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PHYSICAL CHARACTERIZATION OF NATURAL POZZOLANAS FOR THEIR IMPROVEMENT AND USE IN CONSTRUCTION

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ABSTRACT

This research work deals with the physical characterization of the black pozzolanas, brown pozzolanas and black volcanic ashes. The results showed that the black volcanic ash sands with dimension less than or equal to 5 mm are classified as lightweight, fine, clean, gap-graded and poorly graded materials; Their use as sands for quality concrete needs correction by addition to them of coarser sands. The black pozzolana sands with dimension less than or equal to 5 mm are classified as lightweight, very clean, gap-graded and well-graded and coarser materials; Their use as sands for quality concrete needs correction by addition to them of finer sands. The brown pozzolana sands with dimension less than or equal to 5 mm are classified as lightweight, very clean, gap-graded and poorly-graded and coarser materials; Their use as sands for quality concrete needs correction by addition to them of finer sands. The black pozzolana gravels and the brown pozzolana gravels *with dimension between 5 and 20 mm, the black pozzolanas and the brown pozzolanas with dimension greater than 20 mm are classified as lightweight and uniform materials. These latest materials could be used as foundation materials for buildings as well as base and foundation layers for roads, and the gravels used with sand to manufacture concrete and concrete blocks.*

Key words: Pozzolana, Volcanic Ash, Volcanic Ash Sand, Pozzolana Sand, Pozzolana Gravel.

1. INTRODUCTION

The natural pozzolana is a granular volcanic material from volcanic projections, or pyroclastics, and having a scoriaceous and alveolar texture. Its colour is usually black or red (brick red to dark brown) and exceptionally gray or yellowish.

The natural pozzolanas are used in various fields of civil engineering, particularly for making lightweight concrete with a reduction of permanent loads (Abdelhadi et al., 2013), thermal and acoustic insulation works (Shink, 2003).

The Pozzolanas and volcanic ashes are widely used for surface course and road embankments, manufacturing of concrete blocks and mortars. Despite the intensive use of these materials in the construction, the mixes designs are not controlled and vary from one site to another, leading most often:

- Either in a rapid deterioration of building elements (case of low compressive and/or tensile strengths);
- Either in cracking of reinforced concrete structural elements;
- Either in underutilized potential of the materials studied, involving unjustified excessive costs (case of excessive strengths).

The objective of this research work is the physical characterization of the black pozzolanas, the brown pozzolanas and the black volcanic ashes for better use in building construction and public works.

2. LITERATURE REVIEW

Many Works had been done on the use of pozzolana aggregates in the manufacture of concretes and mortars, but very few concerned the pozzolana aggregates of the locality of Foumbot where these aggregates are very abundant and very used in civil engineering constructions with design mixes varying from one work site to another, sometimes to the detriment of the compressive strength and tensile strength of concrete and mortar and lifespan of the structure being constructed.

According to GINGER - CEBTP (Europe Engineering Group – Experimental Centre for building and public works France) (2008) and UNICEM (National Union of quarry industries and construction materials in France), the pozzolanas can be found in the form of sands, gravels, and pozzolanas. Moreover UNICEM Auvergne determined some mixes for pozzolana concrete and mortar.

Abdelhadi et al. (2013) proposed a pozzolana concrete mix based on pozzolanic aggregates crushed and screened to obtain four granular classes, namely 0/3 crushed sand and gravels 3/8, 8/15 and 15/20.

Ferhat et al. (2005) determined the geometrical and physical characteristics of pozzolanic gravels 3/8 and 8/16 from Bouhamid deposit located 2.5 kilometers from Beni Saf in Algeria and also determined a concrete mix by combining the above mentioned aggregates with the alluvial sand of Oued M’zi region in Algeria.

Benkaddour et al. (2009) in their research entitled "Durability of mortars manufactured with natural pozzolana and also with artificial pozzolana" proceeded to the characterization of materials used in the manufacture of mortars, in particular the cement, sand, natural and artificial pozzolanas. The mechanical performances of the tests on tensile and compressive strength were also determined at 2, 7 and 28 days.

Wandji (1985) presented the pyroclastics of the locality of Foumbot (blocks, slags, lapillis and volcanic ashes) as intensely exploited in the Noun plain for road surface and foundation layers, manufacture of concrete blocks, mortar, without considering physical properties related mainly to particle size analysis by the method of sieving, porosity testing, specific weight, bulk density, Proctor tests.

Wandji (1995) showed that the gray ash and black pozzolanas of the locality of Foumbot have a proportion of the vitreous phase very similar to that of the gray ash pozzolana of Mount Djoungo used in the manufacture of cement by CIMENCAM. The same work also determined the chemical and mineralogical composition of four pozzolana types from the plain of Noun and three pozzolana types from the plain of Tombel, to show that the studied pozzolanic materials have mechanical strengths and pozzolanic properties that improve with time for pozzolana-cement-water mixes. The results of pozzolanicity tests, coefficient k of FERET and percentage of vitreous phase, show that black pozzolanas of Noun Plain are better than those of Mount Djoungo used by CIMENCAM in the plain of Tombel.

Wandji and Njie (1988) showed that the pyroclastic products of the locality of Foumbot are uniform aggregates and have high porosity, low density and the coarser pozzolana has good compressive strength Rc for blocks (Rc = 19.3 bars or (1.93 MPa)). The soil formations of the locality showed a significant Pozzolanicity that improves with time and are interesting for the manufacture of mortar and roman cement. Roman cement or rapid hardening cement, suitable for works under very wet and saturated conditions with water, is obtained by combining the pozzolana with lime. The results obtained by Wandji and Tchoua (1988) confirmed the value of Rc above (1.93 MPa).

Wandji and Tchoua (1988) showed that pyroclastics, not welded products issued by volcanism in the locality of Foumbot consist of blocks, ashes and lapillis and the rapid decomposition of ashes and other projections largely contributed to the great fertility of this region of the country that provides both food crops, vegetable (tomato, cabbage, leek, lettuce, potato, onion, plantain, yam, sweet potato, etc.) and export products (Arabica coffee mainly). Tests on compressive strength and tensile strength of mortars made with cement and pozzolana and with cement and natural sand were also performed and the results showed that the mortar manufactured with the normal sand is stronger than that manufactured with pozzolana.

Other studies show some physical characteristics and mechanical tests on the pozzolana from Foumbot (Wandji, 1985; Wandji and Njie, 1988; Wandji and Tchoua, 1988; Wandji and Tchoua, 1993).

Ninla (2008) defined pozzolanas as natural or artificial materials rich in silica and alumina, which can react with the lime in the presence of water to form products exhibiting binding properties. The work also showed that pozzolanas are employed in cementry for their pozzolanic properties (ability to fix lime at room temperature and form products with binding properties) and the main pozzolanas are volcanic materials (ash, slag), the ashes from thermal power plants, blast furnace slag, rice husks ashes, bagasse from sugar cane, and calcined clay. In Cameroon several volcanic pozzolanas deposits exist, particularly around Mount Manengouba, Mount

Cameroon, in the locality of Foumbot, Djoungo, Kumba and Adamawa Plateau. Part of this pozzolana is sometimes used in the roads construction, or as an additive in the production of cement and mortars.

Mbessa et al. (2012) proposed a concrete and mortar mix from the river Sanaga sand 0/5, the gravel 12.5/16 from Nkometou in Lekie Division and the pozzolana from Djoungo crushed into powder and varying percentages of the powder in the mix, cement and water.

Bidjocka (1990) showed that pozzolana lightweight concretes are pozzolana aggregate concretes, or porous aggregate concretes. The density of these concretes is between 1100 and 1500 kg / m^3.

Meukam (2004) presented two sampling sites of pozzolana in Cameroon, namely the plain of Tombel where the quarry of Djoungo is located and the Plain of Noun with four quarries considered as the most important in the locality of Foumbot. Moreover, this pozzolana can be employed in agriculture, roads construction, manufacture of cements and concretes.

Bilong et al. (2013) had proceeded to the determination of specific gravity of five pozzolana samples from Ngouogouo and Fessang in Foumbot in the West Region and Djoungo in the Littoral Region of Cameroon and the results showed that the materials are heavy. At the same time particle size analysis, chemical and mineralogical analyses were performed on the same materials. The work here interested the use of these pozzolanas in sustainable cement like materials.

Of all the previous works above, none of them provided mix design of concretes and mortars with pozzolana aggregates of Foumbot for the manufacture of concrete blocks, mortars for masonry, rendering and plastering works by performing screening, particle size analysis, determination of specific gravity, water absorption coefficient, sand equivalent values, the fineness modulus of the above mentioned aggregates and the proportion of each of the sands in the mix by Abrams' rule. Hence the importance of the present work.

3. MATERIALS AND METHODS

3.1. Materials

According to GINGER - CEBTP (2008) and UNICEM, the pozzolanas can be found in the form of sands, gravels, and pozzolanas (dimension > 20 mm). The samples used for the present study are the black volcanic ashes of Baïgom (photograph 1), the black pozzolanas of Ngouogouo (photograph 2) and the brown pozzolanas of Mfosset (photograph 3) collected in the locality of Foumbot in the West Region of Cameroon. The black volcanic ashes were screened to obtain the black volcanic ash sand 0/5. The black pozzolanas were screened to obtain the black pozzolana sands 0/5, black pozzolana gravels 5/20, black pozzolana cobbles and boulders with dimension greater than 20 mm. The brown pozzolanas were screened to obtain the brown pozzolana sands 0/5, brown pozzolana gravels 5/20, brown pozzolana cobbles and boulders with dimension greater than 20 mm.

Photograph 1: Black volcanic ash sands of Baïgom (**black sand** S_1)

Coarse black sand S_2 (0/5)

Black Gravel G_1 (5/20**)**

Black Cobbles and Boulders C_1 (> 20 mm)

Photograph 2 Black pozzolanas of Ngouogouo

Coarse brown sand S_3 (0/5)

Brown Gravel G_2 (**5/20)**

Brown Cobbles and Boulders C_2 (> 20 mm)

Photograph 3 Brown pozzolanas of Mfosset

3.2. Sampling

Sampling sites in Foumbot, namely Ngouogouo, Mfosset and Baïgom were selected because of the massive use of the volcanic ashes and pozzolanas for construction. Different disturbed samples were collected, packed in bags and transported to the Civil Engineering Laboratory of the Fotso Victor University Institute of Technology as described in NF EN 932-1 (1996). The smaller quantities for Laboratory testing were obtained by the method of quartering from large representative samples of the materials studied as described in NF EN 932-2 (1999).

3.3. Particle size distribution and fineness modulus

The particle size distribution was determined by the method of dry sieving, according to the Standard NF EN 933-1 (2012).

The coefficients of uniformity (C_u) and curvature (C_z) were determined by the following formulas 1 and 2:

$$C_u = \boldsymbol{D_{60}/D_{10}} \quad (1)$$

$$C_z = (\boldsymbol{D_{30}})^{\mathbf{2}}/(\boldsymbol{D_{60}\ x\ D_{10}}) \quad (2)$$

where D_{60}, D_{10} and D_{30} are respectively the particle dimensions corresponding to 60%, 10% and 30%, respectively, passing on the cumulative particle size distribution curve.

The fineness modulus was determined to be equal to one hundredth of the sum of the cumulative percentages of mass retained on the following sieve sizes: 0.16, 0.315, 0.63, 1.25, 2.5, 5.0 mm according to the standard NF P 18-540 (1997). In the case of sand particle size distribution requiring correction, Abrams' law was used (formula 3):

$$\boldsymbol{X_1 = \frac{MdF - MdF_2}{MdF_1 - MdF_2}} \ \boldsymbol{and}\ \boldsymbol{X_2 = \frac{MdF_1 - MdF}{MdF_1 - MdF_2}} \ \boldsymbol{with}\ \boldsymbol{MdF_2} < MdF < \boldsymbol{MdF_1} \qquad (3)$$

where MdF_1 is the fineness modulus of sample with mass M_1, MdF_2 that of sample with mass M_2 and MdF the desired fineness modulus for the mix from the two samples. X_1 and X_2 are the proportions of absolute volumes of samples with masses M_1 and M_2 respectively in the mix.

3.4. Sand Equivalent

The sand equivalent of the materials studied was determined by the method of graduated plastic cylinder previously filled partially with washing solution according to the standard NF EN 933-8 Part 8 (1999) to measure the cleanliness of the materials studied with dimension less than or equal to 5 mm and is calculated as the average of the values of the visual and the piston values.

3.5. Specific gravity

The specific gravity is the mass per unit volume of the material excluding all the voids between aggregates. The specific gravity of the materials studied was determined by the method of pycnometer as described in the standards NF P 94-054 (1991) and NF P 18-555 (1990).

3.6. Water Absorption coefficient

The water absorption coefficient of the pozzolana sands was determined by drying in an oven at 105°C for 24 h, immersion in water for 24 hours, drying by means of hot air and weighing according to NF P 18-555 (1990). The water absorption coefficient of the pozzolana gravels was determined by drying in an oven at 105°C for 24 h, immersion in water for 24 h, then sponging and weighing according to the standard NF P 18-554 (1990).

4. RESULTS AND DISCUSSION

4.1. Particle size distribution

The particle size distribution determined for pozzolana sands, gravels, cobbles and boulders is presented in the form of particle size distribution curves.

4.1.1. Pozzolana sands for D ≤ 5 mm

The particle size distribution curves of the pozzolana sands are shown in Figure 1.

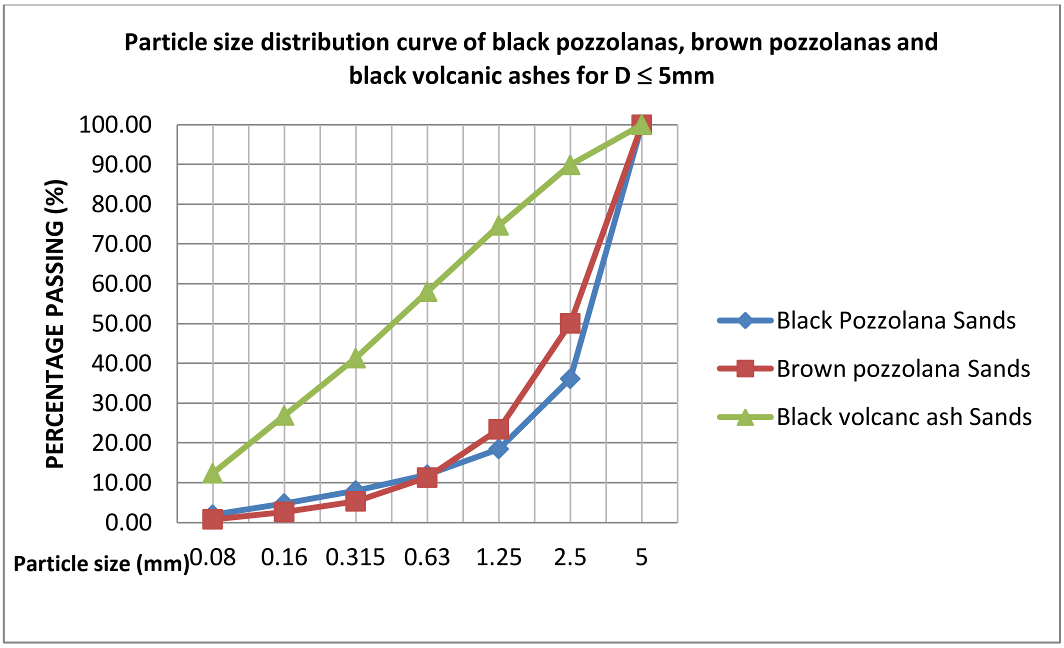

Figure 1 Particle size **distribution** curves of **the** pozzolana sands for D ≤ 5 mm.

Figure 1 shows that the values of the fineness modulus (FM) are 2.09, 4.21 and 4.07 respectively for the black volcanic ash sands, the black pozzolana sands and the brown pozzolana sands. The coefficient of uniformity (C_u) and the coefficient curvature (C_z) are respectively 9.13 and 0.62 for the black volcanic ash sands, respectively 7.79 and 2.25 for the black pozzolana sands and respectively 5.18 and 1.29 for the brown pozzolana sands.

4.1.2. Pozzolana gravels for 5 <D ≤ 20 mm

The particle size distribution curves of the pozzolana gravels are shown in Figure 2.

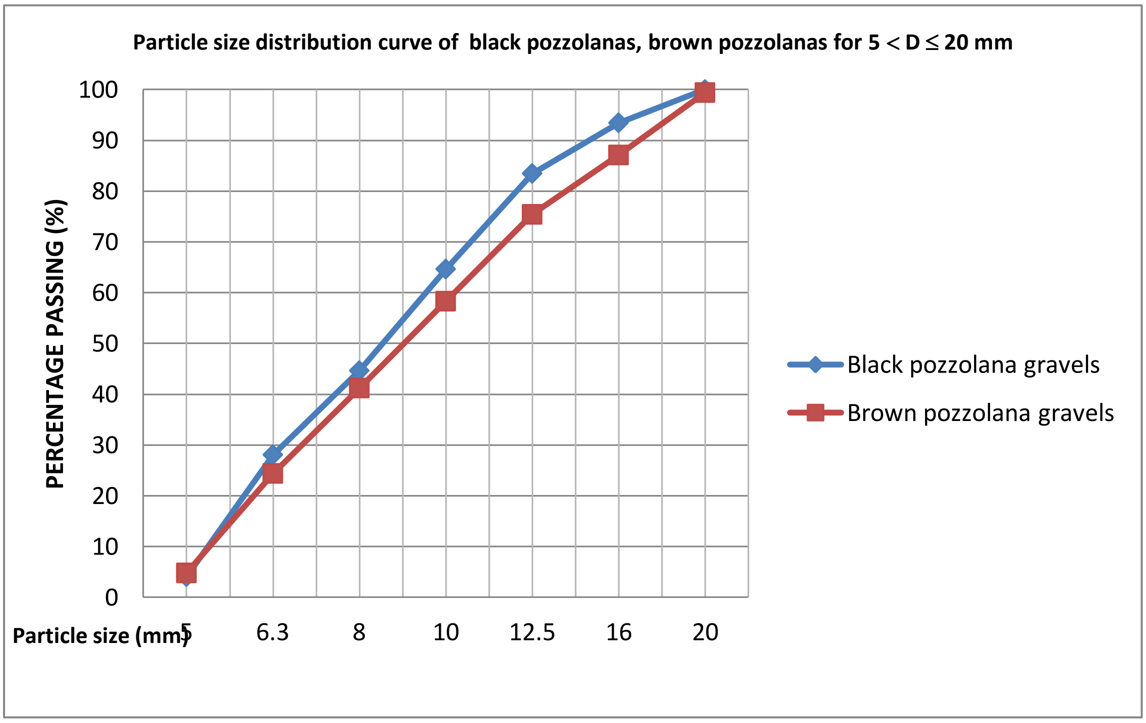

Figure 2 Particle size distribution curves of the pozzolana gravels for 5 <D ≤ 20 mm

Figure 2 shows that the coefficient of uniformity (C_u) and the coefficient of curvature (C_z) are respectively 1.76 and 0.82 for the black pozzolana gravels. For brown pozzolana gravels C_u and C_z respectively 1.91 and 0.85.

4.1.3. Pozzolana cobbles and boulders for D> 20 mm

The particle size distribution curves of the pozzolana cobbles and boulders are shown in Figure 3.

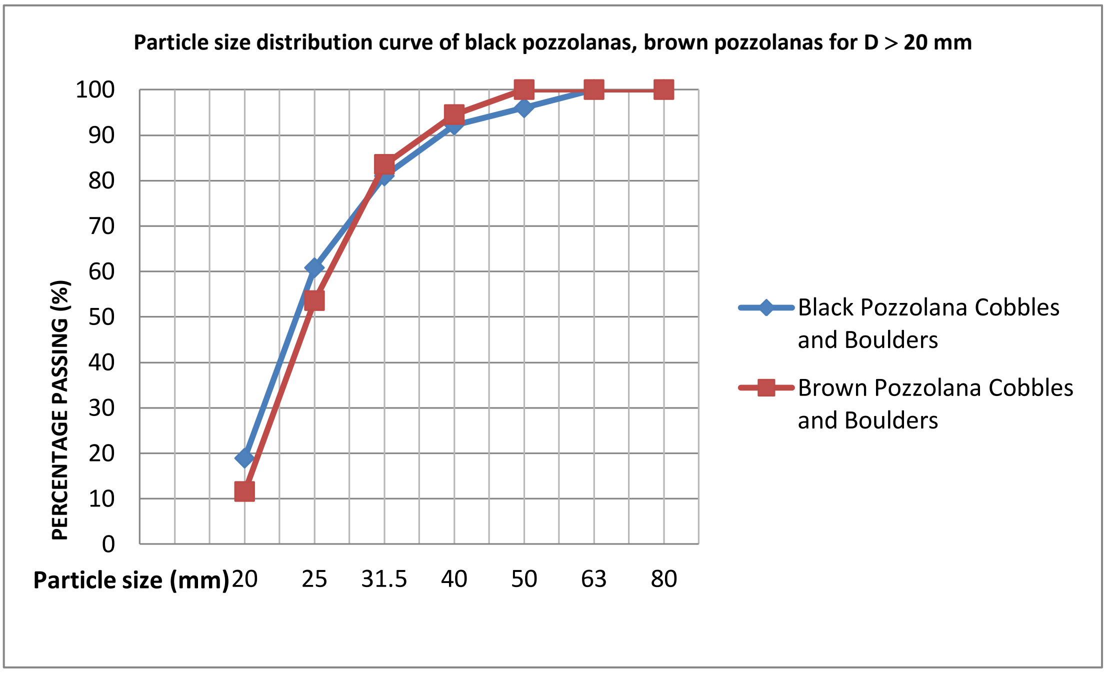

Figure 3 Particle size distribution curves of the pozzolana cobbles and boulders for D > 20 mm

Figure 3 shows that the coefficient of uniformity (C_u) and the coefficient of curvature (C_z) are respectively 1.47 and 1.06 for the black pozzolana cobbles and boulders and respectively 1.33 and 0.95 for the brown pozzolana cobbles and boulders.

4.1.4. Summary of Results and Discussion

After conducting the particle size analysis on the materials studied, the coefficient of uniformity and the coefficient of curvature were determined and the results presented in Table 1.

Table 1 Coefficient of uniformity and coefficient of curvature of the **black** volcanic ashes**, the** black pozzolanas and the brown pozzolanas

Materials studied	**Coefficient of uniformity C_u**	**Coefficient of curvature C_z**
Black volcanic ash sands **for** D ≤ 5 mm	9.13	0.62
Black pozzolana sands **f**or D ≤ 5 mm	7.79	2.25
Black pozzolana gravels **f**or 5 <D ≤ **20** mm	1.76	0.82
Black pozzolanas **f**or D> 20 mm	1.47	1.06
Brown pozzolana sands **f**or D ≤ 5 mm	5.18	1.29
Brown pozzolana gravels **f**or 5 <D ≤ **20** mm	1.91	0.85
Brown pozzolanas **f**or D> 20 mm	1.33	0.95

Table 1 shows that the value of the coefficient of uniformity (C_u) is less than 2 for the black pozzolana gravels, the black pozzolanas with dimension greater 20 mm, the brown pozzolana gravels and the brown pozzolanas with dimension greater than 20 mm, therefore the aggregates are uniform (Robitaille and Tremblay, 1997).

The value of the coefficient of uniformity C_u is greater than 6 and the value of the coefficient of curvature (C_z) is between 1 and 3 for the black pozzolana sands and the aggregates are gap-graded and well graded (Robitaille and Tremblay, 1997). The value of C_u is greater than 6 but C_z is not comprised between 1 and 3 for the black volcanic ash sands and the aggregates are gap-graded and poorly graded (Robitaille and Tremblay, 1997). The value of C_u is between 2 and 6 and C_z is comprised between 1 and 3 for the brown pozzolana sands and the aggregates are gap-graded and poorly graded (Robitaille and Tremblay, 1997).

4.2. Sand Equivalent and fineness modulus

The sand equivalent and fineness modulus values of the studied materials are presented in Table 2.

Table 2 Sand Equivalent and fineness modulus values of the black volcanic ashes, the black pozzolanas and the brown pozzolanas

Physical Characteristics	**black volcanic ash sands for D ≤ 5 mm**	**Black pozzolana sands for D ≤ 5 mm**	**Brown pozzolana sands for D ≤ 5 mm**
Sand Equivalent	78.9	96.1	95.8
Fineness modulus	2.09	4.21	4.07

Table 2 shows that the Sand Equivalent value is equal to 78.9 for the black volcanic ash sands and according to Dreux and Festa (1998) and Dupain and Saint-Arroman (2009), these aggregates are clean with low percentage of fine dust or clay-like materials and are very suited for quality concrete. The black pozzolana sands and the brown pozzolana sands with dimension less than or equal to 5 mm have Sand Equivalent values of 96.1 and 95.8 respectively, showing that the aggregates are very clean. The almost total absence of fine dust or clay-like materials may cause lack of plasticity of the concrete that should be corrected by increasing the quantity of cement in the mix (Dreux and Festa, 1998; Dupain and Saint-Arroman, 2009).

The fineness modulus of the black volcanic ash sands is between 1.8 and 2.2 (Table 2). According to NF P 18-541 (1994), the aggregates are very fine and can reduce the strength of concrete while facilitating the workability when used alone as sands: They can be corrected by providing a coarser sand to bring the fineness modulus between 2.2 and 2.8. The fineness modulus of the black pozzolana sands and brown pozzolana sands with dimension less than or equal to 5 mm is greater than 2.8: According to NF P 18-541 (1994), the aggregates are coarse, not good for the manufacture of concrete and can only be used after correction with a finer sand to bring the fineness modulus between 2.2 and 2.8.

4.3. The Specific gravity and Water absorption coefficient of the volcanic materials

The specific gravity and the water absorption coefficient of the materials investigated are presented in Table 3.

Table 3 Specific gravity and water absorption coefficient of the studied materials

Materials Studied	Specific gravity (g / cm3)	Water absorption coefficient (% Aggregates dry weight)
Black volcanic ash sands for D ≤ 5 mm	2.52	25
Black pozzolana sands for D ≤ 5 mm	2.23	25
Black pozzolanas for D > 5 mm	2.06	25
Brown pozzolana sands for D ≤ 5 mm	2.53	25
Brown pozzolanas for D > 5 mm	2.37	25

The values of the specific gravity of the black volcanic ash sands, the black pozzolanas, the brown pozzolanas and the water absorption coefficient are shown in Table 3. The specific gravity values are between 2 g / cm^3 and 3 g / cm^3. The water absorption coefficient is between 20 and 30% of weight of the dry materials: According to NF EN 12620 (2008), NF XP18-545 (2004), EN 13055-1 (2002), NF P 18-554 (1990) and NF P 18-555 (1990), and also UNICEM Auvergne, the aggregates are very porous and lightweight aggregates.

5. PROPOSALS

The following propositions have been made for a good mix design of concretes and mortars manufactured with the studied pozzolanic materials.

The black volcanic ash sands are fine, the black pozzolana sands and the brown pozzolana sands are coarse; therefore concrete and mortar mixes should be designed so that the value of the fineness modulus of the mixture of the black volcanic ash sands and the pozzolana sands is between 2.2 and 2.8 for quality concrete and mortar. This fineness modulus will be taken as 2.5, and Abrams' rule used to obtain in terms of absolute volume or volume of solids 81% of the black volcanic ash sand (S_1) and 19% of the black pozzolana sand (S_2) for mixture S and 79.4 % of the black volcanic ash sand (S_1) and 20.6% of the brown pozzolana sand (S_3) for mixture S'.

These aggregates when dry should be pre-saturated with water determined from the water absorption coefficient of the aggregates to take into consideration the porosity of the aggregates being studied in the design of concrete or mortar mix (In this case 25% aggregates dry weight).

Naturally occurring volcanic aggregates should be used in road technique (drainage layers for trenches, drains backfill, surfacing course for slippery sections of earth roads), in sport equipments such as athletics tracks, land tennis courts, evolution platform and bowling green, football, rugby, golf and hockey fields. Naturally occurring volcanic aggregates should also be used for racetracks, in the building (paving, all types of pipe laying, waterproofing of flat roofs, all foundations housing residential building, septic tanks filter and bacteria filter for sewage treatment plants).

6. CONCLUSIONS

The results obtained in this study led to the following conclusions:

The black volcanic ash sands with dimension less than or equal to 5 mm are classified as lightweight, fine, clean, gap-graded and poorly graded materials; Their use as sands for quality concrete needs correction by addition to them of coarser sands.

The black pozzolana sands with dimension less than or equal to 5 mm are classified as lightweight, very clean, gap-graded, well-graded and coarser materials; Their use as sands for quality concrete needs correction by addition to them of finer sands.

The brown pozzolana sands with dimension less than or equal to 5 mm are classified as lightweight, very clean, gap-graded, poorly-graded and coarser materials; Their use as sands for quality concrete needs correction by addition to them of finer sands.

The black pozzolana gravels and the brown pozzolana gravels with dimension between 5 and 20 mm, the black pozzolanas and the brown pozzolanas with dimension greater than 20 mm are classified as lightweight and uniform materials.

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