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Research paper

Physical and mechanical characterization of aggregates in Burkina Faso: implications for use as endogenous knowledge in civil engineering

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Abstract

Aggregates are the world's most widely exploited resource, surpassing even fossil fuels. They are mainly used for concrete production. On the one hand, due to restrictions on the use of river sand in some parts of the world to conserve river beds, demand for alternative fine aggregates in the construction sector has increased considerably. The need to characterize and continuously update local and site-specific information on crushed aggregates and natural sand, in order to stimulate optimal use, is essential. As a contribution to strengthening the use of local aggregates in civil engineering, this study focuses on the characterization of aggregates. The various analyses enabled us to determine properties such as specific weight, grading class, flattening coefficient (only for crushed aggregates) and sand cleanliness (sand equivalent). Densities (apparent and absolute) meet the specifications of standard NF EN 12620, which stipulates an apparent density of between 1300 kg/m³ and 1600 kg/m³ and an absolute density of between 2500 kg/m³ and 2700 kg/m³. The results revealed a fineness modulus of 1.8. In view of this result, the sand complies with the requirements of standard NF P 18-541, which sets a fineness modulus of between 1.8 and 3.2, depending on the deposit, and requires an optimum modulus of 2.5. The (LA) results for 5/15 and 15/25 aggregates give values of 20.2% and 28.8% respectively. Analysis of the results shows that the aggregates studied are acceptable for concrete production.

Keywords: *Characterization; Natural Sand; Crushed Aggregates; Concrete; Civil Engineering.*

1. Introduction

Rocks and their weathering products are the most abundant natural resources used in building technology, civil engineering and infrastructure development [1]. Based on their availability and operability, demand for and use of them in civil engineering projects has increased considerably over the last few decades [2]. Disposal of industrial by-products, on the other hand, is a serious challenge due to stringent environmental requirements. The use of industrial by-products as an alternative to fine aggregates in concrete is a reasonable long-term approach to excessive river exploitation and the disposal of industrial by-products. Although previous research on alternative fine aggregates is available, a comprehensive assessment taking many industrial by-products into account is lacking [3]. In some parts of the world, particularly in developing countries, infrastructure and public works construction is booming with growing concerné [4]. This is because people and companies sometimes use these materials without prior knowledge of their properties. One of the resulting consequences is the premature destruction of structures. In Adrar (southern Algeria), whether in arid or semi-arid zones, dune sand is available almost everywhere. This material contains more than 50% fine grains with a diameter of less than 1 mm. It is essential to emphasize that the use of dune sand in concrete without correction of its grain size poses several problems, such as discontinuity of the grain curve, low consistency in the fresh state and low compressive strength in the hardened state.

The selection of concrete constituents; their properties; the hydration of the binder used; the workability of concrete and its characteristics in the fresh and hardened states are parameters that can be influenced by various factors. Over the past four decades, geotechnical knowledge and characterization of construction materials has increased considerably in Cameroon [5]. Researchers' interest in the chemical, physical and mechanical behaviour of these materials used for civil engineering purposes is still very much alive and kicking. Thus, it is necessary to characterize and continuously update information at local and site scale, in order to stimulate optimal use. To date, however, no preliminary study has been carried out on the geotechnical characterization of pyroclastic materials in this area. Thus, as a contribution to strengthening the use of pyroclastic materials in civil engineering, the present study focuses on the physical and mechanical characterization of pyroclastic rocks in Burkina Faso. In addition, this study continues to document and explain particle size correction, with the aim of improving the quality and durability of structures. Our work will firstly present the materials, then show the methods used to characterize the aggregates, and thirdly discuss the results obtained from the analyses.

2. Materials and methods

2.1. Aggregate sampling

The aggregates used for our glass recovery experiment are essentially 15/25 aggregate, 05/15 aggregate and natural sand. They were sampled on September 05, 2022 at the KANAZOE et Frères (KF) site in Koubri (Ouagadougou).

2.2. Sampling

Aggregate sampling refers to the methods used to select a subset of aggregates within the sampled heaps in order to estimate the characteristics of the whole.

In order to carry out the glass recovery experiment in the construction field, while complying with current civil engineering standards, we worked with the Laboratoire National du Bâtiment et de Travaux Publics (LNBTP). Test samples included natural sand and crushed granite in sizes 5/15 and 15/25.

2.3. Sample distribution

In this part of the work, we proceeded to homogenize the heaps. Each heap, now a homogeneous mixture, will be divided into four equal parts and reduced to two heaps by summing the opposite parts. We continued the splitting operation with one of the heaps until we obtained a homogeneous mass acceptable for testing (i.e. 6kg). This process, identical for all the above-mentioned piles, was spread over a period of one hour. Figure 1 shows photos of the natural sand, 5/15 and 15/25 crushed aggregate samples.

Fig. 1 : Photos of Samples of Natural Sand, Crushed Aggregates 5/15 and 15/25

After separation and labeling, each sample is sent to a specific test section to determine properties such as specific weight, particle size class, flattening coefficient (only for crushed aggregates) and sand cleanliness (sand equivalent).

2.4. Methods

Physical analyses were carried out at the Laboratoire National de Bâtiment et des Travaux Publics (LNBTP).

Water content was determined in accordance with standard NF P 94-050. AFNOR 1991 Paris, which prescribes the weighing of pyroclastic materials sampled on site and after oven-drying at 105°C to a constant mass corresponding to the mass of the dried materials. Particle size analysis has three aims: to determine grain size, to identify the proportions of grains of the same size (% by weight), and to deduce the fineness modulus (Mf). The dry mass (Ms) of the sample subjected to particle size analysis is calculated as follows:

$$M_S = \frac{M_{1s}}{M_{1h}} M_h \tag{1}$$

Granulometry therefore consists in fractioning aggregates using a column of sieves with standardized mesh sizes decreasing from top to bottom between 80 mm and 0.063 mm in accordance with standard NFP 18-560. The percentage of the mass of accumulated rejects (P_{mar}) is calculated as follows :

$$P_{mar} = 100 \times \frac{M_{i1}(R_n + T_n)}{M_{s1}} < 2\% \tag{2}$$

The flattening coefficient was determined in accordance with standard NFP 18-561

$$A = 100 \times \frac{\Sigma M_e}{M} \tag{3}$$

Based on the parameters obtained above, the fineness modulus (Mf) was reduced.

The fineness modulus Mf is an important characteristic, especially for sands. The test is carried out on a 121 g sample of the sand to be studied. Sieving is carried out wet, to avoid losing any fine elements.

The sample is washed according to a standardized process. A "washing" solution is used to separate the fine clay elements and cause flocculation. After settling, we measure the height of flocculated fines (clean sand + fine elements = h1) and the height of clean sand (h2 if using a piston or h'2 if using a ruler). In accordance with standard EN-933-8, sand equivalent (SE) is calculated for each specimen with decimal precision, and the arithmetic averages are rounded to the nearest whole number. The formula for sand equivalent is as follows :

$$SE = \frac{h_2}{h_1} \times 100 \quad (4)$$

Sedimentometry aims to determine the mass and volume of the test sample, and to calculate its actual density. Mass is calculated by weighing the sample after drying it in an oven for 08 hours. The volume is determined from the weight of the volume of water displaced by the dry particles, either by reducing the weight in an immersed metal basket, or in a pycnometer of known volume.
The actual pre-dried density is as follows:

$$\rho_p = \rho_w \frac{M_2 - M_1}{M_4 - (M_3 - M_4)} \quad (5)$$

3. Experimental process

3.1. Particle size analysis

- Washing

In the case of particularly clayey materials, the sample is soaked for 04 hours prior to washing. The wet sample, together with any soaking water, is poured onto one or more discharge sieves protecting the washing sieve. The mesh size of the washing sieve corresponds to the smallest mesh size of the column used for sieving. Care must be taken to ensure that the water does not overflow the washing sieve. This can be done using a vibrotamis with non-vertical vibrations. The material is considered to be correctly washed when the water flowing under the washing sieve is clear.
The sieve is either disposed of with the wash water, or recovered for further analysis. Figure 2 shows a photo of the washing process.

Fig. 2: Photo of Sieve Washing.

The reject is recovered and dried in the oven for 08 hours until a constant mass is obtained. The corresponding mass is Ms1.

3.2. Sieving

The process, which takes 2 minutes per sieve, is as follows:

- Pour the washed and dried material into the sieve column. This column is formed by interlocking the sieves, sorting them from top to bottom in descending order of mesh size.
- Shake the column manually or mechanically, then take up the sieves one by one, starting with the one with the largest opening and fitting a bottom and lid. Shake each sieve by tapping the frame evenly by hand.
- Generally speaking, a sieving operation can be considered complete when the reject on a sieve does not change by more than 1% in one minute of sieving.
- Pour the sieved material collected at the bottom onto the next lower sieve.

Fig. 3 : Shows Images of the Sieves, Scales and Brushes Used.

Figure 3 : Photo of sieves, scales and brushes

- Weighing
- The maximum allowable reject on each sieve must be less than : 100 g if d < 1 mm, 200 g if d between 1 and 4 mm and 700 g if d > 4 mm.
- Weigh the reject of the sieve with the largest mesh. Let R1 be the mass of this reject.
- Repeat the same operation with the next-lowest sieve; add the reject obtained to R1 and weigh the whole. R2 is the combined mass of the two rejects.
- Repeat the same operation with all the sieves in the column to obtain the masses of the various accumulated rejects R3, R4, ..., Ri, ..., Rn.
- Weigh the last sieve, if any. Let Tn be its mass.
- If, after the test, the results show that one (or more) sieve(s) has (have) been overloaded, the test must be repeated manually using this sieve(s)..

3.3. Sand equivalent test (NF P 18-598)

This test took place on September 12, 2022, as follows:

- Fill with washing solution up to the first line,
- Place the mass of material mh = 120 (1 + w) in the test tube,
- Soak sand for 10 min in washing solution.
- Shake the test tube (60 cycles in 30 s), wash the sand with the washing solution, and fill up to the second line.
- Start settling, duration 20 min.
- Measure sand height h1 of sand plus flocculate.
- Measure sand height h2 at piston.

Fig.4 : Shows A Photo of the Sand Equivalent Test Procedure.

3.4. Procedure sedimentometry

For the sedimentometry procedure, you need to :

- Maintain the water bath at a temperature of (22±5) °C throughout the test until constant mass is reached.
- Allow to cool to room temperature for 30 min.
- Weigh the pycnometer and its funnel (M1). Carefully place the test sample into the pycnometer. Insert funnel into pycnometer and weigh (M2).

Note 1: To prevent the funnel from sticking to the pycnometer, a small amount of silicone gel can be applied to the contact area before weighing.

Fill the pycnometer with water at (22±3) °C, up to approx. 03 minutes from the lapped part of the neck. Carefully stir the pellets with the glass rod to remove occluded air and adhering air bubbles.

Note 2: this can also be achieved by rotating and tapping the pycnometer, or by placing it on a vibrating table.

Once the air has been eliminated, refill the pycnometer (with the funnel installed) with water up to approx. 20mm from the mark on the funnel, and place in the water bath at a temperature of 22±3°C for approx. 1 hour.

Note 3: The water level in the water bath should be about 20mm below the neck of the pycnometer.

Fill the pycnometer with water up to the mark. Remove the pycnometer from the water bath, carefully dry the outside walls and weigh (M3). Repeat the procedure with the second test sample.

Record all weighings with an accuracy equal to or greater than 0.1% of the test sample mass (M2-M1). Figure 5 shows the procedure for extracting air from sample boxes.

Fig. 5 : Photo of Air Extraction Procedure in Sample Boxes.

4. Results and discussion

4.1. Particle size analysis

The results obtained in application of standards NFP 94 050, NFP 18 560 AG and P18 553 respectively for the parboiling method, particle size analysis by sieving and the definition of how to prepare a test sample are presented in Table 1.

Table 1: Preparation of A Particle Size Analysis Test

Aggregate Characteristics Test on September 12, 2022	Natural sand	Crushed 15/25	Crushed 5/15
M1h(g)	461	411	456
M1s(g)	445	411	456
Mh(g)	4455	4244	4288
Ms(g)	4300	4244	4288
Ms1(g)	4179	4219	4252
Ri (%)	0,21	0,47	0,21
Rn+Tn	4170	4199	4243

- M1h: total wet weight
- M1s: total dry mass
- Mh: wet mass of test sample
- Ms=Mh (M1s/M1h): dry mass of test sample
- Ms1: total mass of sample after washing
- Ri: percentage of mass of accumulated rejects

A granulometry test is carried out on a sample of aggregate in the laboratory. Granulometry consists in fractioning aggregates using a column of sieves with standardized mesh sizes decreasing from top to bottom between 80 micrometers and 0.063 micrometers, in accordance with standard NFP 18-560.

To ensure the validity of the particle size analysis, standard NF P 18-560/NF P 18-561 stipulates that the sum of the masses, Rn and Tn, must not differ by more than 2% from the mass Ms1. This condition was verified for all the Rn+Tn values of all the aggregates studied. This leads us to validate the particle size analysis of natural sand and crushed granites 5/15 and 15/25.

4.1. Measuring the flattening coefficient (NFP 18-561)

Determining the flattening coefficient is one of the tests used to characterize the more or less massive shape of aggregates ranging from 4 mm to 80 mm. The reject of each granular class is then sieved on the corresponding E-gap sieve. The production of cement concrete, as well as the manufacture of pavement bodies and wearing courses, requires the use of only aggregates with a fairly compacted shape, to the exclusion of flat aggregates. Flat aggregates are not suitable for producing very compact concrete, and cannot be used in road construction because they lead to slippery wearing courses. The flattening coefficient is obtained by carrying out a double particle size analysis, using a series of standardized square mesh sieves and a series of standardized slotted sieves for the same aggregate sample. The flattening coefficient was determined for 5/15 and 15/25 aggregates. Figures 6 and 7 show the flattening coefficient test curves for 5/15 and 15/25 crushed aggregates.

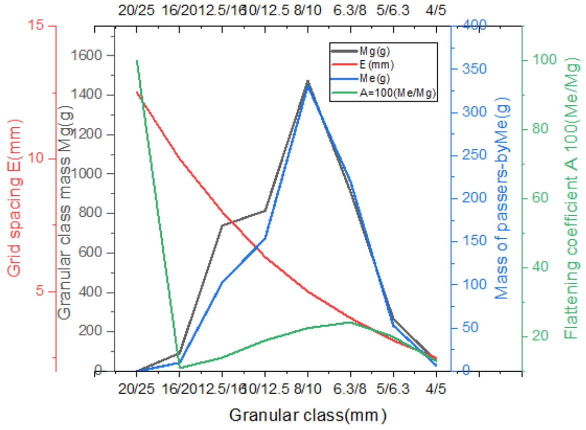

Fig. 6: Crushed 15/25.

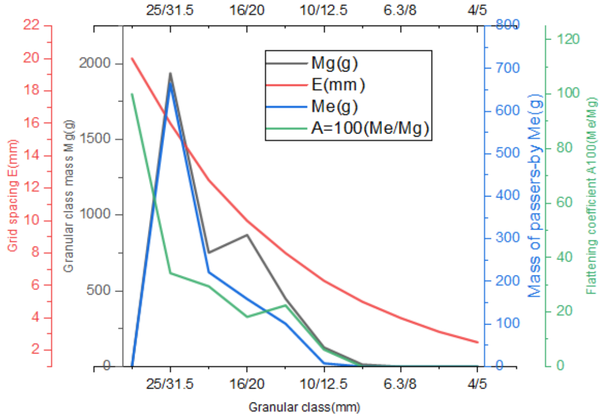

Fig. 7: Crushed 5/15.

The minimum mass of the Mg (g) granular class gives a value of 00g, a grate spacing E(mm) of 12.5, a mass of Me(g) passings of 00g and a flattening coefficient 100(Me/Mg) with a value of 100 for a granular class(mm) and 20/25 for the 5/15 aggregate. That of the 15/25 aggregate is 00g with an E(mm) grid spacing of 20 mm, a Me(g) passer mass of 00g and a 100(Me/Mg) flattening coefficient with a value of 100 for a 31.5/40 granular class. The maximum mass of the Mg(g) granular class is 1470g with an E(mm) grid spacing of 5mm, a Me(g) bypass mass of 331g and a flattening coefficient 100(Me/Mg) with a value of 22.47 for a granular class of 8/10 for the 5/15 aggregate. The maximum mass of the Mg(g) granular class is 1938g with an E(mm) grid spacing of 16mm, a Me(g) passer mass of 665g and a 100(Me/Mg) flattening coefficient of 27.82 for the granular class and 25/31.5 for the 15/25 aggregate.

The sum M of the masses of the granular class Mg (M=ΣMg) is equal to 4348g for the 5/15 aggregate and the mass of the reject at the 4mm sieve (Mo) is 4349g. M must not deviate from Mo by more than 2%. This assumption is verified for both 5/15 and 15/25 aggregates, as the differences between (4349g and 4348g for 5/15 aggregate) and (4152g and 4151g for 15/25 aggregate) do not exceed 2% of M. The overall flattening coefficient A =100(Σme/M) =20.19% for 5/15 aggregate and 27.82% for 15/25 aggregate with Σme sieve spacing E(mm). Crushed aggregates offer good wear resistance, bearing in mind that standard NF P 18-572 requires maximum tolerated values of less than 35%.

4.2. Characterization of crushed granites and natural sand

The various analyses enabled us to determine properties such as specific weight, particle size class, flattening coefficient (only for crushed aggregates) and sand cleanliness (sand equivalent). Table 5 shows the aggregate characteristics.

Table 2 : Aggregate Characteristics

Aggregate Characteristics	Sand	Crushed 15/25	Crushed 5/15
Grading - d/D	0/5	16/25	6,30/12,5
Fineness - 1%	3,5	1,0	1,0
Fineness modulus - MF	1,830	-	-
Surface cleanliness - P%	-	0,8	1,3
Flattening coefficient - A%	-	27,8	20,2
Sand equivalent - ES	80	-	-
Los Angeles coefficient - LA	-	26	28,0
Real density - MVR(kg/cm^3)	2,69	2,73	2,72
Apparent density - MVA(kg/cm^3)	1,60	1,55	1,56

Densities (apparent and absolute) meet the specifications of standard NF EN 12620, which stipulates an apparent density of between 1300 kg/m³ and 1600 kg/m³ and an absolute density of between 2500 kg/m³ and 2700 kg/m³ for clean sand. The results in the table show that the fineness modulus is equal to 1.8. In view of this result, the sand complies with the requirements of standard NF P 18-541, which sets a fineness modulus of between 1.8 and 3.2, depending on the deposit, and requires an optimum modulus of 2.5. Aggregates acceptable for concrete production must have a LA≤ 40% coefficient in accordance with French standard NF P 18-573. The (LA) results for

5/15 and 15/25 aggregates give values of 20.2% and 28.8% respectively. We can therefore say that the Los-Angeles coefficients are satisfactory for these aggregates.

[12] suggested that the compressive strength of concrete decreased when dune sand content exceeded 60%. Thus, the compressive strength of concrete is always related to the nature of the sands in the concrete [7]. According to [9], the compressive strength results of concrete prepared with crushed sand were better than those of concrete prepared with natural sand, because the properties of crushed sand were better than those of natural sand. They show that maximum compressive strength was achieved with a replacement rate of 40-50% of the crushed sand used [9].

According to [11] [12] the most desirable aggregates for concrete are those with high proportions of cubic particles (increasing the compactness of the granular skeleton) and roughness (increasing paste-aggregate adhesion. In the same dynamic [8], we demonstrate that aggregate shape and roughness can imply greater difficulty for air bubbles to extract from concrete during vibration. They also found that the fineness modulus of dune sand is low when it contains fine grains, and its granular distribution is outside the reference range, requiring correction with natural sand. According to [8], the excellent mixing ratio that gives an acceptable fineness modulus is 60% natural sand + 40% dune sand, and also has better compressive strength than concrete with dune sand. Looking at the results of the various researchers above, we can say that, in general, there is no method of concrete composition that is universally recognized as the best. Concrete composition is always the result of a compromise between a series of generally contradictory requirements. However, a concrete composition method can be considered satisfactory if it produces a concrete that complies with the following specifications.

Experimental studies have shown that grain size and maximum aggregate size have an impact on the relative proportions of aggregates, the quantities of binder and water required, workability, porosity, shrinkage and durability of concrete. Any variation in aggregate size has a serious influence on the uniformity of concrete from one batch to the next [10]. According to [13], aggregates with neither a great deficiency nor an excess of particles of a given diameter and with a regular grading curve give the best results. Variety in particle size helps to reduce the total volume of voids between aggregates. Ravindrarajah and his team have shown the influence of crusher selection and old concrete performance on the regularity of particle size curves [2]. On the other hand, according to [6], crushed sands require a higher dosage of admixture to overcome the unfavorable particle shape and texture. The shape of crushed sand particles has a significant effect on the cross-linking of paste particles and aggregates, leading to an improvement in the compressive strength of concrete.

Based on the results obtained, we can say that these aggregates are suitable for use in civil engineering.

5. Conclusion

In conclusion, the natural sands and crushed aggregates studied have characteristics that make them suitable for use in concrete formulations. Indeed, the Los Angeles and sand equivalents provide information on aggregate hardness and sand cleanliness respectively. Our analysis confirms a better distribution of grains, ideal for improved concrete compactness. In addition, a more comprehensive study of the various parameters could influence a concrete made with these sands and aggregates. Complementary characteristics were determined (size distribution derived from granulometry). Concrete is a material that is often perceived as a potential site for waste, due to its composite nature and because it is widely used.

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