International Journal of GEOMATE, Nov., 2016, Vol. 11, Issue 27, pp. 2782-2789
Geotec., Const. Mat. & Env., ISSN: 2186-2982(Print), 2186-2990(Online), Japan

CHARACTERISATION OF NATURAL POZZOLAN OF "DJOUNGO" (CAMEROON) AS LIGHTWEIGHT AGGREGATE FOR LIGTWEIGHT CONCRETE

Willy Juimo[1], Toufik Cherradi[2], Larbi Abidi[3] and Luiz Oliveira[4]

[1,2,3] Mohammadia School of Engineering, Mohammed V University of Rabat, Morocco ; [1] Higher Institute of the Sahel, University of Maroua, Cameroon ; [4] C_MADE-Centre of Materials and Building Technologies, University of Beira Interior-Covilhã, Portugal

ABSTRACT: Cameroon has an appreciable quantity of volcanic pozzolanic materials, but a very low proportion is used as cement additions. These materials are abundant but are rarely or very little used because of the lack or limited of studies to develop, promote and popularize its use naturally as an addition or as aggregates in the production lightweights aggregates concretes. The main objective of this study is to promote these sources of low environmental impact construction materials. Its aim is to characterize and value the natural pozzolan source "Djoungo" as lightweight aggregate for lightweight concrete. Analyses and tests conducted in this study were performed on aggregates produced from this resource. It's concern the chemical and mineralogical analysis, the production of aggregates (Crushing and Sieving), physical properties (appearance and shape, natural water content, porosity, density and water absorption) and mechanical (Compressive strength, tensile strength and elastic modulus) to optimize the mechanical properties and durability of lightweight aggregate concrete obtained from this resource. Chemical composition is according with ACI (American Concrete Institute) standard on natural pozzolans. Two categories of lightweight aggregates were obtained. Those derived by simply sieving have more than 82% of rolled particles and those obtained after crushing have more than 84% of flatter and elongate particles. The bulk density is ranging around 560-820 kg/m^3 and specific density around 1,580-2,730 kg/m^3. The water absorption after 48 hours is around 12 to 28% and depending of grading class.

Keywords: Characterisation, Natural Pozzolan, Lightweight Aggregate and Concrete.

1. INTRODUCTION

Natural pozzolans, when they are used as constituents of Portland cements, such as additions or as aggregates in concrete, can improve its performance. Therefore, some technical advantages of the use of pozzolan in concrete can be obtained when ordinary Porland Cement is partially replaced by this material. Those advantages include: the high workability, reduced hydration heat as well as improved resistance to sulfates and alkali-aggregate expansion. Moreover, in many cases, the use of pozzolan in concrete proves to be economic and allows for important energy savings [1]-[4].

Cameroon has an appreciable amount of volcanic pozzolan materials (the "Djoungo" of lowland of Tombel, one source among many existing) with a very small proportion used as a cement addition (6-35% according Cameroonian Standard NC 234 : 2009-06) by local cement factories for portland cement (CEM II / A, CEM II / B, and CPJ 35) and pozzolanic cement (CEM IV / A and CEM IV / B), as base coat of pavement, strengthening of unpaved roads and very rarely as aggregates into the formulation of lightweight concrete [4]-[8]. These natural pozzolan are abundant but rarely or very little used because of the inadequacy or lack of studies to develop, promote and popularize its use as a lightweight aggregate.

Cameroon has been affected by a gigantic tectonic accident linking the Sao Tome and would continue until the Tibesti. This accident is observed by the alignment of forty massifs lie amidst over 500 km, from the Atlantic Ocean to Lake Chad which is the "Cameroon Volcanic Line"(CVL).

The CVL is a suite of volcanic and sub volcanic devices, that are aligned in the direction North 30° East. 1600 km long, it is dotted with volcanic massifs of the Southwest to Northeast. It comprises Gulf of Guinea islands, mostly volcanic: Bioko Pagalu, Sao Tome, Principe and also some sea-mounts; the region of West Cameroon, with alternating mountains: Mount Cameroon (Altitude: 4100 m), the Manengouba Mountains (shield volcano of 20 km in diameter, with no known historic activity presents some Strombolian cones Bamboutou, Mbam and Oku and grabens (Kumba, Tombel, Mamfe, Mbos, Ndop) and end the Tikar lowland (Foumban in Banyo). These massifs located in the western part of the country at the border with Nigeria are dotted with their shallow by many slag deposits. Especially on the slopes of Mount Cameroon (Fig. 1), the slopes of Mount Manengouba, Mount Galim, the plains of Tombel around Djoungo, Kumba plain, the plain of Noun around Foumbot, Lake Nyos area and the plateau of the Adamaroua [8].

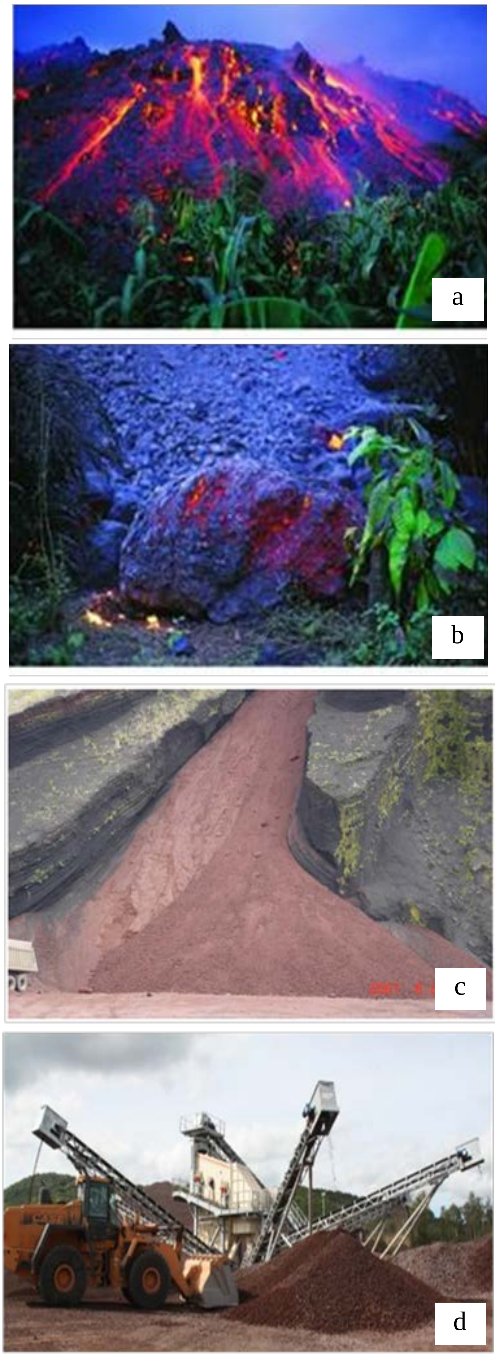

Fig.1 Mount Cameroon (a) active larva (b) larva casting Front of the eruption of 1999 (Picture: Patrick Barois); Pozzolan Djoungo (c) Part of the site, (d) Operating Career [5].

Volcanic scoria of locality of Djoungo on the plain of Tombel (Longitude: 9°37'32" East Latitude: 4°35'16" North) are the pozzolan which has been of the greatest number of studies. The slag Djoungo, purplish black and brick red, clean, without clay, are exploited because of their privileged geographical location (near the railway and seaport). These are fragments of vesicular magma of low density (<1), internal structure constituted by cells and more or less tight pore (Fig. 1). The ability to use these materials in manufacture of lightweight concrete can be an important economic asset [4, 6].

2. MATERIALS AND METHODS

2.1 Materials

The volcanic scoria samples were extracted from the site of "Djoungo" in Cameroon on January 2015. The samples have been kept in plastic bags and then packed in cartons and sent to Rabat (Morocco) by flight (Fig. 2).

Fig.2 Packaging of specimens.

The reduction of volcanic scoria samples was performed, in the “Laboratoire Traitement des Minerais of Département des Mines of Ecole Nationale Supérieure des Mines de Rabat (ENSMR), initially by sieving in order to separate the small volcanic scoria and large ones, followed by crushing and sieving to classify the different grading sizes. The figure 3 shows two types of crushers used to reduce the samples and composed the aggregates grading.

The scoria samples size reducing was performed on the material dried in open air environment during 24 hours for the removal of moisture in the rocks. For crushing, a cylinder (Roll) crusher for of scoria size less than 80 mm and a jaw crusher to those of size greater than 80 mm was used (Fig. 4). After crushing the volcanic scoria samples was sieved using the 20, 10, 5, 2.5 and 1.25 mm stainless steel sieve of 20 cm diameter. Each sieving operation is carried out for 2 minutes.

Fig.3 Crushers : (e) Roll crusher (f) Jaw crusher and scoria samples (g) before and (h) after crushing.

Lightweight aggregates obtained were classified into two categories: those derived by simply sieving and those obtained after crushing. Figure 4 shows eight types of aggregates here studied, which differ in the method of production and their sizes.

These aggregates are subsequently appointed by the terminology introduced in the Fig.4 legend. The first two letters are references to the aggregate sample size origin: small volcanic scoria (SVS) and large volcanic scoria or volcanic tuffs (LVS). Numerical values indicate the size range of d/D where d (mm) is the minimum diameter D (mm) the maximum diameter of aggregates.

An observation with the naked eye of the various aggregates (Fig. 4) shows the macroscopic geometry of the aggregates, namely more angular shape for crushed aggregates LVS5/10, LVS10/20 and LVS20/30 and more or less rolled for aggregates SVS1.25/2.5, SVS2.5/5, SVS5/10, SVS10/20 and SVS20/30.

Legend			
N°	Aggregate	N°	Aggregate
1	SVS20/30	5	SVS5/10
2	LVS20/30	6	LVS5/10
3	SVS10/20	7	SVS2.5/5
4	LVS10/20	8	SVS1.25/2.5

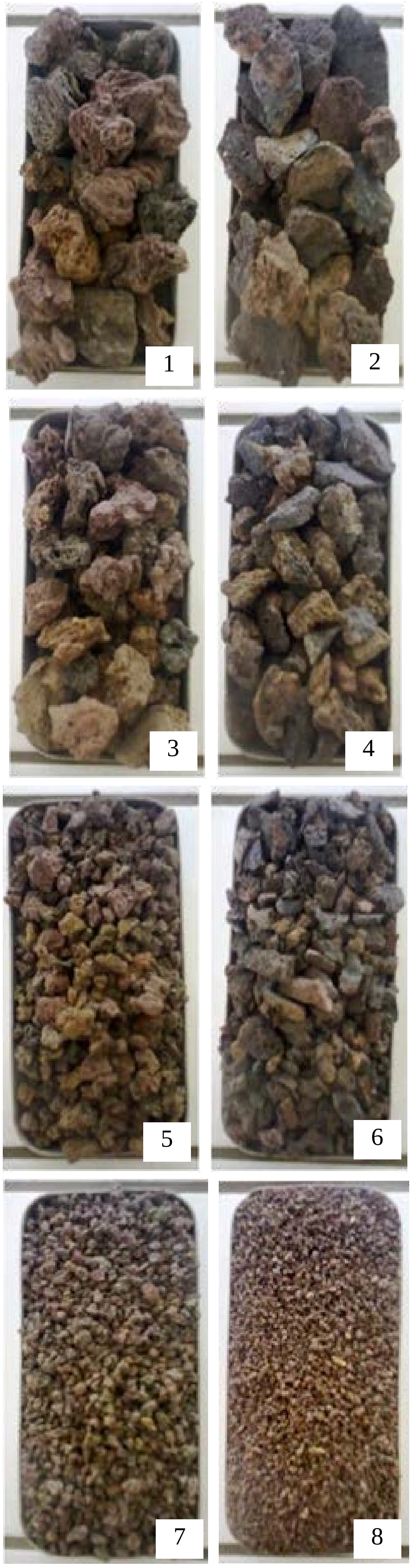

Fig.4 Macroscopic view of different aggregates.

2.2 Methods

2.2.1 Chemical and mineralogical characterization

The chemical and mineralogical characterization of "Djoungo" scoria samples were realized through overall chemical analysis and X-ray diffractometric analysis (XRD) on obtained by crushing powders (grain size 63-80µm) by several authors [4]-[6].

To perform the study of the chemical composition, the aggregates are first crushed. Then, these specimens were prepared in pellet form after fusion. The analyzed volume is of the order of several μm^3.

Chemical and mineralogical composition, texture, size and shape affect the physical and mechanical proprieties of aggregates. For this purpose we conducted analyzes to identify the influence of these parameters on the proprieties of the aggregates obtained.

2.2.2 Physical properties

The particle size is one of the most important parameters to consider in establishing a formulation of concrete. His knowledge allows for the precise dosage of aggregates to optimize the granular composition. The Particle size distribution was determined according to NF EN 933-1, 1997.

The determination of aggregates particle shape was realized according NF EN 933-4, a study protocol to measure by a vernier caliper was established: the length (L) corresponds to the greatest distance of a pair of parallel tangent planes; the width (l) and thickness (e) are respectively the largest and the smallest gap of a couple taking tangent parallel.

Scoria is sieved to the sieve 20, 25, 28, 31.5, 35.5, 40, 50 and 63 mm. For aggregates obtained after crushing, they are sieved to sieves of 5, 6.30, 8, 9, 10, 12.5, 14, 16 and 18 mm. A test specimen of 20 aggregates is taken from each sieve. The flattening coefficient (p=e/l) and the elongation coefficient (l/L) were used to identify the shape of the removed scoria and aggregates obtained.

The water content, bulk density, specific density and porosities are defined for aggregates according to the procedure used in the laboratory, accordance with NF EN 1097, 2006.

Knowledge of the water absorption coefficient of aggregates used to adjust the mixing water content in the composition of the concrete. Measurements of the absorption of water by the aggregates were therefore carried out following the procedure of NF EN 1097-6, 2001 standard. The water absorption coefficient is defined as the ratio of the absorption coefficient is defined by:

$$W_a = \frac{M_e}{M_s} . 100\% \quad (1)$$

Where M_e is the mass of water absorbed and M_s the dry mass of the specimen after drying oven at 105°C.

2.2.3 Mechanical properties

The scoria and crushed aggregates mechanical properties as compressive strength, tensile strength and modulus of elasticity were approximate applying the empirical formulas and literature data [11].

3. RESULTS AND DISCUSSION

Table 1 presents the results of chemical analysis of Djoungo scoria obtained by different authors. These results show that natural pozzolan of "Djoungo" is composed of SiO_2, Fe_2O_3 and Al_2O_3 as main elements (% by weight more than 10%), CaO, MgO, MnO, Na_2O, K_2O, TiO_2 and P_2O_5 as minor elements (less than 10%) and the loss on ignition (L.O.I.) is less than 2%. This composition is according with ACI (American Concrete Institute) standard on natural pozzolans [9].

In the pozzolans, it is possible to find characteristics easily measurable and correlate with their activity. Among these characteristics, the chemical composition plays an important part. In the Table 1, it can be seen that the chemical composition of natural pozzolan of "Djoungo" have acid character, having (SiO_2+Al_2O_3) content ranging around 59.30-61.51% of the total. Between the two oxides, silica prevails in all cases. It reaches percentages greater than 44%. The importance of the content is clearly emphasized by the fact that the active vitreous phases of pozzolans generally are richer in silica and alumina content. Chemical composition of volcanic scoria of "Djoungo" is incoherent, and tuffs are rich in silica. The loss on ignition is between 0.2% and 1.1%. The natural pozzolans to use as a mineral admixture in portland cement must meet certain chemical and physical requirements. For instance, ASTM Standard C 618 Class N [10] admixtures must have a minimum content of 70% in SiO_2+Al_2O_3+Fe_2O_3, whereas natural pozzolan of "Djoungo" have between 72.02% and 74.32%. This chemical requirement is arbitrary for the purpose and does not have direct relationship with properties of material.

Table 1 Chemical analysis of "Djoungo"

Ref.	[6]	[5]	[4]	[3], [9]
	DVS	ZD	DB1	ACI
SiO_2	45.57	44.04	45.79	43–72
Al_2O_3	15.94	15.26	15.68	9–20
Fe_2O_3	12.81	12.77	12.83	1–12
CaO	8.97	9.29	9.60	1–15
MgO	5.76	7.00	6.26	0.5–7
MnO	-	0.17	0.17	/
Na_2O	3.28	5.64	3.54	0.5–11
K_2O	1.03	1.35	1.39	0.2–8
SO_3	-	0.01	-	0–1.4
TiO_2	2.11	2.87	2.84	/
P_2O_5	-	0.53	0.60	/
L.O.I.	0.20	1.1	0.31	0.2–19
SiO_2	45.57	44.04	45.79	43–72

Note: DB1, ZD and DVS are name's codes using by authors respectively in reference [4], [5] and [6] ACI : American Concrete Institute.

The X-ray diffractogram of scoria presented in Figure 6 shows more crystalline phases, the presence of a dome that extends between 20 and 40°(2s). This dome expresses the existence of the amorphous phase [5]. In summary, volcanic scoria contains amorphous phases. These materials, due to the presence of amorphous phases within them are therefore well suited as raw materials for the production of aggregates.

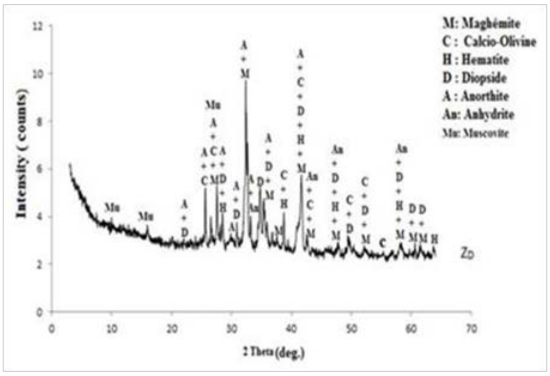

Fig.5 Diffractogram of "Djoungo" scoria [6]

Figure 6 shows the grading curves of aggregates with theirs different size ranges. Curves of particle size analyzes express only average grain size.

Figure 7 shows particles shape of natural scoria and crushed aggregates. The shape of aggregates varies according to their method of production and size. Aggregates particle shape (Flatter and elongate, flatter, elongate or rolled) have been observed. The collected scoria has a more or less rolled. Aggregates obtained by sieving have a rolled shape and those obtained after crushing are flatter and elongate.

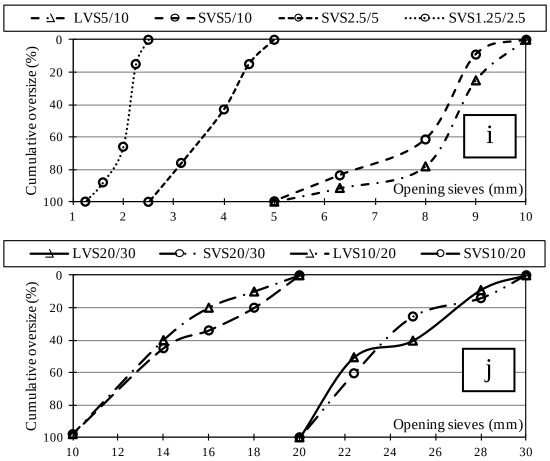

Fig.6 Grading: (i) SVS1.25/2.5, SVS2.5/5, SVS5/10 and LVS5/10; (j) SVS10/20, LVS10/20, SVS20/30 and LVC20/30

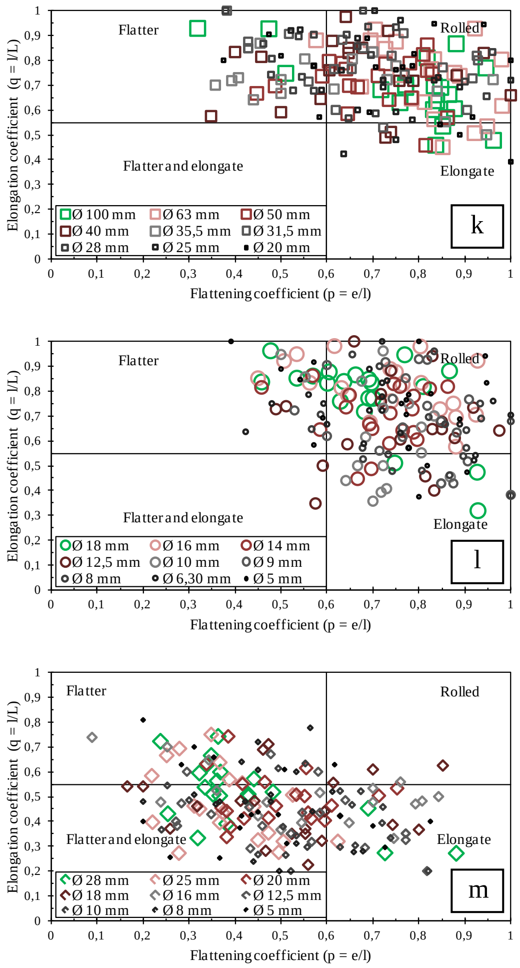

Fig.7 Particle shape of scoria in the natural state (k) and (l), aggregates obtained by crushing (m)

The results presented in Figure 7 are also summarized in the Table 2 by the percentage of different particle shape composing natural scoria and the different aggregates size classes.

Table 2 The percentage of different particle shape in scoria and crushed aggregates classes

Aggregate	Flatter and elongate	Flatter	Elongate	Rolled
Scoria "Djoungo"	0%	21%	12%	67%
SVS20/30	0%	11%	4%	85%
LVS20/30	87%	9%	4%	0%
SVS10/20	1%	8%	9%	82%
LVS10/20	91%	3%	4%	2%
SVS5/10	0%	8%	6%	86%
LVS5/10	84%	7%	8%	1%
SVS2.5/5	x	x	x	✓
SVS1.5/2.5	x	x	x	✓

Table 3 shows water content, bulk density specific density and porosity of natural scoria and crushed aggregates (namely more angular shape for crushed aggregates LVS20/30, LVS10/20 and LVS5/10). The water content increase with the size class for crushed aggregates. The bulk density and specific density increase also with aggregate grading. The porosity is around 50% for all crushed aggregates.

Table 3 Water content, densities and porosity

Aggregate	Water content (%)	Bulk density (kg/m^3)	Specific density (kg/m^3)	Porosity (%)
Scoria "Djoungo"	2.56	560	1,580	51
LVS20/30	1.25	670	2,240	48
LVS10/20	1.04	790	2,520	51
LVS5/10	1.88	820	2,730	54

The results of water absorption after immersion during 48 hours of these materials are presented in Figure 8. These results show that, water absorption increase with grading size.

Table 4 shows approximation of compressive strength, tensile strength and modulus of elasticity of the scoria and crushed aggregates.

Many studies have focused on the use of volcanic scoria as lightweight aggregate. Different sources of materials have been explored (Tab. 5).

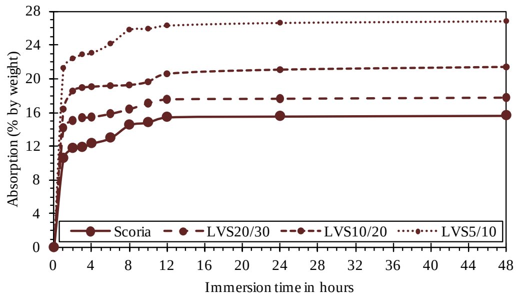

Fig.8 Water absorption evolution with the time

Table 4 Mechanical properties of aggregates according to their bulk densities

Ref.	European Standard EN 13055-1, [10]			
	Scoria	LVS20/30	LVS10/20	LVS5/10
$\mathbf{d_V}$	0.56	0.67	0.79	0.82
$\mathbf{f_{gpot}\ 1}$	7.37	14.74	22.78	-
$\mathbf{f_{gpot}\ 2}$	9.43	13.94	-	-
$\mathbf{f_{eg}\ 1}$	15.09	26.95	39.89	43.12
$\mathbf{f_{eg}\ 2}$	52.52	74.74	98.98	105.04
$\mathbf{f_{tg}}$	2.41	3.19	4.05	4.26
$\mathbf{E_g}$	2508.8	3591.2	4992.8	5379.2

$\mathbf{d_V}$: Bulk density ; $\mathbf{f_{gpot}\ 1}$ and $\mathbf{f_{gpot}\ 2}$: Compressive strength in pot ($\mathbf{f_{gpot}1 = 67(d_V - 0,45)}$ with $\mathbf{0,45 < d_V < 0,82}$), ($\mathbf{f_{gpot}\ 2 = 41(d_V - 0,33)}$ with $\mathbf{0,38 < d_V < 0,73}$) ; $\mathbf{f_{eg}\ 1}$: Hydrostatic compression strength of individual aggregate ($\mathbf{f_{eg}\ 1 = 107,8(d_V - 0,42)}$); $\mathbf{f_{eg}\ 2}$: Hydrostatic compressive strength of aggregates taken in batches ($\mathbf{f_{eg}\ 2 = 202(d_V - 0,30)}$) ; $\mathbf{f_{tg}}$: Wire tensile strength ($\mathbf{f_{tg} = 3,9(1,82d_V - 0,40)}$) in MPa ; Elastic modulus : $\mathbf{E_g = 8000\ \rho_g^2}$ where $\mathbf{E_g}$ is expressed in MPa and $\mathbf{\rho_g}$ in t/m^3.

Table 5 Data of Some natural pozzolan lightweight aggregates studies by different authors

Aggregate	Origin	Class	Ref.
LWCA1	Béni-Saf, Algeria	2-8	[1]
LWCA2		8-16	
CVPA	Papua New Guinea	1.18-20	[2]
FVPA		0.15-9.5	
DB1	Djoungo, Cameroon	5-10	[4]
FB1	Djimbouot, Mfesset, Fosset (Foumbot), Cameroon	5-10	
FB2		5-10	
FB3		5-10	
FB4		5-10	
G3/8	Béni-Saf, Algeria	3-8	[7]
G8/15		8-15	
Scoria	Iceland	0-100	Euro LightCon

Figures 9-11 compare the properties of fifteen pozzolan lightweight aggregates results obtained in this work with those of the literature. It is possible to observe that are similar.

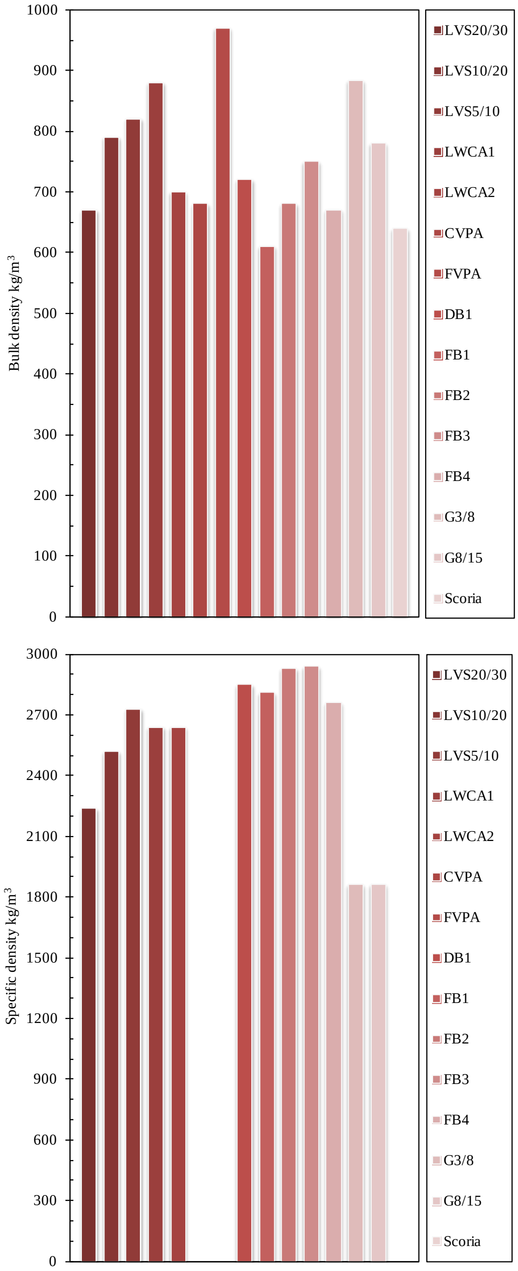

Fig.9 Diagrams of (a) bulk density and (b) specific density

The bulk density and specific density are shown in Figure 9. It was found that the bulk density ranging around 610-970 kg/m^3 and specific density around 1,862-2,940 kg/m^3. The middle value of bulk densities is 749 kg/m^3. Bulk densities of "Djoungo" materials are up to the middle value excepted natural scoria and LVS20/30, The middle value of specific densities is 2,565 kg/m3. Specific densities of "Djoungo" materials are down to the middle value excepted LVS5/10. The results also showed that "Djoungo" materials can be used as lightweight aggregates for making the low initial strength concrete to ensure the economical benefits in constructions.

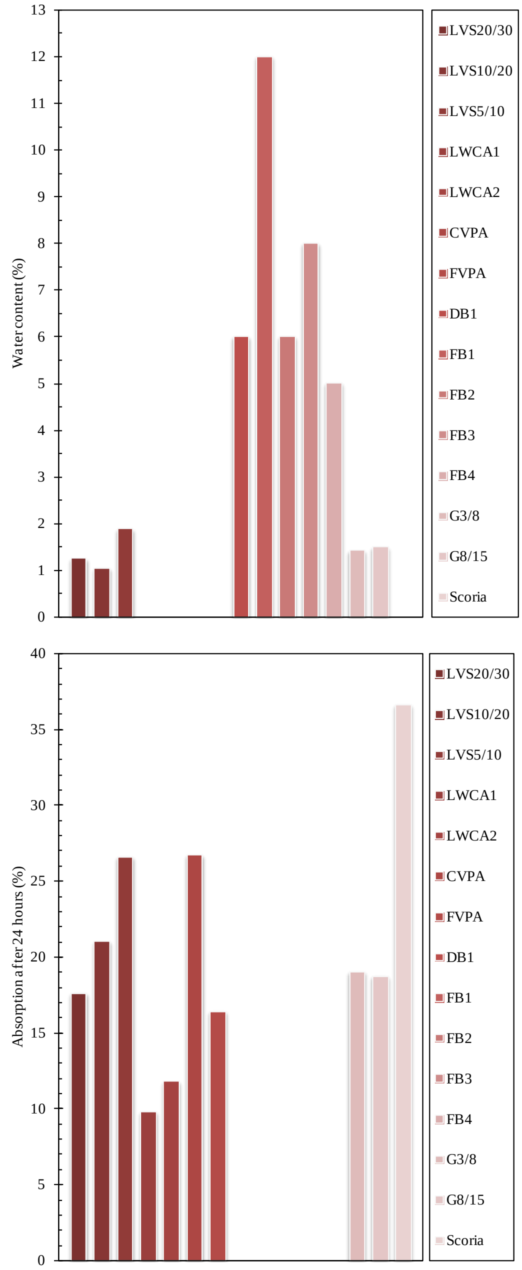

Fig.10 Diagrams of (c) natural water content and (d) water absorption after 24 hours

Similar to normal dense aggregates, the water content in the mix plays an important role in the strength achievement of concrete. Figure 10 shows water content and water absorption after 24 hours of these natural pozzolans aggregates. All aggregates, whether natural or artificial, absorb water at a rate which decreases with time. Such absorption is important because it will influence, for example the, density, workability and free water content of the fresh concrete.

For an individual aggregate particle, the amount of water absorbed and the rate of absorption depend primarily on the pore volume, the ratio between connected (with the outer surface) and disconnected pores and diameter of the pores. The specific density of the different scoria aggregates presented is around 2565 kg/m^3. The pore volume is calculated by subtracting the particle density from specific density. Figure 11 shows porosity of these materials.

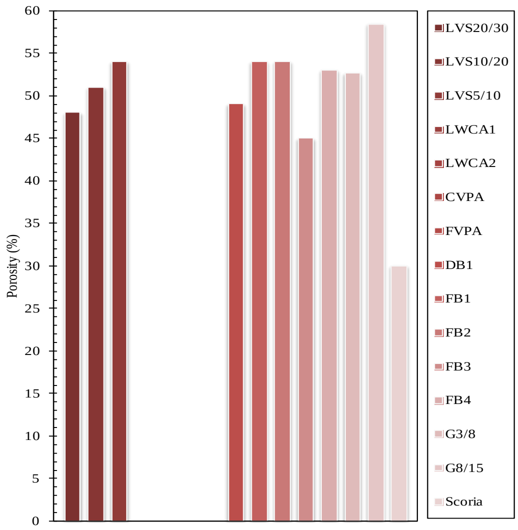

Fig.11 Diagrams of porosity

This means that the volcanic scoria has the largest pore volume, a lot pores connected with the outer surface and thus the biggest water absorption. Because of these connected pores, the water absorption is very fast. Volcanic scoria aggregates have, relatively, a larger pore volume than normal weight aggregates. Therefore the rate of water absorption is likely to be higher than for natural dense aggregates. Also the surface zones of aggregate particles have a large influence on absorption.

4. CONCLUSION

Based on the results of experimental work, "Djoungo" scoria lightweight aggregate can be used in the production of lightweight concrete. It will reduce the coast and environmental pollution. Knowledge about physical, chemical and mechanical properties can be help to control castings, mechanical properties and durability for lightweight aggregate concrete production.

5. REFERENCES

[1] Mouli M and Khelafi H, "Performance characteristics of lightweight aggregate concrete containing natural pozzolan", Building and Environment 43, 2006, pp. 31–36.

[2] Hossain K M A, Ahmed S and Lachemi M, "Lightweight concrete incorporating pumice based blended cement and aggregate: Mechanical and durability characteristics", Const and Build Mater 25, 2011, pp.1186-1195.

[3] Kaid N, Cyr M, Julien S and Khelafi H, "Durability of concrete containing a natural pozzolan as defined by a performance based approach", Const and Building Materials, 23, 2009, pp. 3457-3467.

[4] Bidjocka C, "Conception de bétons légers isolants porteurs. Applications aux pouzzolanes naturelles du Cameroun", Thèse de doctorat, INSA de Lyon, 1990, 167p.

[5] Billong N, Melo U C, Njopwouo D, Louvet F and Bonnet J P, "Physicochemical characteristics of some Cameroonian pozzolans for use in sustainable cement like materials", Materials Sc. and App. , 4, 2013, pp. 14-21.

[6] Tchakouté K H, "Elaboration et caractérisation de ciments géopolymères à base de scories volcaniques", PhD Thesis, UY I, 2013, 170 p.

[7] Ferhat A, Goual SM, Goual I et Khelafi H, "Valorisation de la pouzzolane de Beni-Saf (Algérie) par transformation en granulats de bétons légers", Actes Séminaire International Innovation et Valorisation dans le genie civil, Hammamet, Tunisie, 5-7 fév 2009, pp. 447-455.

[8] Tsafack J P F, Wandji P, Bardintzeff J-M, Bellon H and Guillou, "The Mount Cameroon stratavolano (Cameroon Volcanic Line, Central Africa) : Petrology geochemistry, isotope and age data", Geochemistry, Mineralogy and Petrology, Sofia, 47, 2009, pp. 65-78.

[9] ACI, "Use of Raw or Processed Natural Pozzolans in Concrete", ACI Committee 232, Manual of Concrete Pratice ACI 232.1, 2000.

[10] ASTM Standard C 618-98, Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete, vol. 4.02, pp. 298 – 300.

[11] Ke Y, "Caractérisation du comportement mécanique des bétons de granulats légers: expérience et modélisation", Thèse de doctorat , Université de Cergy Pontoise, 2008, 316 p.

International Journal of GEOMATE, Nov., 2016, Vol. 11, Issue 27, pp. 2782-2789.

MS No. 1310 received on July 29, 2015 and reviewed under GEOMATE publication policies.

Corresponding Author: Willy Juimo