
S6	2.55	1.21	1.10	0.52	2.55	24.39
S7	2.46	1.14	1.14	0.53	2.46	20.34
S8	2.46	1.22	1.01	0.50	2.46	40.91
Maximum	2.55	1.40	1.14	0.53	2.55	51.25
Minimum	2.42	1.14	0.88	0.44	2.42	20.34
Average	2.50	1.22	1.04	0.50	2.50	38.44

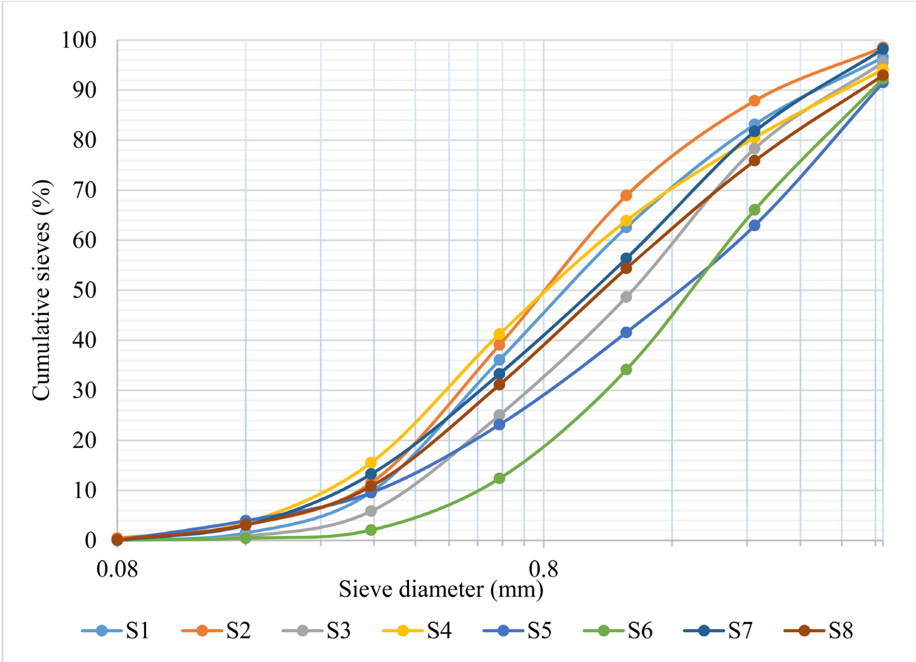


Figure 2. Particle size distribution curves of the natural sands of Bamendou.

From the granulometric analysis of the studied sands, the results of the fineness moduli (FM) of the said materials are obtained. These values vary from 2.91 to 3.92 with an average of 3.31. These values being close to those obtained by Ngapgue et al. (2009) in Cameroon (MF = 3.32) and Tchouata et al., 2020, (MF = 3.10), are furthermore far from those obtained by Bouaziz et al. (2010) in Southern Algeria (MF = 2.8). These results indicate and confirm that these materials do not belong to the prescribed range to which a fineness modulus should belong, for obtaining a quality concrete (2.2 ≤ MF ≤ 2.8). In the Canadian General Specifications and Guidelines (CCDG) classification system, a soil is a sand when it contains less than 50% of the particles passing through the 80 µm sieve and therefore more than 50% of the particles retained on this sieve passing through the 5 mm sieve. A soil is fine sand when it contains more than 50% of particles passing the 315 µm sieve. Coarse sand is soil with less than 50% of particles passing through the 1.25 mm sieve. According to the Canadian General Specifications and Guidelines (CCDG) classification (**Table 3**), the sands of Bamendou are medium sands, except for the sands of Bamendou Technical High School, Troukwet and Nkounny 2 which are coarse sands.

With regard to the values of the uniformity and curvature coefficients (**Table 4**), the Bamendou sands are spread out and poorly graded, with the exception of sample S3. These sands are marked by the absence of certain diameters between D10 and D60.

Table 3. Parameters for particle size analysis of the materials studied.

Sable	Passing Screen 5 mm (%)	Passing Screen 1.25 mm (%)	Passing Screen 0.315 mm (%)	Passing Screen 0.08 mm (%)	MF
S1	96.72	62.67	9.71	0.0001	3.10
S2	98.56	68.93	11.49	0.45	2.90
S3	95.56	48.66	5.86	0.035	3.45
S4	94.13	63.91	15.56	0.04	3.00
S5	91.53	41.58	9.54	0.04	3.66
S6	92.27	34.13	2.07	0.07	3.92
S7	98.21	56.36	13.27	0.06	3.13
S8	92.96	54.37	10.84	0.13	3.31

Table 4. Uniformity coefficients and coefficient of curvature of the materials studied.

Sand	D_{10}	D_{30}	D_{60}	C_u	C_c
S1	0.31	0.55	1.05	3.33	0.91
S2	0.31	0.52	1.05	3.35	0.83
S3	0.39	0.47	0.84	2.13	0.67
S4	0.23	0.47	1.05	4.43	0.90
S5	0.31	0.83	2.31	7.33	0.96
S6	0.65	1.09	2.19	3.65	0.91
S7	0.27	0.56	1.51	5.55	0.76
S8	0.31	0.62	1.56	5.00	0.80
Maximum	0.6	1.09	2.31	7.33	0.96
Minimum	0.23	0.47	1.10	3.5	0.71
Average	0.34	0.68	1.58	4.75	0.84

5. Conclusion

At the end of this work on the characterisation and valorisation of Bamendou sands in the formulation of concrete, the identification and classification of the eight (08) sands samples taken from the most representative quarries show that they are mainly clayey, as their sands equivalents vary between 30.54 and 85.77 with an average of 57.54. However, with regard to the statistical distribution of the materials according to their state of cleanliness, 50% are sandy-clayey in nature, which predisposes them to a risk of shrinkage or swelling, hence their rejection for quality concretes; 25% are slightly clayey sands, hence their potential admission for common quality concretes when shrinkage is not particularly feared; and 25% are very clean sands. In terms of grain size of the studied sands, several do not fit into the range of good sands for the production of quality concrete. The determination of the fineness moduli shows that they vary from 2.9 to 3.92 with an average of 3.3. Therefore, according to their statistical distribution, 50% are medium-coarse sands, which are usable sands for achieving high strengths, but have poor workability and a risk of segregation; 25% are sands that are well suited for achieving satisfactory workability and good strength with limited risk of segregation; and 25% are very coarse sands, to be rejected.

The studied sands should undergo an improvement in the washing quality in order to evacuate as many fine particles as possible; a contribution of approximately 46.14% of corrective sand is necessary to modify the granulometry; the using mode of these materials in the formulation of the concretes should not be done with the method known as "Common", but according to a process which takes into account several geotechnical parameters, in order to guarantee a better resistance in compression at 28 days. This will have the impact of either reducing the use of steel reinforcement in the design of structures (economic impact) or increasing the lifespan of structures (infrastructure impact).

Conflicts of Interest

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

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