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Characterization of materials in the formulation of high-performance concrete: Case of Chad

Ignabaye Pontchombé Adolphe[1], Bianzeubé Tikri[2], Alexis Mouangué Nanimina[3], and Djonglibet Wel-Doret[4]

[1]Laboratory of Buildings and Public Works, University of N'Djamena, N'Djaména, Chad

[2]Laboratory of Resistance of Materials and Mechanical Construction (LRMCM), Polytechnic University of Mongo, N'Djamena, Chad

[3]Mechanical Engineering Department, Higher National Institute of Sciences and Technics of Abéché (INSTA), Abéché, Chad

[4]Laboratory of Study and Research in Industrial Technology, Faculty of Applied Sciences, University of N'Djamena, N'Djamena, Chad

ABSTRACT: The formulation of high-performance concretes is deduced from that of ordinary concretes which are a mixture in the appropriate proportions of binder, aggregates, water and optionally, admixtures. These types of concrete composed of ultrafine materials, including metakaolin in the case of this study, are characterized by high mechanical resistance and good workability due to the addition of a water-reducing superplasticizer. However, for a successful formulation, materials must be carefully studied to ensure their use. This research project aims to characterize all the materials used in the composition of high-performance concrete to serve as a reference in other similar work in Chad. These are the physical, chemical and mechanical characteristics of materials including cement, gravel, sand, superplasticizer and metakaolin, coming from various locations in Chad. After analysis, the characteristics of these materials are satisfactory and comply with international standards and hence favorable for the composition of high-performance and sustainable concretes.

KEYWORDS: High-performance concretes, Metakaolin, Superplasticizer, Sustainable, Workability.

1 INTRODUCTION

The use of materials in construction must be preceded by a thorough knowledge of them. Even with good design of the structure, poor quality of its constituents can lead to its collapse. It is first necessary to identify the available resources or raw materials, study their properties and regulate their use in the best possible way. The appropriate formulation of concrete rarely attracts the attention of construction stakeholders in Chad given the high price of materials. Studies are rarely not carried out to guarantee the formulation of concrete according to the size of the structure, local environmental conditions and the nature of the mineral resources available.

Until 1940, the formulation of concrete was very simple: 800 liters of gravel, 400 liters of sand, 4 to 8 bags of cement and plenty of water [1]. However, innovations are being made to encourage the construction of structures subject to greater loads, more severe environmental constraints and also new technological or aesthetic constraints. It was finally in 1980 that we discovered the way to improve the properties of concrete with the addition of ultrafine mineral additions and plasticizer-type admixtures, leading to the production of High Performance Concrete (HPC). This concrete is characterized by high compressive strength (>50MPa at 28 days), good workability and a very dense microstructure observed with a Scanning Electron Microscope [2].

The performance of concrete is induced by that of its constituents, hence resistant materials give more efficient concrete. Aitcin P.C. concluded that the use of mineral additions in the manufacture of high-strength concrete is a preferable alternative, because the introduction of a certain quantity of mineral additions facilitates the maintenance of the rheological properties of fresh concrete [3]. In the case of this study, we used kaolin because it is quite widespread in Chad but little known. This, once treated and calcinated, allows to obtain metakaolin which, added to the concrete, essentially plays a granular role by filling the micro-voids and a pozzolanic role by combining with lime during the hydration of the cement to form hydrated calcium silicates. The best known deposits are those of Aboudeia in the Salamat region and in the south of the country: East of Pala, near Kelo, in Maïssou 75km from Moïssala and also near Mbaïnamar [4].

The objective of this work is therefore to present, through laboratory tests, the characterisation of the materials used during our research work for of formulating high-performance concretes in Chad. We will therefore concisely present all the materials used, their origin as well as the properties obtained following the various tests.

2 Material And Method

2.1 Material

2.1.1 Cement

The cement used is a Portland compound cement, designation CEM II 42.5R, from the CIMAF TCHAD cement plant in N'Djamena (Sadjéré) on the way to Lamadji.

2.1.2 Aggregates

The aggregates analyzed are fine sand, coarse sand and gravel. The sand is obtained from the Chari River while the gravel is obtained from the blasting and crushing of granite exploited by the Société Nouvelle d'Etudes et de Création (SNER) at the Hadjer Lamis quarry.

2.1.3 Superplasticizer

The superplasticizer used is Sika ViscoCrete® Krono-20 HE from Cameroon from the SIKA Company which produces construction materials and additives.

2.1.4 Metakaolin

The kaolin ordered for the study is obtained from the Salamat region but sold on the local market. Metakaolin was therefore obtained by calcination of the latter at high temperature.

2.2 Method

The working procedure consisted of identifying and choosing the materials commonly used for the formulation of concrete. The characterization therefore consisted of carrying out laboratory tests on each material to define its properties. These include physical, chemical and mechanical tests, which are carried out according to each type of material as follows:

- Cement: Its characterization consisted of highlighting its chemical and mineralogical properties (SO_3 and chloride content), physical (density, specific surface area) and mechanical properties (consistency, compressive strength);
- Aggregates: For all aggregates (fine sand, coarse sand and gravel) we have carried out particle size and density analysis tests but only the Los Angeles test for gravel;
- Metakolin: Its characterization was conditioned by the heat treatment of the kaolin and then its density as well as its particle size were determined. According to Perlot, the properties of metakaolins strongly depend on their specific surface area, particle size and mineralogical composition [5];
- Superplasticizer: It has been characterized by its chemical composition, its pH, its density, etc.

3 Results And Discussions

After some characteristic tests in the laboratory, we managed to establish the properties of the different materials.

3.1 CEMENT

The cement used is CIMAF manufactured in Chad, all its physical, chemical and mechanical properties have been provided in a technical sheet after analysis in the laboratory. These characteristics are presented in Table 1 along with the standards that govern them.

Table 1. Characteristics of the cement used

Characteristics		Unity	Value
SO_3 content (NF EN 196-2)		%	≤ 2.5
Chloride content (NF EN 196-2)		%	≤ 0.01
Absolute density (NF EN 196-6)		g/cm^3	3.1
Blaine finesse (NF EN 196-6)		cm^2 /g	≥ 4400
Normal consistency (NF EN 196-3)		%	26-28
Setting time (NF EN 196-3)	Beginning / end	Hour : minute	2 :30 / 3 :30
Compressive strength (NF EN 196-1)	2 days	MPa	≥21
	7 days		≥31
	28 days		≥43

At first glance, we realize that the results obtained by the company during the various tests correspond to the French standards specified in the table above. Several values are consistent with other types of cement, such as absolute density, normal consistency and setting time. These are the same characteristics that we found for example on Robust cement manufactured in Cameroon, unlike the fineness and mechanical resistance which are slightly below those of Cimaf Chad which we used. Therefore this type of cement is indicated by its characteristics for the formulation of high-performance concrete. J. Festa and G. Dreux had already testified that the cements best suited to the manufacture of BHP for which the resistance must be close to 60 MPa (at 28 days), induced CPA-CEM I cements of classes 52.5 or 52.5 R and CPJ-CEM II/A 52.5 or 52.5 R with the use of water-reducing superplasticizer but portland cement or portland compound with strength class 42.5 N or 42.5 R by administering additions with great care [6].

3.2 AGGREGATES

3.2.1 SIEVE ANALYSIS (NF EN 933-1)

The particle size analysis was carried out on samples of fine sand (0/2 mm), coarse sand (0/5 mm) and gravel (5/15 mm). It consists of separating a material into several granular classes of decreasing dimensions using a series of sieves.

Fig. 1. Sieve analysis equipment

We call refusal on a sieve the material which is retained and sieve that which passes. The mass of aggregates lost during the analysis must not exceed 2%. We note the mass of cumulative refusals and we determine the percentages of cumulative refusals as being:

$$\%\ of\ cumulative\ refusals = \frac{Rn}{M} \times 100 \tag{1}$$

Where:

Rn is the mass of cumulative refusals in grams (g);

M is the initial mass of the sample in grams (g).

We deduce the cumulative percentages of passers-by according to equation 2.

$$\%\ of\ cumulative\ tamisates = 100 - \%\ of\ cumulative\ refusals \tag{2}$$

The analysis values allowed us to draw the particle size curves in Figure 2.

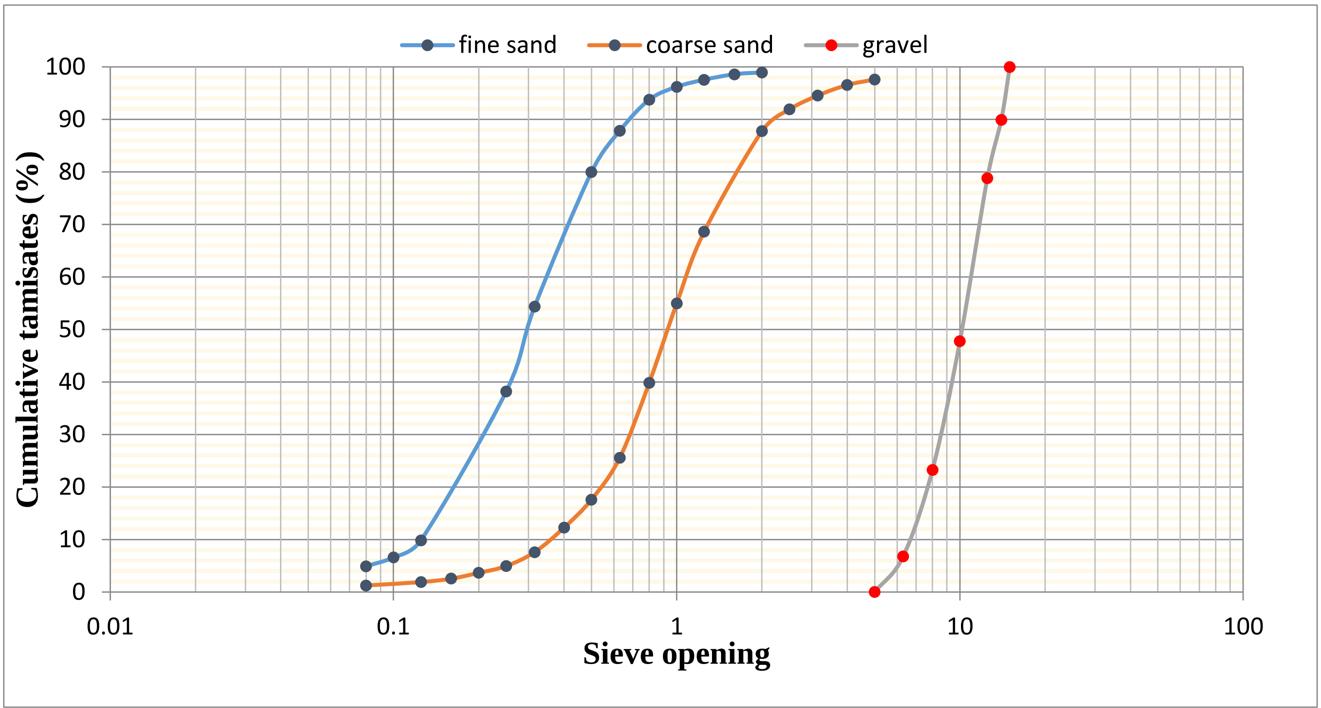

Fig. 2. Granulometric curves of aggregates

It is very important to control the fineness modulus of the sand so that the concrete can have good workability. The sand fineness modulus is obtained by making 1/100th of the sum of the refusals, expressed as a percentage on the different sieves of the 0.125-0.25-0.5-1-2-4 mm series. The fineness moduli of the two sands were calculated in accordance with the EN 12620 standard and the results obtained are mentioned in Table 2.

Table 2. Fineness moduli of the two sands

Fine sand	Coarse sand
1.78	3.39

According to these results, the fine sand used has a very low fineness modulus, which will result in a need for additional water. Also, coarse sand has a high fineness modulus so it lacks fines and the concrete will lose workability. Therefore, it is necessary to make a correction to the fineness module by mixing the two sands appropriately before any use. Abrams proposed a mixing rule based on obtaining a certain overall fineness modulus for the mixture of aggregates from knowledge of the fineness moduli of the aggregates to be used. In other words, it makes it possible to calculate the relative percentages of aggregates with fineness modules MF1 and MF2 to obtain a fineness module MF chosen for the mixture. The latter is chosen so as to reduce the voids in the mixture and has a value between 2.2 and 2.8 for a good concrete sand. The determination of the different proportions of sand according to the Abrams formula is described by equation 3.

$$S1 = \frac{MF - MF_2}{MF_1 - MF_2} \; ; \qquad S2 = \frac{MF_1 - MF}{MF_1 - MF_2} \tag{3}$$

Where:

S1 is the proportion of sand with too high fineness modulus MF_1;

S2 is the proportion of very fine modulus sand MF_2;

MF is the regulatory fineness module of the mixture.

We therefore carried out a fineness modulus correction using the Abrams formula and we obtained an approximate mixture of 50% for fine sand and 50% for coarse sand, for a regulatory fineness modulus of 2.6.

3.2.2 DENSITIES (NF EN 1097-6)

In addition to the apparent and absolute densities, other physical characteristics of the aggregates such as porosity, void ratio and compactness were determined.

Apparent density allows you to determine the density of a material with all the voids it contains. It consists of weighing aggregates using a calibrated container of precise volume (notably 1000 cm3 for sand and 5000 cm3 for gravel). To ensure the reliability of the final result, it is recommended to carry out 4 weighings, starting the test procedure each time. Successive weighings must not exceed ±25g for sand and ±50g for gravel. The apparent density is thus calculated according to equation 2.1.

$$\rho_{app} = \frac{m_1 - m_0}{v_0} \tag{4}$$

Where:

ρapp is the apparent density in kg/dm3;

m0 is the empty mass of the container in kg;

m1 is the average of the 4 weighings obtained in kg;

$V0$ is the volume of the container in dm3.

The absolute density allows us to determine the density of the aggregates without the voids. It consists of immersing the aggregates for 24 hours in order to weigh them after carefully cleaning them up. The absolute density ρab is given by the formula:

$$\rho_{ab} = \frac{m_2}{v_2 - v_1} \tag{5}$$

Where:

ρ_{ab} is the apparent density in kg/dm^3;

m_2 is the mass in kg of the saturated and cleaned aggregate;

v_1 is the initial volume of water in dm^3;

v_2 is the final volume of water containing the saturated and sponged aggregate in dm^3.

Thus the porosity P is calculated as a percentage by the formula described by NF 18-554:

$$P = \left(1 - \frac{\rho_{app}}{\rho_{ab}}\right) x \; 100 \tag{6}$$

We can deduce the compactness in the loose state as being:

CL=100-P **(7)**

Also, the void index is calculated as the ratio of porosity to compactness.

e =P/CL **(8)**

The results obtained are transcribed in Table 3.

Table 3. Characteristics of aggregates

Aggregates	Apparent density ρapp (kg/dm^3)	Absolute density ρab (kg/dm^3)	Porosity P (%)	Compactness CL (%)	Void index e
Fine sand	1.526	2.731	44.12	55.88	78.95
Coarse sand	1.510	2.567	41.72	58.28	71.59
Mixture of two sands	1.640	2.650	37.93	62.07	61.11
Gravel	1.530	3.000	49.00	51	96.08

According to these results, the absolute densities of these aggregates are greater than 2 kg/dm^3. Which means that these aggregates are of the common or normal type. The most porous aggregate is gravel. This leads to low compactness of the material and a fairly high vacuum index. Likewise, fine sand shows greater porosity than coarse sand. With the addition of the two sands, the porosity and void ratio decrease while the compactness increases. The mixture therefore offers more advantages for the formulation of concrete.

3.2.3 Los Angeles (Nf En 1097-2)

It makes it possible to measure the resistance to fragmentation by impact of the elements of a sample of aggregates combined with wear by reciprocal friction in the cylinder of the Los Angeles device in figure 3.

Fig. 3. Los Angeles device

For this test, the gravel was sieved to have a particle size of 10/14 mm. The principle consists of measuring the mass of elements smaller than 1.6 mm generated by subjecting materials to the shock of standardized balls for 15 minutes (500 revolutions) and corresponding to each granular class. After steaming, the material is weighed and the resistance to fragmentation is determined by the Los Angeles coefficient according to equation 9. For very good quality gravel, this coefficient must be less than 35%.

$$LA = \frac{m_0 - m_1}{m_0} \, x \, 100 \qquad (9)$$

Where:

m0 is the initial mass of the sample in grams (g);

m1 the result of weighing the rejects using a 1.6 mm sieve, in grams (g).

An initial mass of 4840g was taken and after following the test standards, the mass of the rejects on the 1.6 mm sieve was 2987g. The Los Angeles coefficient deduced is 38.29%, therefore slightly higher than 35%, which means that the gravel analyzed is of fair quality. It is therefore important to note that this aggregate can be used for the formulation of high-performance concrete.

3.3 MÉTAKAOLIN

The metakaolin obtained comes from traditional calcination at 750℃ for 5 hours of kaolin in the oven with a temperature rise of 5°C/min. The kaolin was passed through a 315µm sieve before calcination.

Fig. 4. Kaolin before and after calcination

The latter was analyzed and the characteristics are given in table 4.

Table 4. Characteristics of metakaolin

Characteristics	Metakaolin
Apparente density	0.76 kg/dm^3
Absolute density	2.5 kg/dm^3
Granulometry	3 µm

The absolute density corresponds exactly to that reported in the work of Gruber et Al [7]. According to the works of Measson [8], the maximal temperature of the thermal treatment of the métakaolins is also a factor influencing the density. Also, the particle size average is around 3 µm, therefore equivalent to the average recorded in the literary review. Thus, the incorporation of metakaolin will improve the compressive strength of concrete at 28 days as clearly shown by Khatib [9] in his work.

3.4 SUPERPLASTICIZER

In order to compensate for the loss of workability due to the low quantity of water in the formulation of high performance concretes, a new generation non-chlorinated high water reducing superplasticizer, named Sika ViscoCrete® Krono-20 HE was used. According to 0dler [10], the superplasticizer can delay the hold of the cement and reduce mechanical properties of the concretes to the young age.

Fig. 5. Superplasticizer Sika ViscoCrete® Krono-20 HE

These properties comply with Standard NF EN 934-2 and its characteristics have been provided by the manufacturer in a technical sheet and are summarized in table 5.

Table 5. Characteristics du superplasticizer

State	Liquid
Color	Yellowish
Density	1,085 ± 0.020
PH	4,5 ± 1,0
Function	High water reducer
Chloride ion content (Cl-)	≤ 0,1 %
Sodium oxide content (NaO2)	≤ 1 %
Dosage range	0.1 to 5.0% of the weight of the cement

4 CONCLUSION

This research work aimed to identify and characterize the materials that could contribute to the formulation of high-performance concrete in Chad. In addition to cement, gravel and sand which are known to everyone, two new products have appeared which are metakaolin and superplasticizer. Metakaolin is an ultrafine mineral substance obtained by treatment and calcination of kaolin at a temperature varying from 650 to 850°C, playing an important granular and pozzolanic role in the making of high-performance concrete. The superplasticizer is an adjuvant which, when added to the concrete in an appropriate manner, makes it possible to improve the workability of the concrete without excessive addition of water. After analysis of the materials using several laboratory tests, we can confirm that the materials studied are of good quality and comply with international codes and standards. It is therefore possible, due to their properties stated above, to use them for the formulation of high-performance concretes for the construction of large-scale infrastructures. The advantage of characterizing materials before their use is therefore to make it possible to understand the relationship between the chemical composition, internal structure, physical properties, performance and application that the material can offer.

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