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Mechanical Characterization of Pyroclastic Products for Use in Civil Engineering Works

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Abstract: *This article presents the results of a research campaign on the quality and criteria for the use of pyroclastic products in hydraulic concretes and road construction. Their knowledge makes it possible to predict their behaviour in concrete and under other mechanical stresses. The experimental results obtained on screened samples of these aggregates shows good shock resistance and frictional wear. The Los Angeles (LA) coefficients for the 6.3/10 and 10/14 fractions are 19 and 19.80 respectively. As for wet abrasion, for the same granular fractions, the micro Deval coefficients (MDE) of 8.20 and 7 respectively are observed. The sand friability test on the 0.2/4 leads to coefficient of friability of the sand (Fs) of 10.30. These hardness coefficient values are all below 20 and therefore meet the specifications in force for the manufacture of hydraulic and bituminous concretes.*

The 28-day simple compressive strength values of hydraulic concrete formulated according to the Dreux-Gorisse method with different 42,5R Portland cement dosages of 300 kg/m³, 350 kg/m³ and 400 kg/m³ are 31.50 MPa, 34.32 MPa and 44.24 MPa respectively. The same average compressive strength at 400 kg/m³ of the mortars is 29.57 MPa. This test was extended over 90 days and conducted respectively for the same dosages at 33.58 MPa, 36.77 MPa and 47.02 MPa values, thus confirming a significant increase in the simple compressive strength of concretes over time. These results are quite innovative and suitable for quality work. The sclerometric hardness test confirms them with a determination coefficient R^2 (= 0.999) of the polishing function. As for the traction by splitting, for dosages of 350 kg/m³ and 400 kg/m³, the values of the strength are 3.34 MPa and 3.73 MPa respectively, giving these concretes "class 6" and therefore a favourable use of these aggregates for high mechanical stresses. The study of the bearing capacity parameters of these materials led to an optimal dry density of 2.07 with an optimal water content of 10.50% and a CBR at 95% of the OPM of 85. In view of these properties, the use of pyroclastics as building materials in civil engineering is of significant interest.

Key Words*: mechanics, Characterization, pyroclastic products, civil engineering.*

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I. Introduction

In Cameroon, the construction and public works sector is booming. In construction or rehabilitation work, aggregates remain one of the most widely used components and are becoming increasingly rare, especially those of good quality. Aggregates are used both in the construction of embankments and in the production of hydraulic and hydrocarbon concretes [1]. For example, the natural granitic pyroclastic aggregates from the Takouche quarry are exploited by municipalities and local populations of Bafoussam for different civil engineering works. Their form, nature and granular constitution are factors that determine the types and properties of the materials [2] resulting from them.

The objective of this study is to analyze the granular mechanical properties such as hardness, frictional wear, compressive and tensile strength of concrete based on pyroclastic products with a view to their best use for Building and Publics Works. To do this effect, aggregate samples collected from several representative points of the quarry were analyzed in the Cameroon National Laboratory of Civil Engineering. The results make it possible to determine the granular mechanical potential of these pyroclastic and to provide professionals (engineers, technicians, design offices, contractors) with data on these aggregates intended for multiple uses in construction. The result of the present work is a database, as well as proposals for an optimal use of these aggregates.

II. Methods

2.1- Location of study points and sampling

Figure 1 shows a map showing the study area of the Takouche-Baleng quarry, which covers approximately 39 hectares. It is found between 5° 34' and 5°36' of North latitude, 10° 26' and 10°28' of East longitude. Climatic conditions are typically "mountainous Cameroonian", [3] with an average annual rainfall of 1741*mm* and an average temperature of 20.2 °C.

In order to have the most representative samples of the quarry, the points chosen were those located in different areas and presenting all the apparent diversities in terms of form, colour, size and presence of voids based on a macroscopic auscultation and verification of the different existing pyroclastic profiles. For most of the points, sampling works was facilitated by using new and old trenches and embankments done by local operators. However, some trenches were specially made for the present investigation. All these samples were collected in bulk (disturbed sample) through excavations ranging from the most superficial granular layer (stratum 1) to the deepest (stratum 5). It follows samples resulting from the mixing of the five strata jointly exploited and offering an aggregate of the ungraded sand type [4]. These materials (from the mixing of all strata) were processed in the laboratory according to the specific standards for each test.

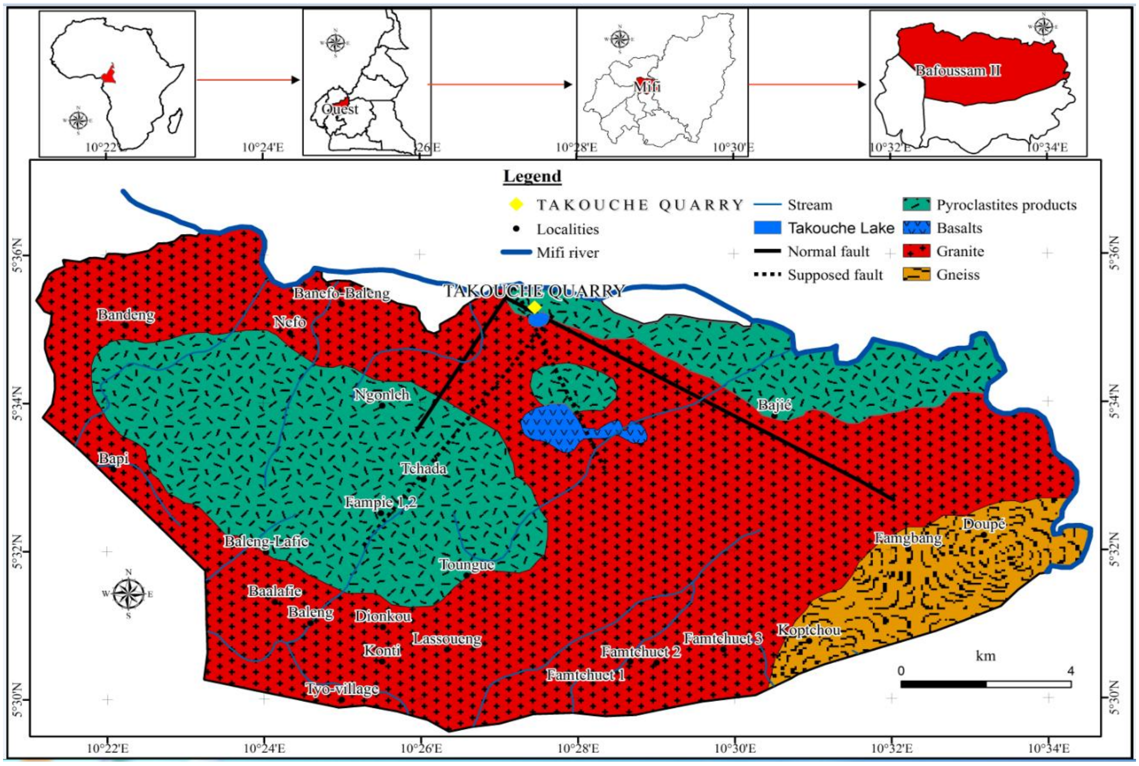

Figure 1*:* Location map of Takouche-Baleng quarry

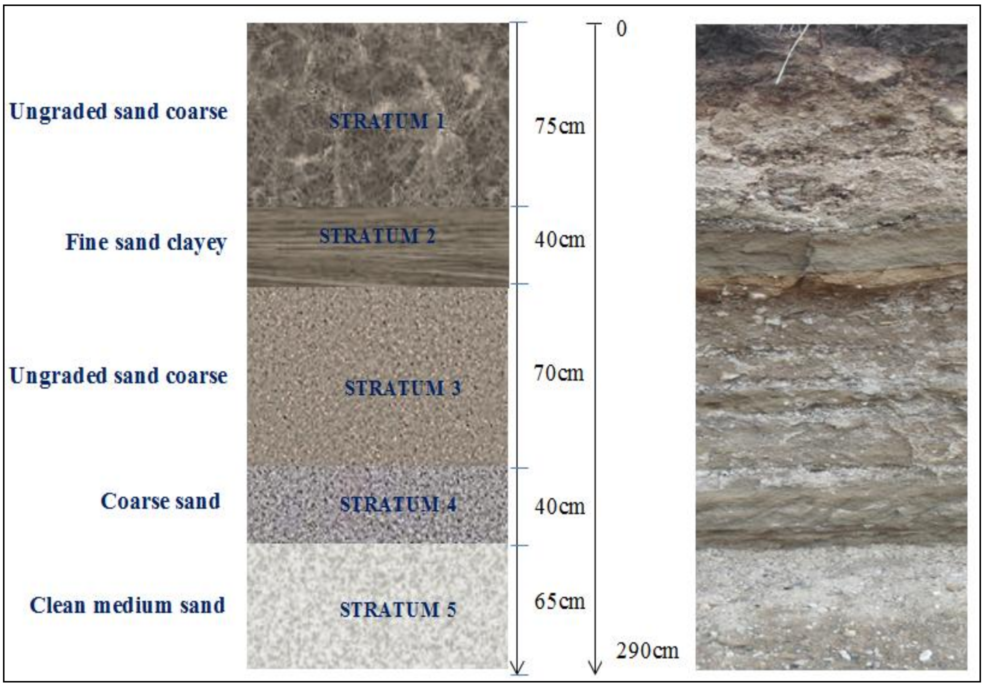

Figure 2: stratigrafic profile of pyroclastites in situ

2.2- Experimentation

The Laboratory work consisted of identification and mechanical behaviour tests, according to the details and procedures of the standards in force:

The identification tests consisted of the determination of the moisture content by drying the materials (NF P 94-050) [5], the absolute density (NF EN 1097-7) [6], the apparent density (NF P 18-554) [7], the flattening coefficient (NF EN 933-3)[8], and the dry particle size analysis (NF EN 933-1) [9]. Following the results of the latter, the fineness modulus, uniformity coefficient and curvature coefficient of the material were calculated using their various existing mathematical formulas:

$$M_f = \frac{\%R_5 + \%R_{2,5} + \%R_{1,25} + \%R_{0,63} + \%R_{0,315} \%R_{0,160}}{100} \quad (1)$$

where $\%R_i$ is the percentage by mass retained on the sieve size i mm,

$$C_u = \frac{D_{60}}{D_{10}} \quad (2)$$

$$C_z = \frac{{D_{30}}^2}{D_{10}.D_{60}} \quad (3)$$

Where $D_{10,}$ $D_{30,}$ and D_{60} are the diameter corresponding to *10%, 30% and 60%* finer in the particle-size distribution respectively.

The cleanliness of the aggregates has been determined in accordance with the requirements of standard NF EN 933-8+A1 [10]. The resistance to grain fragmentation by impact was measured by means of the Los Angeles (*LA*) test, according to the requirements of standard NF EN 1097-2 [11] on gravel fractions 6.3/10 and 10/14. The abrasion wear resistance was measured using the Micro Deval wet test on aggregates of classes 6.3/10 and 10/14, according to standard NF EN 1097-1 [12]. The measurement of the friability resistance of the sands was carried out on sand samples of 0.2/4 class in accordance with the standard NF P 18-576 [13]. The design of hydraulic concretes and mortars was carried out using the Dreux-Gorisse method. This method made it possible to determine the optimal quantities of materials required for making one cubic metre of concrete. The binder used is Portland cement CPA 42.5 R according to the standard EN197-1 [14]. Sand sample is a pyroclastic product taken from Takouche quarry and gravel is crushed holy granite (very widespread in the region). After mixing, the cylindrical specimens with a diameter of 16 cm and a height of 32 cm (200.96 cm^2 section) were made and stored in accordance with standard NF EN 12390-2 [15]. The compressive strength was determined according to the requirements of EN 12390-3 [16] standard. For each dosage studied, fifteen samples were made. These were dismountled after 24 hours and immersed in water. Strength tests were performed on three specimens for each of the corresponding ages (7, 14, 28, 60, and 90). The measurement of the tensile strength by splitting has been determined according to the requirements of standard NF P94-422 [17]. The specimens were made and stored under the same conditions described above. The surface resistance measurement by bouncing with a sclerometer was carried out in accordance with standard NF EN 12504-2 [18]. The bearing capacity of the various samples was determined by modified Proctor test according to the process defined by NF P 94-093 [19] and the *C.B.R* (Californian Bearing Ratio) coefficient according to the requirements of NF P 94-078 [20].

III. Results and analysis

3.1 Grain hardness and fragmentation

The hardness of the aggregates was assessed by the Los Angeles (*LA*) test, the Wet Micro Deval (*MDE*) test and the Sand Friability (*Fs*) test. The resulting results are co-signed in Table 1.

Table 1*:* Results of grain hardness and friability tests

Classes	Los Angeles (*LA*)	Wet Micro Deval (MDE)	LA + MDE	Sand Friability (*Fs*)
0.2/4	-	-	-	10.3
6.3/10	19	8.20	27.20	-
10/14	19.8	7	26.80	-

Table 1 shows that each of the granular classes studied meets the following conditions: LA + MDE < 35 with LA < 25, MDE < 20 and Fs < 20. This indicates that this aggregate is effectively resistant to impact fragmentation and wear [21], and can therefore be used for medium and heavy traffic road pavements and for the manufacture of high performance concrete.

3.2- Design of concretes and mortars

In order to determine the proportions of each granular class for an optimal combination to obtain both good workability and good mechanical strength, certain material characteristics are essential. The results of the identification tests carried out for this purpose on aggregate samples are shown in Table 2 and Figure 2.

Table 2: Aggregate characteristics

Parameters	Ungraded Sand	Gravel 5/15	Gravel 15/25
Natural water content (%)	4	2.61	2,30
Apparent density (t/m³)	1.62	1.46	1.43
Absolute density (t/m³)	2.58	2.87	2.90
Flattening coefficient (%)	3.70	17.31	15
Maximum diameter: Dmax (mm)	25	15	25
Absorption coefficient (%)	2.02	1.55	1.34
Surface cleanliness of gravel (%)	-	1,60	1,10
Sand equivalent (%)	85.91	/	/
Glide module	3.40	/	/
Uniformity coefficient (Cu)	11.36	/	/
Coefficient of curvature (Cz)	0.89	/	/

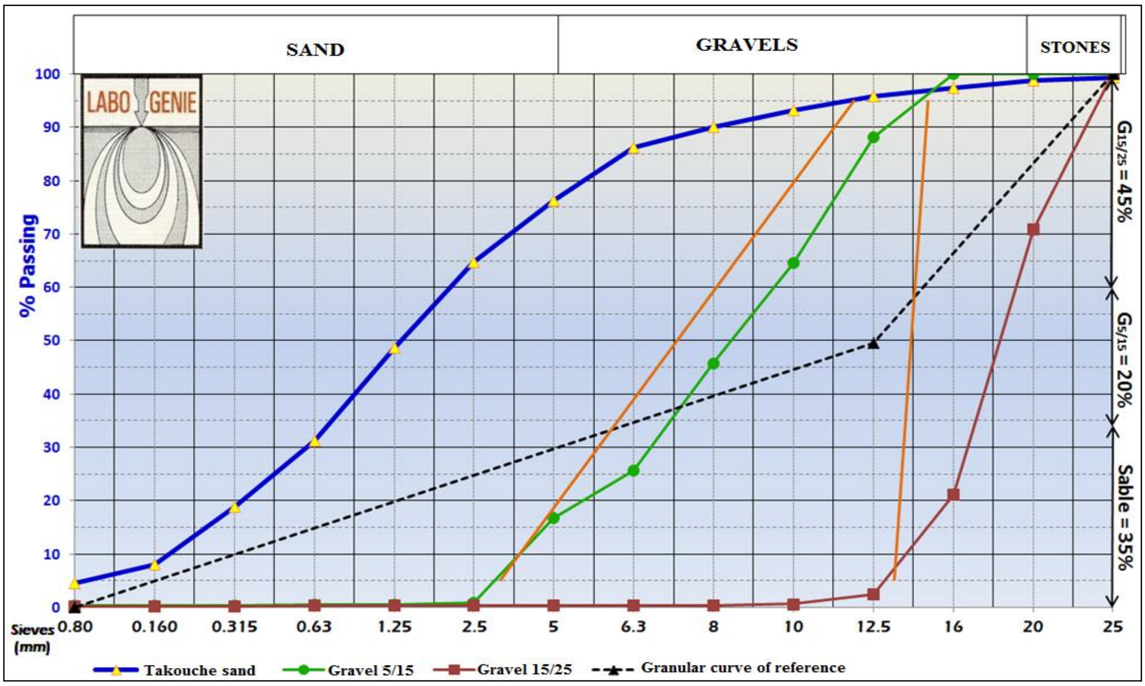

Figure 3: Granulometric curves and granular curve of reference

The design of concretes was carried out in order to obtain a concretes of firm consistency (Slump Test aimed at: A= 2 to 5 cm) [22]. Three types of dosages were test. The nominal resistances targeted and the quantities of materials resulting from them for the manufacture of one cubic metre of concrete are presented in table 3:

Table 3: Nominal resistances and composition of the different dosages of concretes and mortars

Cement dosages (kg/m3)	Target nominal resistors: *fc28 (Mpa)*	Dosages in other components (kg/m3)		Volumic masses (t/m3)
Concretes				
300	28	Sand	652.5	2.36
		Gravel 5/15	353	
		Gravel15/25	891.5	
		Mixing water	163.4	
350	30	Sand	637.8	2.38
		Gravel 5/15	345.3	
		Gravel15/25	871.5	
		Mixing water	191	
400	40	Sand	623.4	2.42
		Gravel 5/15	337.2	
		Gravel15/25	851.5	
		Mixing water	218.5	
Mortar				
400	28	Sand	1835.4	2.45
		Mixing water	220	

Abrams cone collapse and compressive strength

The results of Abrams cone slump and compression tests performed on hydraulic concrete and mortar specimens at different ages and at different dosage are presented in table 4.

Table 4: Summary of data and results of the Slump test and the concrete compression test.

Cement dosages (kg/m3)	Sagging (cm)	Age (days)	Density (t/m3)	Compressive Breaking Force (kN)	Compressive strength fcj (MPa)
Concretes					
300	4.3	7	2.37	452	21.14
		14	2.38	570.75	28.39
		28	**2.40**	632.94	**31.48**
		60	2.42	664.98	33.07

		90	2.43	675.28	33.58
350	4.5	7	2.39	540.75	26.9
		14	2.4	645.05	32.08
		28	**2.42**	689.94	**34.32**
		60	2.44	715.22	35.57
		90	2.45	739.32	36.77
400	4.6	7	2.43	734.32	36.52
		14	2.45	876.64	43.6
		28	**2.47**	889.95	**44.24**
		60	2.48	925.01	46
		90	2.49	945.39	47.02
Mortar mortar					
400	5	7	2.29	500.11	24.87
		14	2.24	527.45	26.23
		28	**2.28**	594.61	**29.57**
		60	2.28	635.41	31.6
		90	2.3	657.58	32.7

From table 4, it appears that:

- The consistency of the different specimens is suitable, as the values of the different slumps are all less than 5cm [22]. This attests to the validity of this result.
- The increase in the average strength of concrete between 7 and 14 days is rapid, so concretes designed with this sand quickly reach high strength;
- The different densities of the concretes are between 2.4t/m^3 and 2.5 t/m^3 so we are in the presence of common concretes [2].
- The compressive strength of concrete at 28 days *(fc28)* is higher than that of C30/37 class concrete. For a dosage of 400kg/m³, an ordinary concrete of class C 45/55 is used [2].
- The 60 and 90-day compressive strengths ranging from 33.07 to 33.58 MPa, 35.57 to 36.77 MPa and 46 to 47.02 for the 300 kg/m³, 350 kg/m³ and 400 kg/m³ cement dosages respectively confirm once again that, over time, the compressive strength values of concrete can exceed those obtained at 28 days.

3.3- Tensile strength by splitting (Brazilian test)

The tensile strength by splitting in this study was measured on 350 kg/m^3 and 400 kg/m^3 cement test pieces. The results of these tests on mortar and concrete specimens at different ages are presented in table 5.

Table 5: Summary of the results of the Brazilian concrete test.

Type of material and cement dosage (kg/m3)	Age (days)	Breaking Force in compression (kN)	Tensile strength $_{ftk}$ (MPa)
Concrete dosed at 350	7	240.01	3.03
	14	258.20	3.26
	28	**262.06**	**3.34**
	60	268.6	3.40
	90	270.18	3.41
Concrete dosed at 400	7	270.67	3.41
	14	290.33	3.66
	28	**292.67**	**3.73**
	60	295.03	3.73
	90	298.19	3.77
Mortar dosed at 400	7	238.71	3.01
	14	256.42	3.23
	28	**264.8**	**3.34**
	60	268.12	3.38
	90	273.11	3.4

From table 5 above, it appears that at 28 days, concretes dosed at 350 kg/m3 and 400 kg/m3 have a tensile strength greater than 3.3 MPa, which is the specified upper value of Class 6 concretes. Concrete of this class is intended for the manufacture of high load-bearing pavements (aeronautical pavements)[21].

The 90-day tensile strength also confirms that, over time, the values of concrete's tensile strength against splitting can exceed those obtained at 28 days, which attests to the validity of this result.

3.4- Surface hardness: Sclerometer

Sclerometer surface hardness values were measured on 28-day-old concrete and mortar specimens as well as the deviations between them and the compressive strength under press. In fact, at an early age, the test pieces do not produce results that can be easily interpreted. The surface hardness values on concrete specimens are presented in table 6.

Table 6: Results of the differences between the results of the concrete test hammer (Sclerometer) and the 28-day compression test

Cement dosages of concrete and mortar (kg/m3)	Sclerometric rebound strength (MPa)	Compressive strength in press (MPa)	Deviations (%)
Concrete C300	**28.11**	31.55	10.79
Concrete C350	**30.72**	34.32	10.50
Concrete C400	**39.50**	44.21	10.63
Mortar C400	**27.43**	29.60	10.81

The resistances determined by crushing are slightly higher than those determined by the sclerometer with a maximum difference of:

- 10.79% for 300kg/m³ dosage,
- 10.50% for 350kg/m³ dosage ,
- 10.63% for 400kg/m³ dosage,
- 10.81% for mortar.

3.5- Parameters at the modified Proctor optimum

The parameters at the modified optimum Proctor of Takouche pyroclatic aggregates are shown in Figure 4.

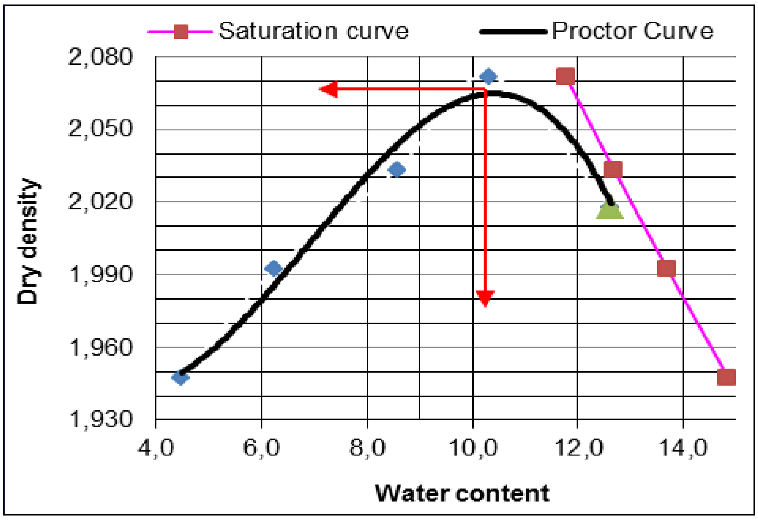

Figure 4: Modified Proctor and saturation curve of pyroclastic materials

Figure 4 shows that the optimal dry density at Modified Optimum Proctor (OPM) for Takouche pyroclastic products is 2.07. In addition, the water content at the OPM is 10.50%, which attests that these materials are recommended for the preparation of base and foundation layers for pavements [19] (because, $1.9t/m^3 \leq \rho^{OPM} \leq 2.1t/m^3$ ρ^{OPM} , likewise $7\% \leq w_{OPM} \leq 13\,\%$).

3.6- The CBR index after 4 days of immersion

The 95% CBR bearing capacity index of the OPM after 4 days of immersion of the pyroclastic aggregates studied is presented as a curve in Figure 5.

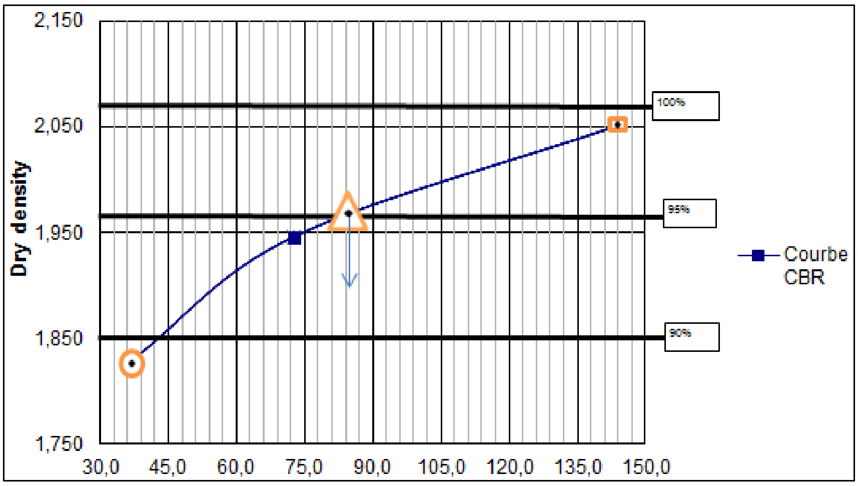

Figure 5: CBR curve of pyroclastic materials

From Figure 5, the pyroclastic aggregate resulting from the mixture of different strata available at Takouche Quarry has a CBR coefficient of 85 to 95% of the OPM. This value of the CBR bearing index being higher than 80, attests that this material can be used as a base layer in road construction [20; 23].

In addition, it shows that the value of the swelling index of the said material is 0.08%, that is less than 2%, which is the specific upper value for materials to be used as a pavement base [20; 23]. This confirms the absorption coefficient values obtained above and indicates that these pyroclastic aggregates are quite suitable for road construction.

IV. Conclusion

The experimental study carried out focused on determining the mechanical characteristics of granite alteration products for their best use in civil engineering. It was based on standardised tests carried out at the Cameroon National Civil Engineering Laboratory (LABOGENIE). The study reveals that the values of the hardness coefficients are all below 20, showing that the wear and impact strengths of these materials are suitable. Therefore, the materials studied are good for obteinning good concrete. The grain size curve deviates from the preferential spindle of sands for concrete with a spread out, concave upwards pace and a fineness modulus of 3.4, which reflects its coarse, ungraded sand type character. The compressive strength at 400 kg/m³ of mortars based on pyroclastic is 29.57 MPa. The values of the results of compression tests carried out on hydraulic concrete specimens designed according to the Dreux-Gorisse method at different cement dosages of 300 kg/m³, 350 kg/m³ and 400 kg/m³ are 31.5 MPa, 34.32 MPa and 44.24 MPa respectively. These good strengths attest to the validity of the proportions appropriately determined in this work. These proportions can be used for the production of good ordinary concrete. Overall, pyroclastic products studies have very good mechanical properties, making them suitable for use in special concrete and road construction, both as base and wearing course materials. An investigation of these aggregates as hydrocarbon coated aggregates is also necessary to further confirm the present study and predict their behaviour in asphalt mixes.

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