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Influence Of The Fineness Modulus Of Sand On The Compressive Strength Of Its Corresponding Mortar: A Mathematical Model Proposal

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***Abstract*—This work proposes a mathematical model describing the evolution of compressive strengths of mortar with the fineness moduli of natural sand used as filler. Five different sands samples were selected from various locations analyzed through particle size distribution and the determination of their respective fineness moduli. The obtained result show that the fineness moduli varied between 2.2 and 3.3 and the organic matter content of each sand sample were below 0.5%. The values of compressive strengths of mortar specimens issued from natural sands mortars vary from 18 to 27 MPa and increase with the fineness modulus. SB3 sand (FM=3.1) and SG5 sand (FM=2.2) were mixed to vary the fineness modulus from 2.2 to 3 and the compressive strengths of each corresponding mortar specimen determined after 28 days. The compressive strength of the mortar issued from the mixed sands is observed to be greater than that issued from the natural sand of the same fineness modulus. The compressive strength of mortar and the fineness modulus of corresponding sand are related by a function of the form: y=ax+b.**

Keywords—sand, fineness modulus mortar, compressive strength mathematical model

I. INTRODUCTION

Sand is an aggregate used in many fields such as industry (glassware), civil engineering, health etc… [1]. In countries with low industrial potential, sand finds its greatest application in the construction sector, particularly in concrete manufacturing [2]. Its use in one or the other class of concrete is conditioned by its particle size distribution. Indeed, the particle size of sand varies from 0.075 to 4.75 mm, ranging from fine to coarse sands (2 to 4.75 mm) [3-4]. According to ASTM C33/ C33M [5] concrete is a composite material made of aggregate, cement and water, and usually called mortar when the aggregate used is sand of size between 0 and 5 mm. Thus, the characteristics of concrete depend on each element of the mixture according to the law of composite materials [6]. This is why the strength of a mortar is strongly dependent on the quality of the sand, as it represents more than 30% of the total volume of the material [7]. Several studies [8-12] agree that the grain size of sand strongly influences the compressive strength of the corresponding concrete. Apart from strength, another important quality of a mortar is its workability. Besides, Lefeu and Francy [13] showed that the grain size distribution of sand can be assessed by the fineness modulus, a dimensionless size that gives information on the fineness of the sand, meanwhile other authors [14-15] concluded that the fineness moduli of natural sands vary between 1.8 and 3.3 and give good quality concretes between 2.2 and 2.8. But between 2.8 and 3.3, more resistant but difficult to handle concretes are obtained. Moreover, normal sand has a fineness modulus between 2.6 and 2.8 according to standard NF EN 196-1 [16]. Thus, the fineness modulus of a given sand sample can be improved by mixing it with another sand according to the desired applications [17]. By modifying the fineness modulus of sand by mixing with another one, we can obtain compressive strengths of their corresponding mortars, cured during 28 days, before an optimization rate which can reach up to 30% of those of the mortars of the original individual sands [18-19]. However, it remains difficult to predict the compressive strength of a given concrete solely by knowing the fineness modulus of its constituent sand, and thus to know if a given as-mined sand is suitable for use in the production of concrete. Although the fineness modulus of sand has a considerable effect on the compressive strength of its corresponding mortar, there is a lack of quantitative data on the subject. So, the present study aims at modeling the compressive strength of a sand mortar as a function of its fineness modulus.

II. MATERIALS AND METHODS

II.1. Location of samples

The samples were taken in Garoua 3 sub-division, northern Cameroon, as shown in figure (1) below. Three samples (SB1, SB2, SB3) were taken in the same river Babla and SG5 and SN4 in two different rivers.

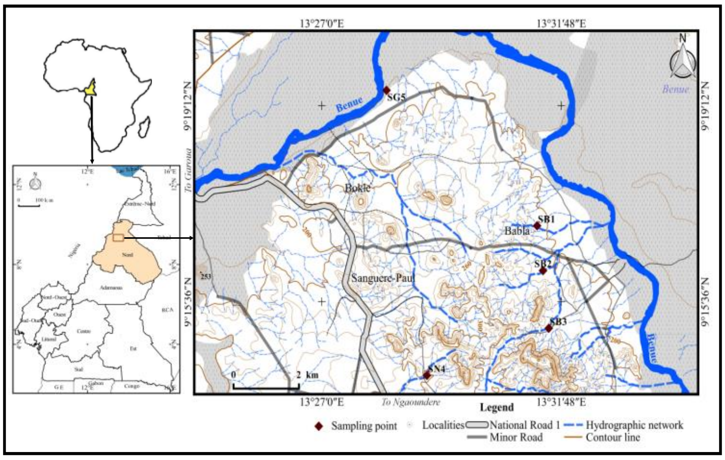

Figure 1: Location of the study area in North Region of Cameroon.

II.2. Laboratory analysis

The work was conducted in the MIPROMALO Materials Analysis Laboratory (Yaounde-Cameroon). The samples were oven-dried at 105°C for 24 hours and then heated in a furnace at 500°C for three hours to determine the organic matter content by applying the following formula [20]:

$$OMC=\frac{M1-M2}{M1}\times 100 \qquad (1)$$

Where M1 is the mass of the oven dried matter, M2 the mass of the heated matter at 500°C and OMC the Organic Matter Content expressed as a percentage.

- Particle size distribution and fineness modulus

The fineness (FM) was calculated using the formula proposed by Lefeu and Francy [13]

$$FM = \frac{Qr\,(0.125) + Qr\,(0.25) + Qr\,(0.5) + Qr\,(1) + Qr\,(2) + Qr\,(4)}{100} \quad (2)$$

Where Qr (i) is the cumulative percentage rejection corresponding to sieve (i).

- - Modification of the fineness modulus

To obtain a sand sample with a desired fineness modulus, we can amend a fine sand sample (FM1) with a coarse one (FM2) using the following formula:

FMd= aFM1+bFM2 (3)

With:

$$\begin{cases} 1 < a, b < 1 \\ a + b = 1 \end{cases} \quad (4)$$

and FMd is the desired fineness modulus [21-22].

II.3. Mortar formulation

Mortars were formulated according to NF EN 196-1 standards in which sand of grain size between 0 and 2mm contributed for 66.67% of the total mass of solid materials, Portland cement for 33.33% of the total mass of solid materials, and finally a cement/water ratio of 2. Cement was thoroughly dry-mixed with sand, and water was added afterwards. The entire mixture was hand-mixed using a spatula till a homogeneous material was obtained. The resulting mortar was moulded in cylindrical moulds of height 7.8 mm and diameter 3.9 mm, and unmoulded immediately afterwards. The specimens were then cured in open air in the laboratory for 28 days at an average temperature of 31°C and 45% average relative humidity.

II.4. Compressive strength

Compressive strength is the capacity of a material to withstand loads tending to reduce size, the maximum compressive stress that under gradually applied load a given solid material will sustain without fracture. It is calculated by the ratio between the force and the cross-section of the tested material as:

$$\sigma = \frac{F}{S} \quad (5)$$

where F is the maximal load in Newton (N), S the cross section in m² and σ the compressive strength in N/mm² [23-24].

III. RESULTS AND DISCUSSIONS

III.1. Particle size analysis and fineness modulus

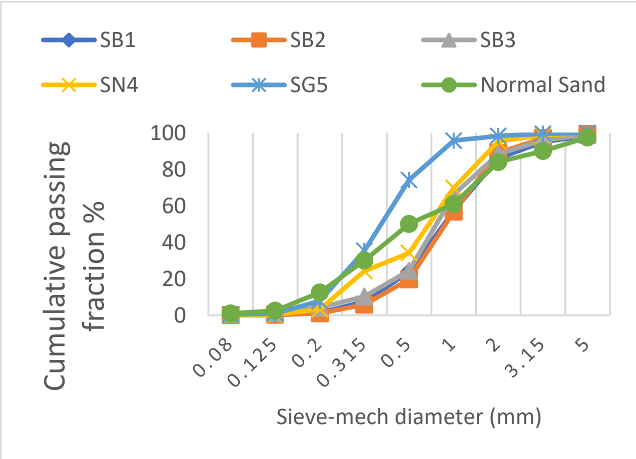

Figure 2: Particle-size distribution curves of the studied sands

The particle size distribution curves of the studied sands have an "S" shape (Fig.2), characteristic of the common curves obtained in sands consisting of elements of varied sizes [21] and similar to those obtained by Kagonbé et al. [25].

Table 1: Fineness modulus of natural sand samples

Sands	SG5	SN4	SB3	SB2	SB1
FM	2.2	3	3.1	3.3	3.3

The fineness modulus values found fall between 1.8 and 3.3 as required by the EN 12620 standard for concrete work. But these sands are not suitable for laboratory characterization of cements because their fineness moduli do not fall between 2.6 and 2.8, unlike that of normal sand [26]. So these natural sands can be used for cement characterization if their fineness moduli are not modified.

III.2.Moisture and organic matter contents

The table 2 below gives the relative moisture and organic matter contents of each sand sample.

Table 2: Moisture and Organic Matter Content of Samples

Sample	Organic matter content (%)	Moisture content (%)
SB1	0,36	0,08
SB2	0,37	0,13
SB3	0.31	0,09
SN4	0,26	0,07
SG5	0,39	0,14

The organic matter content values found are all below 0.5%, as recommended by the ASTM C40 standard (2004).

III.3. Compressive strengths

Table 3: Compressive strength of concrete issued from different natural sands

Sand sample	Fineness Modulus	Compres-sive strength (N/mm²)	Breaking load (kN)	Cross-section area (m²)	Mass at 28 days
SB1	3.3	27	32	0.0012	204.6
SB2	3.3	26	31	0.0012	204.5
SB3	3.1	24	29	0.0012	206
SN4	2.9	21	25	0.0012	203.3
SG5	2.2	18	21	0.0012	189.5
Normal sand	2.7	23	25	0.0011	203.3

The figure below gives the compressive strength of concrete issued from natural sands studied in relation to their respective fineness moduli.

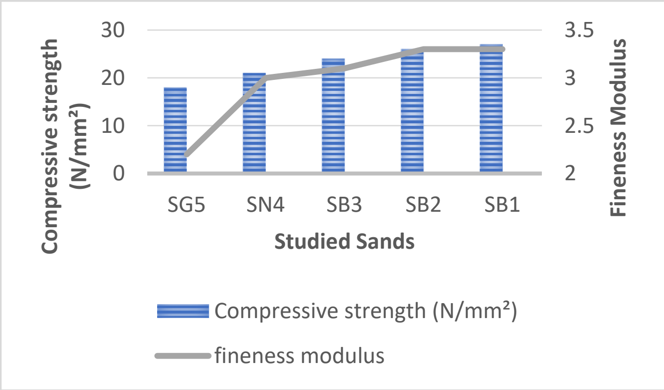

Figure 3: modulus of fineness of the studied sands and Compressive strength of corresponding mortars

The curve shows the growth of the compressive strength with the fineness modulus as we expected according to literature [1] and [18-19]. In the other hand, the compressive strength values found (between 20 and 30 N/mm²) are in accordance with the results found by the Canadian standard CAN/CSA A23.1-3C on concretes issued from mortars cured in open-air in the laboratory, but lower than those of concretes issued from mortars that have experienced wet curing [27]. However, these values are lower than those found by Wioletta et al. [28] with 42.5 portland cement, which were 35 N/mm². This difference can be explained by the fact that the mechanical resistance of CPJ35 portland cement is lower than that of R42.5 portland cement [29]. But, it is difficult to model its evolution because the difference between the values is not uniform. In addition, a difference in values of compressive strength is noted for the SB1 and SB2 sands, though having the same fineness modulus (3.3).

III.4. Sands mixing

In order to better model the compressive behaviour of a concrete as a function of the fineness modulus of the corresponding sand, we made a linear combination of the fineness moduli of the SG1 and SB3 sands according to the formula mentioned above and obtained the following table:

Table 4: variation of fineness modulus and corresponding mortars compressive strengths

Fineness modulus	3	2.9	2.8	2.7	2.6	2.5	2.4	2.3	2.2
Compres-Sive Strength (N/mm²)	26	25	24	23	22	21	20	19	18

This table gives us the values of the fineness moduli of hypothetic hybrid sands, which can be obtained experimentally. Using the Matlab software, we have drawn the function curve σ=f(FM) as shown in the figure below.

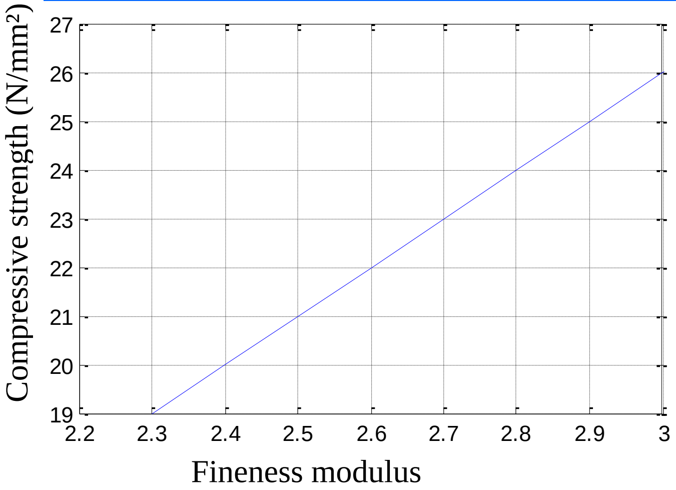

Figure 4: Compressive strength as a function of fineness modulus

This curve is similar to those found by Olsson (1974), Fredrich (1990) and Hatzor (1997). The worked respectively on marble and dolomite and showed that the rock sample's compressive strength is inversely proportional to the square of the grain size [30-32].

The curve obtained shows a linear evolution of the function linking the compressive strength of concrete to the fineness modulus of the corresponding sand. However, the values obtained here are higher than those of natural sands of the same fineness modulus. Indeed, the sand SN4 (FM=3) has a resistance of 21 N/mm², lower than that of an amended sand mortar of 26 N/mm² of the same fineness modulus. SB3 sand (FM=3.1) should in principle have a higher compressive strength. However, an amended sand with a lower fineness modulus (2.9 for example) gives a higher resistance (25 N/mm²). On the other hand, the fineness modulus 2.7 of the almond sand gives the same value as that of the standard sand. This highlights the law of composite materials linking cohesion to the arrangement of particles in the material [33].

Verification of the theory of composite materials

Indeed, 20% of SB3 sand (FM=3.1) mixed with 80% of SG1 sand (FM=2.2) gives a hybrid sand of fineness modulus 2.9 which mortar gives a compressive strength of 25 N/mm², higher than the values obtained by the SG1 and SB3 sands taken individually. However, for natural sands, one would expect a value lower than 24 N/mm². Thus, in addition to the fineness modulus, the particle size distribution of each sand sample must be taken into account to predict its behaviour in the mortar. The amendment of the sand corrects its grain size distribution and allows a better cohesion [34].

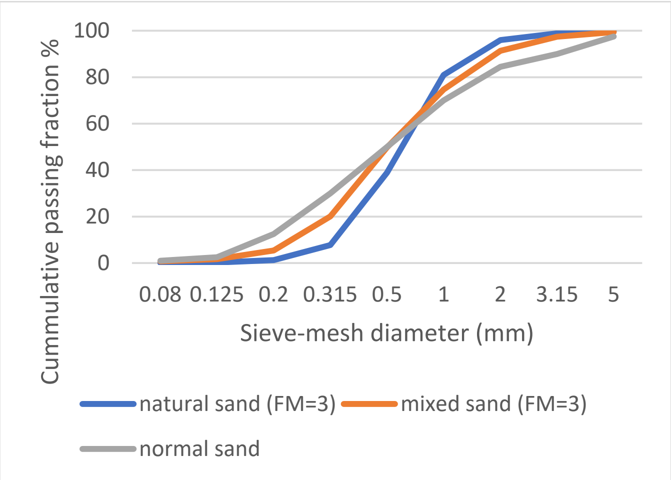

Figure 5: Particle-size distribution curves of two sands having the same fineness modulus

The particle-size distribution curve of mixed sand (FM=3) is closer to the one of the normal sand sample than is the particle-size distribution curve of natural sand SN4 (FM=3). This can explain the fact that the compressive strength of the concrete obtain by the mixed sand is greater than that issued from the natural sand.

III.5. Model proposal

From the curve obtained, an equation linking the compressive strength of a mortar according to the fineness modulus of the sand can be written as:

$$\sigma = 10FM - 4 \quad (6)$$

Normalized sand (FM=2.7) and SG1 sand (FM=2.2) satisfy this equation while the values of others deviate slightly from it, which led to the determination of the accuracy of the model by calculating the range of error.

III.6. Precision testing of the model

Table 5: Range of Formula Error: Applications to the Natural Studied Sands

Sand sample	*σ expéri – mental*	*σ calcu – lated*	***Diffe-rence***	***Error %***	***Mean error %***
SG5	18	18	0	0	10.4%
SB1	27	29	2	7%	
SB2	26	29	3	10%	
SB3	24	27	3	11%	
SN4	21	26	5	24%	

We find that the mean relative error is small (less than 10%) and that the SG5 sand allows us to verify this model which is consistent with the values obtained using the standard sand. In other words, it is possible, from the natural sands of Garoua and its surroundings, to formulate standardized sands following NF EN196.1 for the characterization of concretes in laboratories and in cement factories.

IV. CONCLUSION

-The natural sands studied are suitable for use in the building industry but not for the characterization of concrete in the laboratory because of their fineness modulus values.

- the natural sands studied can be mixed to have a hybrid sand with a suitable fineness modulus for concrete work in laboratory

-The compressive strengths of concretes increase with the fineness moduli of their corresponding sands.

-The compressive strength of an amend sand sample is greater than that of a natural sand sample of the same fineness modulus.

-The curve linking the compressive strength of a concrete specimen and the fineness modulus of the corresponding sand used is a straight line, which is confirmed by normal sand and natural sand SG5.

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