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Physico-mechanical properties of Benin lateritic soils and alterites and their use to make stabilized agglomerates

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Abstract

Faced to the need to promote agglomerates in stabilized earth, this study was initiated in order to overcome the lack of technical studies on the raw materials used in construction and more specifically on lateritic soils and alterites available in Benin. The funding of this research was provided by the West African Economic and Monetary Union (WAEMU) within the framework of its Program of Support to Higher Education (PSHE-WAEMU). As granulometry, plasticity as well as compacting conditions of soils systemically influence the behavior of agglomerates, a determination of the physico-mechanical properties was made through granulometric tests, the determination of the parameters of plasticity and the Proctor compaction references. This study highlights that lateritic soils and alterites, although geologically different, are, from the geotechnical point of view, all silty or loamy soils with varying plasticity, and containing sometimes a small proportion of gravel; lateritic soils are sandier than alterites. The characteristics of the lateritic soils are more interesting than those of alterites for the production of landcretes. According to the ARS 680 standard, Zagnanado, Zakpota, Ketou and Houeyogbe lateritic soils and the alterite from Tanguieta can be accepted as raw materials for landcretes whereas, according to Hydraform recommendations, only the lateritic soils from Zagnanado is usable in the state to make landcretes with a targeted resistance of 4MPa after 28 days with an incorporation of 4 to 7% of cement. Other soils should be improved by adding sand or lime, under conditions to be specified. In the case of the use of the CEN standardized sand conforming to EN 196-1, the proportions of the base material range from 59.73% to 64.90% for lateritic soils and from 56.25% to 97.83% for alterites.

Keywords: Alterite, lateritic soil, granulometry, argilosity, proctor test, agglomerates.

Introduction

Given the high cost of standard building materials and the prohibition of removal and use of marine sand, the promotion of local building materials is required in Benin, with a particular emphasis on the use of stabilized earth agglomerates made of lateritic soils and other alterites abound in Benin[1-3]. These agglomerates, already used in some areas, would make it possible to construct ecological buildings that consume less energy and are less expensive[4,5]. In South Africa, the certificate 96/237 was issued after several experiments with the Hydraform group[6]. African Regional Standards (ARS) for agglomerates already exist like the ARS 680 standard providing information on good practices for the preparation of earth mortars[7]. The lateritic soil represents the most dominant types of soils of southern Benin. Indeed, they are weakly desaturated sandy-clay ferralitic soils on Continental Terminal's clayey sediments or on Cretaceous sandstones[8]. The alterites are cover formations related to the alteration and evolution of climatic and pedogenetic superficial formations in place (crystalline basement) or reworked (alluvium, alluvial spreading). They result from the very extensive alteration of the source rock that is no longer recognizable.

Taking into account the unavailability of a global research of characterization of the physico-mechanical properties of the lateritic soils and alterites covering the whole extent of the Beninese territory, this study aims to make up for the non-existence of technical studies on these raw materials generally used in the manufacture of agglomerates. Specifically, it focuses on the determination of the physico-mechanical properties of Benin's lateritic soils and alterites and then on a conformity study based on existing standards.

Materials and methods

Study area: Benin is a West African country, covering an area of 114.764 km^2 and extending from 6° to 12° N latitude over 700 km. It is subdivided into seventy-seven (77) townships distributed in twelve (12) departments.

The “lateritic soil” was studied on the seven plateaus of South Benin: Abomey, Allada, Aplahoue, Come, Ketou, Sakete and Zagnanado. For alterites, field works were carried out in townships in the Center (Bassila, Ouesse) and the North (Banikoara, Djougou, Kandi, Kouande, Natitingou, Nikki, Parakou Tanguieta and Tchaourou) of Benin.

Twenty-nine (29) sites from various geological domains were studied as follows: eighteen (18) sites of “lateritic soils” and eleven (11) sites of alterite (Table-1)[9-12]. Figure-1 shows their distribution on the map of Benin.

Table-1: Geological domains of sites[9-12].

	Region	Townships	Area codes	Geological domains
«lateritic soils»	Atlantique	Abomey-Calavi	TB1	Plateau of Allada
		Allada	TB2	
		Ouidah	TB3	
	Couffo	Aplahoue	TB4	Plateau of Aplahoue
		Dogbo	TB5	
	Mono	Lokossa	TB6	
		Bopa	TB7	Plateau of Come
		Come	TB8	
		Houeyogbe	TB9	
	Oueme	Adjarra	TB10	Plateau of Sakete
	Plateau	Adja-Ouere	TB11	
		Sakete	TB12	
		Ketou	TB13	Plateau of Ketou
	Zou	Zagnanado	TB14	Plateau of Zagnanado
		Abomey	TB15	Plateau of Abomey
		Agbangnizoun	TB16	
		Bohicon	TB17	
		Za-Kpota	TB18	
Alterite	Alibori	Banikoara	A1	Gneiss, micaschists
		Kandi	A2	Sandstone Cam-Bro-Silurians
	Atacora	Kouande	A3	Ortho-gneiss with muscovite
		Natitingou	A4	Quartz orthogneiss
		Tanguieta	A5	Sandstone and silexites of Buem
	Borgou	Nikki	A6	Migmatites; outcrop of gneiss
		Parakou	A7	Migmatites ; lateritic cuirasses
		Tchaourou	A8	Migmatites; lateritic cuirasses
	Collines	Ouesse	A9	Migmatites; outcrop of granite
	Donga	Bassila	A10	Migmatites and gneissic formations
		Djougou	A11	Gneiss, micaschists

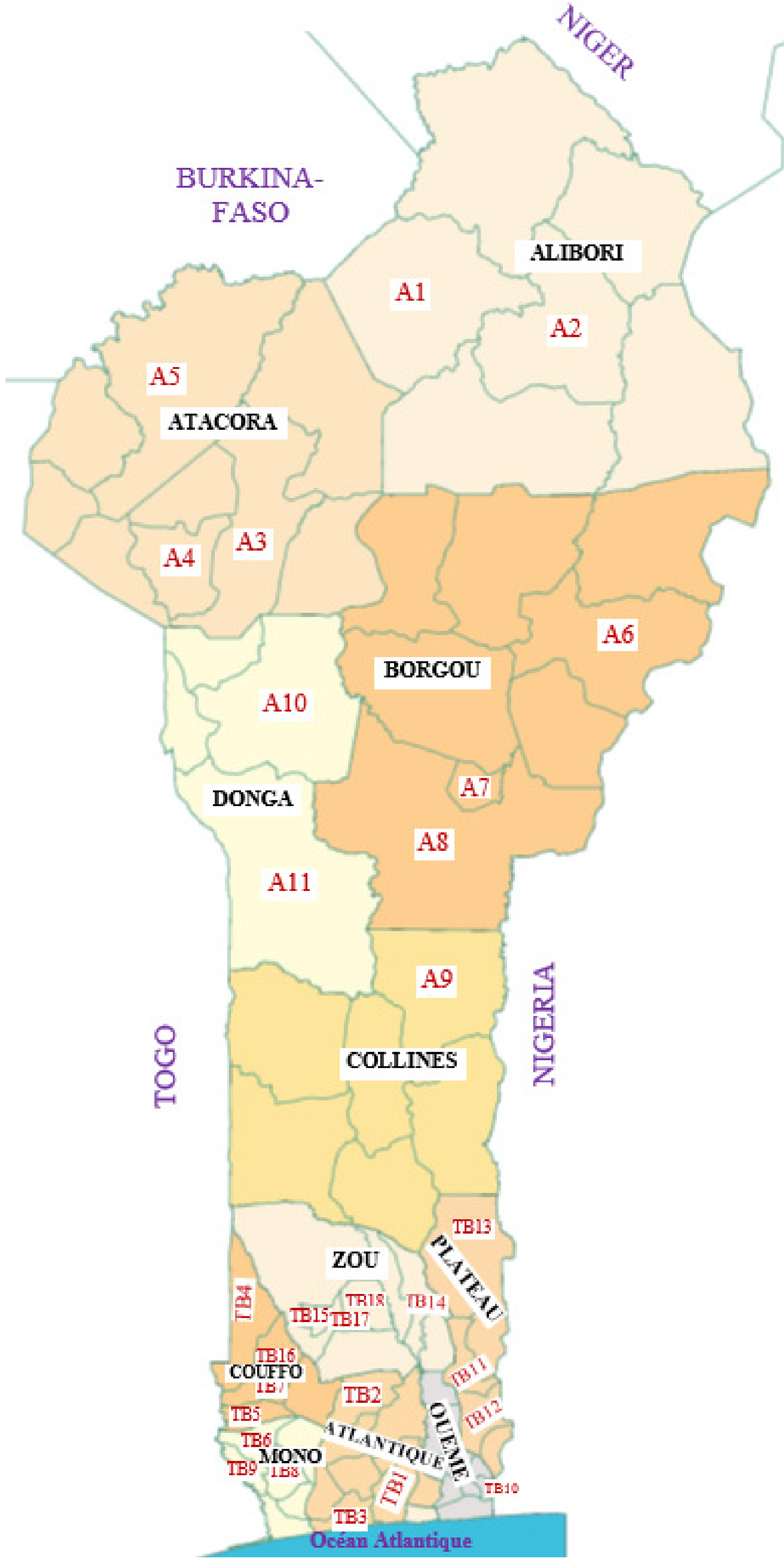

Figure-1: Location of the data collection sites on the map of Benin.

Characterization tests: Identification test and Proctor compaction tests were performed. The identification tests make it possible to assess the granularity and clay content of the soils. The Proctor test allows, through a compacting operation that tightens the texture of the soil, to determine the important parameters that are the Proctor references (maximum apparent dry density ρd_{OP}, optimum water content w_{OP}). Indeed, the maximum compressive strength of the agglomerates is strongly related to the dry density and the compaction water content.

The tests were conducted based on the French standards as follows: i. the water content (NF P 94-050)[13]. ii. particle size analyses, by dry sieving after washing (NF P 94-056)[14]. iii. particle size analyses by sedimentometry (NF P 94-057)[15]. iv. the Atterberg limits: liquidity limit (w_L) and plastic limit (w_p) (NF P 94-051)[16]. The plasticity index is deduced from results of this test ($Ip = w_L - w_p$). v. Proctor references (NF P94-093)[17].

Three soil classification systems were used: i. The "GTR classification"[18], based on the granulometric characteristics: maximum diameter of the grains (D_{max}), passing at 80 µm, passing at 2 mm and on the blue value of the soil and /or the index of plasticity[19]. ii. The "LPC classification" based on granulometric criteria (sieves at 2 mm and 0.08 mm), the shape of the granulometric curve, the plasticity characteristics w_L and IP, and line A of equation $IP = 0.73 (w_L-20)$[20]. iii. The American Highway Research Board (HRB) classification, which takes into account the granulometry (% passing through the 2mm, 0.5 mm and 80 µm sieve) and the Atterberg limits[21].

Results and discussion

Identification Parameters: The granulometric analysis results, the Atterberg limits obtained for lateritic soils and for alterites as well as the classifications are respectively presented in Table-2 and Table-3.

Table-2: Characteristics of lateritic soils.

Department	Townships	Granulometric analysis (% passing)			Atterberg Limits			Classifications		
		2 mm	0.4 mm	0.08 mm	W_l	W_p	Ip	HRB	LPC	GTR
Atlantique	Abomey-Calavi	100	65	26	47	29	18	A2-7	Lp	B6
	Allada	100	80	59	59	26	33	A7-6	At	A3
	Ouidah	100	75	53	51	31	20	A7-5	Lt	A2
Couffo	Aplahoue	100	77	60	51	24	27	A7-6	At	A3
	Dogbo	100	88	51	53	23	30	A7-6	At	A3
Mono	Lokossa	100	80	49	54	30	24	A7-5 à 6	Lt	A3
	Bopa	100	84	58	53	26	27	A7-6	At	A3
	Come	100	71	51	58	31	27	A7-5	Lt	A3
	Houéyogbe	100	82	69	46	23	23	A7-6	Ap	A3
Oueme	Adjarra	100	78	59	59	31	29	A7-6	At	A3
Plateau	Adja-Ouere	100	89	71	54	29	25	A7-6	At	A3
	Sakete	100	74	63	56	33	23	A7-5	Lt	A3
	Ketou	99	74	52	40	20	21	A2-6	Ap	A3
Zou	Zagnanando	95	72	32	30	19	11	A2-6	Ap	B6
	Abomey	100	75	56	53	27	26	A7-6	At	A3
	Agbangnizoun	100	88	75	55	26	29	A7-6	At	A3
	Bohicon	98	86	75	40	19	21	A7-6	Ap	A3
	Zakpota	100	82	53	44	22	22	A7-6	Ap	A3

Table-3: Characteristics of alterites.

Department	Township	Granulometric analysis (% passing)			Atterberg Limits			Classifications		
		2 mm	0.4 mm	0.08 mm	W_l	W_p	Ip	HRB	LPC	GTR
Alibori	Banikoara	88	82	78	65	36	29	A7-5	Lt	A3
	Kandi	96	84	76	64	32	32	A7-5	Lt	A3
Atacora	Kouande	95	70	54	54	20	34	A7-6	At	A3
	Natitingou	94	88	69	52	28	24	A7-6	At	A3
	Tanguieta	98	83	53	33	17	16	A6	Ap	A3
Borgou	Nikki	98	73	56	44	20	24	A7-5	Ap	A3
	Parakou	88	69	61	79	38	41	A7-5	Lt	A4
	Tchaourou	61	51	46	62	31	31	A7-5	At	A3
Collines	Ouesse	97	69	56	45	21	24	A7-6	Ap	A3
Donga	Bassila	94	86	80	45	23	22	A7-6	Ap	A3
	Djougou	97	83	57	38	18	20	A6	Ap	A3

For most of the lateritic soil samples tested, the maximum grain diameter is 2mm and the percentage of sifted material is 100%. Such soils can therefore be considered as sandy soils. Some, especially those from the plateaus of Bohicon, Ketou and Zagnanado have D_{max} slightly higher than 2mm. For all the alterites, the percentage passing at 2mm sieve is less than 100% and varies from 61 to 98%. Most of them are soils with a gravelly tendency.

The percentage passing through the 0.08 mm sieve is one of the very important parameters because beyond 50%, the sample behaves like its fine fraction and its influence on the plasticity parameters becomes very appreciable. This is the case for most of the lateritic soils (51 to 75) studied with the exception of samples from Abomey-Calavi, Lokossa and Zagnanado and all other alterites (53 to 80) except that of Tchaourou. In general, alterites contain much more fines than lateritic soils.

The plasticity index (IP) characterizes the clay content and defines the extent of the plastic domain of the material. The plasticity index varies from 11 to 33 for the lateritic soils and from 16 to 41 for the alterites. Thus, they are soils the plasticity of which varies from less important to more plastic. (Magnan, 1997).

Based on the HRB classification, which takes into account granulometry and Atterberg limits, the lateritic soil samples studied are mostly classified as A-7-5 and A-7-6 (fine clay soils) except the samples from Ketou, Abomey-Calavi and Zagnanado which are classified A-2-6 and A-2-7 (gravels and silty or clayey sands). According to the GTR classification, Abomey-Calavi and Zagnanado are classified "B6" which are sands and clayey to very clayey aggregates. As for Ketou's soil, it is classified A3 like the majority of the studied lateritic soils, that is to say "clays and marly clays or very plastic silt". This designation is confirmed by the LPC classification, which shows that all the studied lateritic soils are little to very plastic clay or silt. Considering the alterites, the same classes are obtained: A3 for all the alterites with the exception of that from Parakou which is a very plastic clay nevertheless classified as a very plastic slime according to the LPC classification. Following the HRB classification, all soils are clayey (A6, A7-5 or A7-6).

Thus, the studied lateritic soils and alterites, although geologically different, are, from the geotechnical point of view, all silty or clayey soils that are less to more plastic with sometimes a small proportion of gravel.

Compaction Parameters: Summaries of the Proctor tests are given in Table-4 and Table-5 respectively for “lateritic soils and alterites. A summary of the results is presented on a graph (Optimum Moisture - Maximum Dry Density) for both types of soil (Figure-3).

Table-4: Recap of Proctor References for lateritic soils.

Department	Township	Optimum water content (%)	Maximum Dry Density (t/m^3)
Atlantique	Abomey-Calavi	09.15	2.073
	Allada	16.92	1.82
	Ouidah	13.5	1.88
Couffo	Aplahoue	12.92	1.877
	Dogbo	13.75	1.947
Mono	Lokossa	12.41	1.95
	Bopa	11.83	2.033
	Come	13.35	1.955
	Houeyogbe	13.72	1.926
Oueme	Adjarra	14.34	1.892
Plateau	Adja-Ouere	16.77	1.825
	Sakete	14.61	1.918
	Ketou	18.25	1.94
Zou	Zagnanado	8.02	2.105
	Abomey	9.04	2.08
	Agbangnizoun	14.39	1.88
	Bohicon	14.74	1.88
	Za-Kpota	12.82	1.961

It can be seen from Table-4 that the optimum water content of the lateritic soils varies between 8.02% (Zagnanado) and 18.25% (Kétou) and that the dry density varies between 1.82 t/m^3 (Allada) and 2.1 t/m^3 (Zagnanado).

Table-5: Recap of Proctor References for alterites.

Department	Township	Optimum water content (%)	Maximum dry density (t/m^3)
Alibori	Banikoara	22.27	1.72
	Kandi	18.91	1.78
Atacora	Kouande	18.38	1.89
	Natitingou	16.20	1.85
	Tanguiéta	12.21	2.1
Borgou	Nikki	15.21	1.91
	Parakou	24.01	1.67
	Tchaourou	21.26	1.87
Collines	Ouesse	15.80	1.86
Donga	Bassila	19.66	1.56
	Djougou	19.35	1.81

The optimal water content of the alterites varies between 12.21% (Tanguieta) and 24.01% (Parakou) and the dry density varies, except for Bassila (1.56 t/m^3) and Tanguieta (2.1 t/m^3), between 1.67 and 1.91 t/m^3.

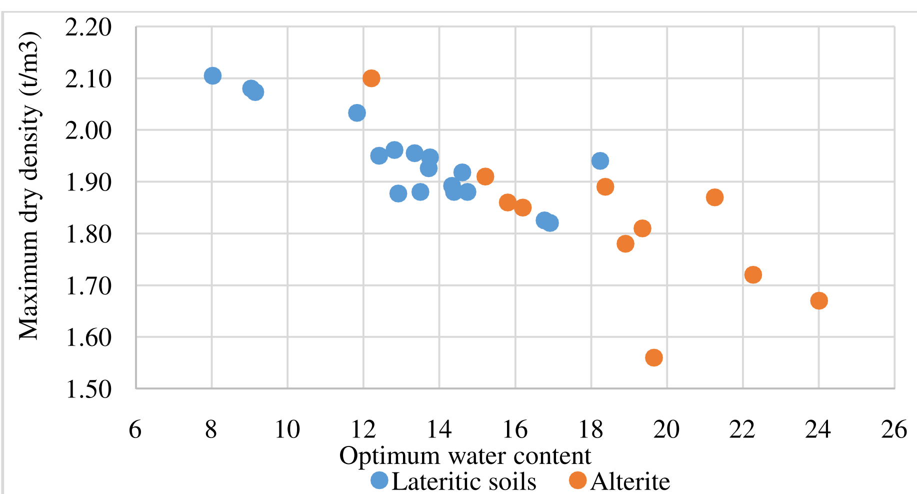

Figure-2: Graph optimum water content - maximum dry density.

Figure-3 shows generally that the Proctor reference points of the lateritic soil are at the left and on top of the alterites, which means that the optimal water content of the lateritic soil is lower than that of the alterites and that their dry densities are greater than those of the alterites except particularly the point (12.21 – 2.1) of Tanguieta alterite and points (18.25 – 1.9); (16.92 - 1.82); (16.77 - 1.82) respectively for the lateritic soils from Ketou, Allada and Sakete. This difference can be explained by the further alteration of the alterites.

Thus, alterites require much more water to be compacted and have a weaker dry density than lateritic soils.

Study of the materials as raw materials for agglomerates: According to ARS 680 standard: According to this standard, soils the texture and plasticity of which are inscribed in the granulometry and plasticity zones (shown in red bold lines in Figure-3, Figure-4 and Figure-5) give satisfactory results in most cases.

Most of the granulometric curves of the lateritic soils enter the spindle (Figure-3) except for samples from Ikpinle, Bohicon, Houeyogbe and Agbangnizoun sites where some overflows are observed from the 80 micron sieve where sifted materials are higher than those of spindle max.

For the alterites (Figure-4), there are also some overflows as in the case of the soils of Bassila, Banikoara, Kandi and Natitingou from 80 microns. Practically all the curves are out of spindles at 2µm except the curve of Tanguieta which is fully inscribed in the granulometric zone.

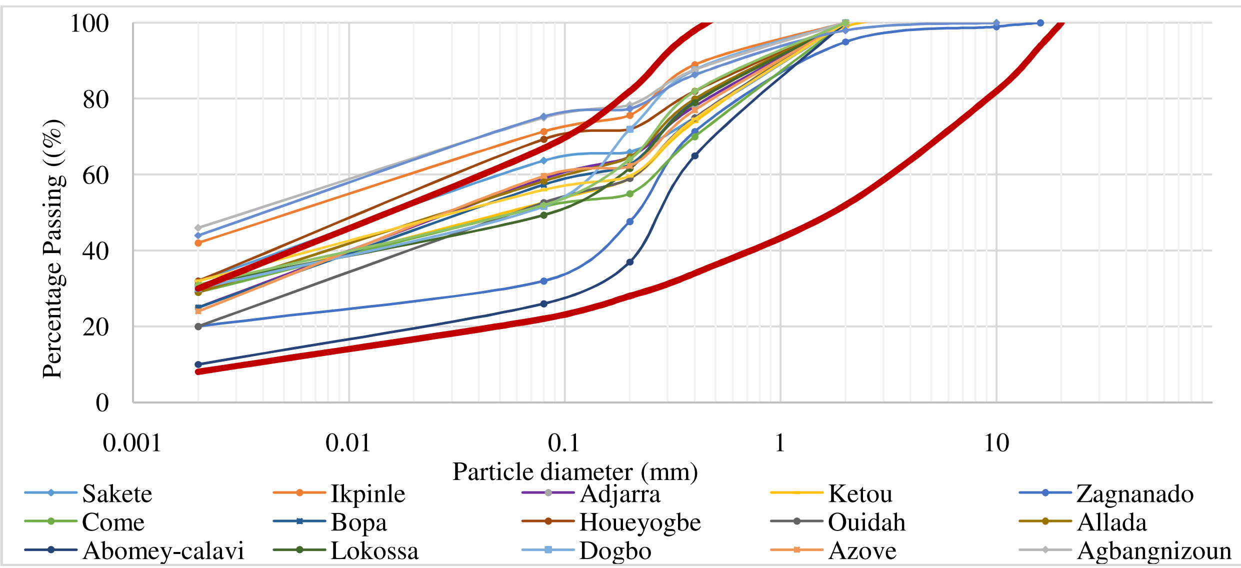

Figure-3: Position of the curves of the lateritic soils on the zone of granulometry according the ARS 680 standard.

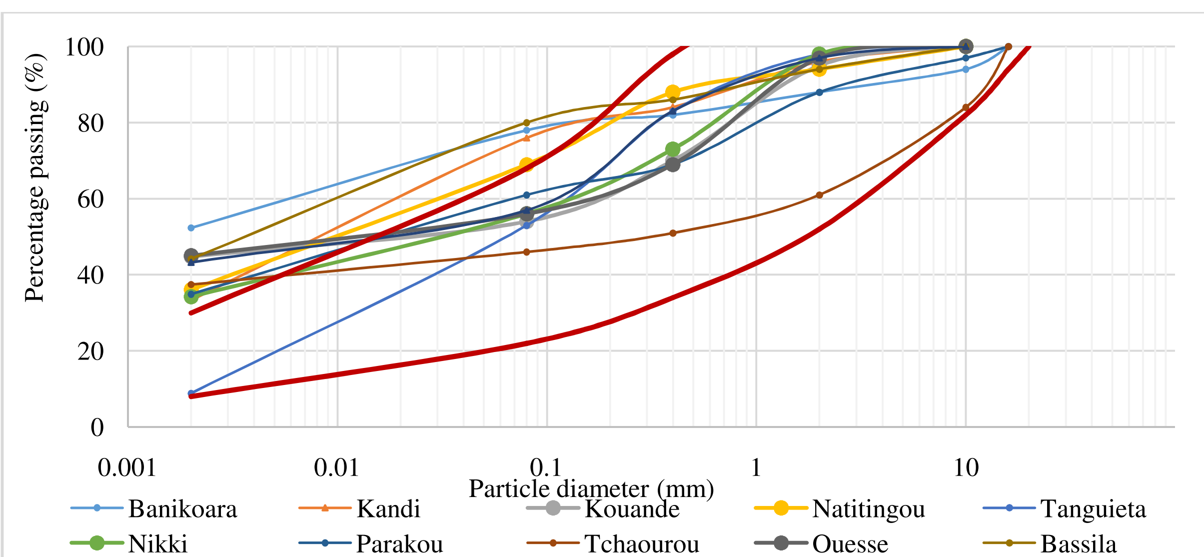

Figure-4: Position of the curves of the alterites on the zone of granulometry according the ARS 680 standard.

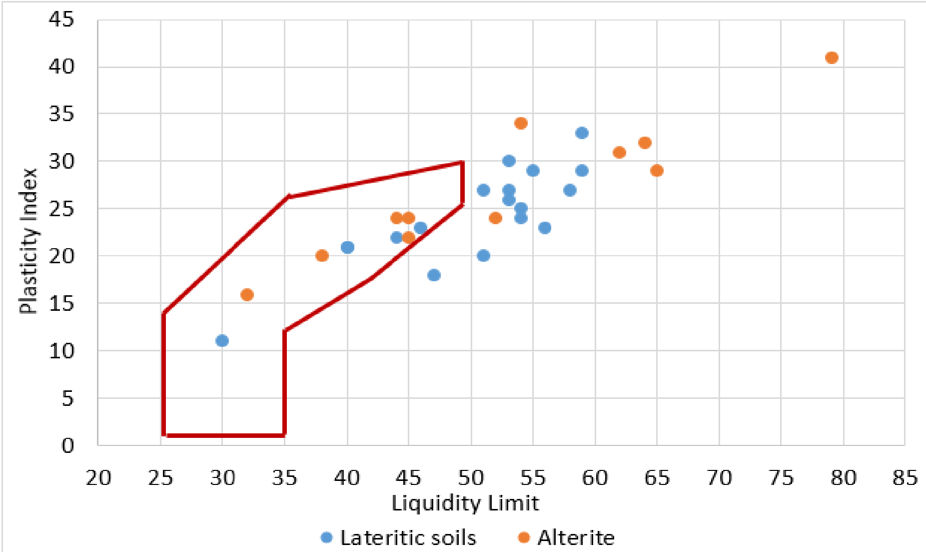

Figure-5: Position of the Atterberg limits on the plasticity zone according to ARS 680.

Regarding clay parameters, there is no clear distinction between lateritic soils and alterites. The alterite of Parakou admits the greatest plasticity. Few soils meet the plasticity criterion (Figure-5).

Referring to the ARS 680 standard, 14 out of 29 or 48.27% of the studied soils (lateritic soil and alterite of Benin) is found outside the granulometric zone and are too much clayey. Comparatively, the lateritic soil is found more in the spindle. Indeed, only 22.22% of surveyed lateritic soils are out of spindles (Agbangnizoun, Bohicon, Houeyogbe, Ikpinle).

Thus, according to this standard, only the lateritic soils of the Ketou, Houeyogbe, Zagnanado and Zakpota sites and the Tanguieta alterites can be accepted as materials that can be used for the manufacture of agglomerates. Djougou and Nikki can also be used because they have clay contents close to the limit.

For other sites, it will first be necessary to carry out an operation that would reduce the clay content and plasticity.

According to Hydraform 96/237 Agreement: A Hydraform type block is produced with a mixture of sandy clay soil and cement. Hydraform's recommendations are set out in Table-6.

Table-6: Soil characteristics recommended by Hydraform[9].

Soil category	% of material passing through the 0.075 µm sieve		Maximum Plasticity Index	Resistance of the block
	Min	Max		
A	10%	35%	15	4 Mpa
B	10%	25%	10	7 Mpa

However, soils with a higher plasticity greater than 15 are acceptable provided that they are treated beforehand with an additive (cement, lime, sand, etc.) under conditions to be defined by complementary tests. It is noted that the criteria according to the recommendations of Hydraform are much more severe than that of the ARS standard. Indeed, it is only the samples from Abomey-Calavi and Zagnanado that meet the grain size criterion with respectively 26 and 33% passing the 0.075 µm sieve. For the samples studied, only Zagnanado lateritic soil has an IP of less than 15, a value recommended for the manufacture of blocks incorporating 4 à 7% cement intended to reach a resistance of 4 MPa after 28 days cure. Thus, only the lateritic soil of the Zagnanado plateau is usable in the state (due to its granulometric and plasticity characteristics) to make blocks.

For samples from all other sites, the plasticity indices are between 18 and 41. These soils are not directly usable if resistances higher than 4 MPa must be reached even after the incorporation of 4 to 7% of cement. They will have to show, under conditions to be specified, an improvement by adding sand or lime, so as to readjust the index of plasticity and to improve the resistance.

Granular correction according to the time zone of ARS 680: In the case of off-zone granulometric curves, an addition of sand is possible so as to have a reconstituted material entering the spindle of the ARS 680 standard from a certain proportion of the base material (A) and a quantity of sand.

In the case of standardized sand (Table 7), the percentage of material passing through a 0.08mm sieve is nil. Let P_A be the percentage of material passing from A and P_M the passing percentage of the mean point of the spindle for the opening 0.08mm (P_M = 45%). If the resulting curve passes through this mean point, the necessary proportion of material A (M_A) is given by the formula[22]:

$$M_A(\%) = \frac{P_M}{P_A} x100 \quad (1)$$

Table-7: Granulometry of a standardized CEN sand certified to EN 196-1[23].

Sieve (mm)	2	1.6	1	0.5	0.16	0.08
Percentage passing	100	93	67	33	13	0

For lateritic soils the granulometric curves of which do not fit into the specified time zone, the necessary proportions of the basic materials to obtain, after incorporation of the standardized sand, reconstituted materials entering the spindle are presented in Table-8 and the resulting corrected curves are shown in Figure-6.

Table-8: Proportion of lateritic soil required for a correction with standardized sand.

	Bohicon	Ikpinle	Houeyogbe	Agbangnizoun
M_A (%)	59.73	63.08	64.90	60.00

For alterites, the same results are shown in Table-9 and Figure-7.

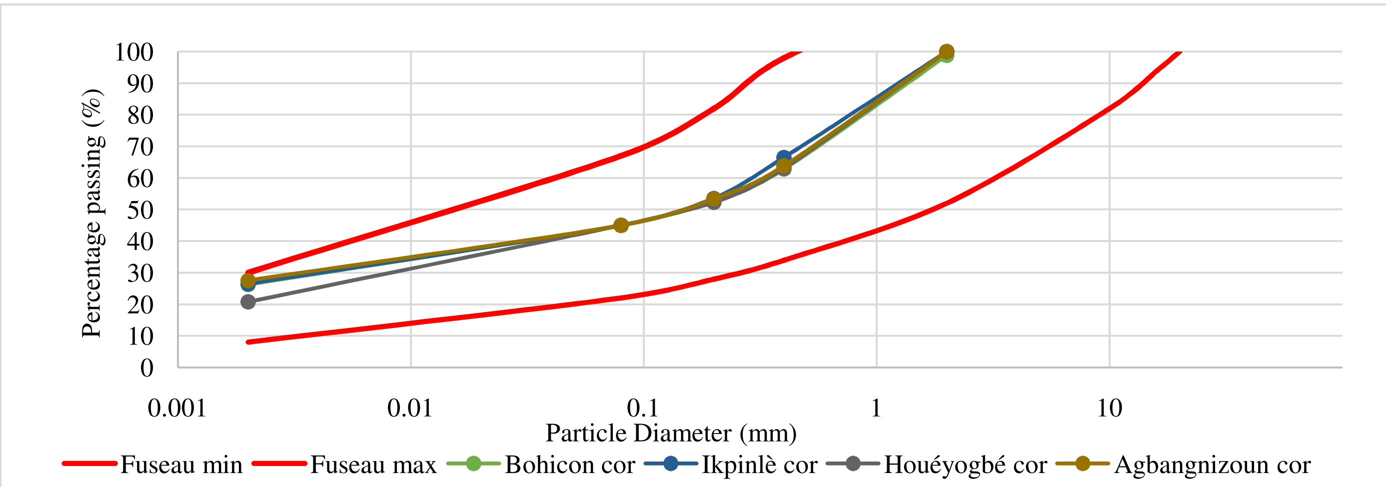

Figure-6: Corrected curves of lateritic soils with standardized sand to respect the spindle.

Table-2: Required proportion of alterites for a correction with standardized sand.

	Banikoara	Kandi	Kouande	Natitingou	Nikki	Parakou	Tchaourou	Ouesse	Bassila	Djougou
M_A (%)	57.69	59.21	83.33	65.22	80.36	73.77	97.83	80.36	56.25	78.95

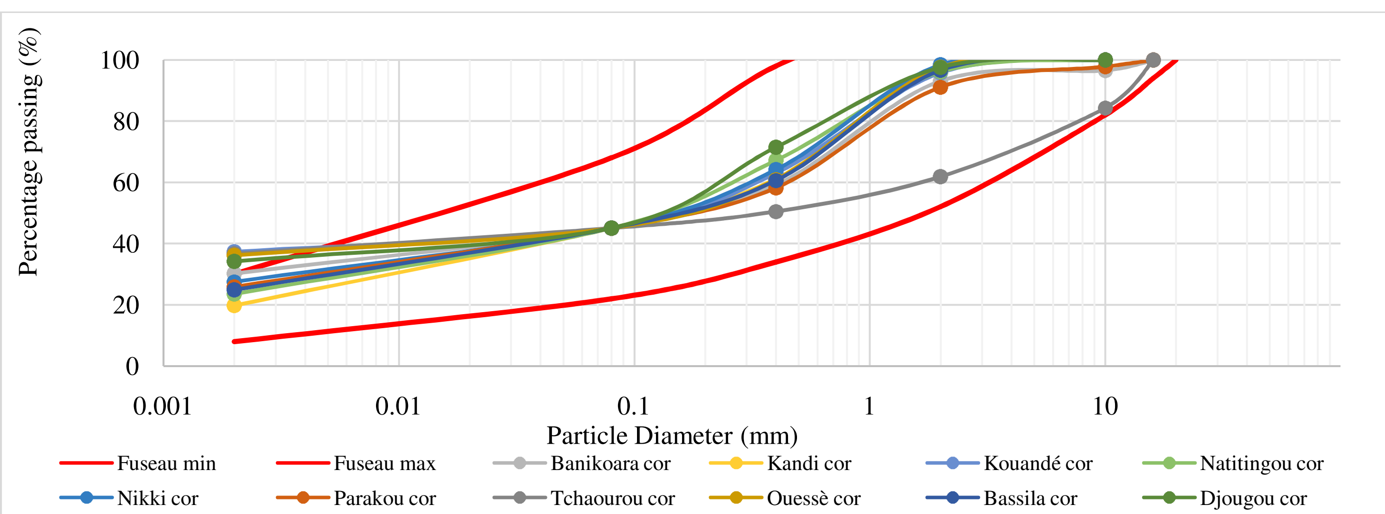

Figure-7: Corrected curves of alterites with standardized sand to respect the spindle.

For lateritic soils, the necessary proportions vary between 59.73% and 64.90%. For each of these sites, the sand will be used up to the complement of 100 of these proportions.

For alterites, the necessary proportions vary between 56.25% for Bassila and 97.83% for Tchaourou. For this site as well as for Ouesse (80.36%), Kouande (83.33%), Djougou (78.95%), the corrected curves always overflow at the level of passing at 0.002mm. Indeed, the relatively high proportions for these soils did not significantly reduce the percentage to 0.002mm. After correction, these contents are respectively 36.7% for Tchaourou, 36.2% for Ouesse, 37.3% for Kouande and 34.14% for Djougou, while the maximum value should be 30%. This excess of fines content may be removed by sieving; indeed, for a quantity M of material admitting a percentage of pass $P_{0.002}$, the maximum quantity to be eliminated (M ') is given by equation 2.

$$M' = \frac{P_{0,002} - 30}{100} xM \qquad (2)$$

Conclusion

To support the promotion of local building materials, this study aims to overcome the lack of technical studies on the raw materials used and on their agglomerates made of stabilized earth. It focused on the physico-mechanical properties of the Benin Lateritic Soils and Alterites.

It comes out of this study that: i. the lateritic soils studied are soils with a sandy tendency while the alterites are soils with a gravelly tendency. The studied soils are all practically fines plastics soils, and alterites have much more fines than the lateritic soils. Overall, the lateritic soils and alterites studied, although geologically different, are from the geotechnical point of view, all loamy or clayey loam soils with very little plastics, sometimes with a small proportion of gravel. ii. agglomerates will absorb less water during compaction and will be compact as the optimal water content of the lateritic soils is lower than that of alterites and their dry densities are greater than those of alterites. iii. referring to the ARS 680 standard, the majority of the studied soils (Benin lateritic soils and alterites) are found outside the granulometric spindle and are too much clayey. In comparison, the lateritic soils are more inscribed in the spindle than the alterites. iv. according to the ARS 680 standard, only the lateritic soil of the Ketou, Houeyogbe, Zagnanado and Zakpota sites and the Tanguieta alterites can be accepted as materials that can be used to make landcretes whereas, according to the recommendations of Hydraform, only the lateritic soil of the Zagnanado plateau is usable in the state to make blocks with a targeted resistance of 4Mpa for 28 days with an addition of 4 to 7% of cement. Other soils should be improved by adding sand or lime under conditions to be specified. v. in the case of use of CEN standardized sand conforming to EN 196-1, the proportions of the base material range from 59.73% to 64.90% for lateritic soils and from 56.25% to 97.83% for alterites.

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References

1. Igué A.M., Floquet A. and Stahr K. (2005). Land use/ cover change and farming systems in central Benin. *Bulletin de la Recherche Agronomique,* 50, 23-37.
2. Igué A.M., Houndagba C.J., Gaiser T. and Stahr K. (2012). Accuracy of the Land Use/Cover classification in the Oueme Basin of Benin (West Africa). *International Journal of Agri Science*, 2(2), 174-184.
3. Houessou A. and Lang J. (1978). Contribution à l'étude du « continental terminal » dans le Bénin méridional. *Sci. Géol.,* 31(4), 137-149.
4. Sorgho B., Zerbo L., Keita I., Dembele C., Plea M., Sol V., Gomina M. and Blanchart P. (2014). Strength and creep behavior of geomaterials for building with tannin addition. *Materials and Structures*, 47(6), 937-946. http:// doi 10.1617/s11527-013-0104-7
5. Samah El-Hadj Ouro Djobo (2005). Construire en matériaux de terre: tradition et modernité. Centre de Construction et de Logement (CCL), Cacaveli, Lomé, Togo.
6. Agrement South Africa (2010). Agrement Certificate 96/237. Hydraform Building System.
7. ARS 680 (1996). Blocs de terre comprimée, renseignant sur les bonnes pratiques pour la préparation des mortiers de terre. ARS.
8. Slansky Maurice (1962). Contribution à l'étude géologique du bassin sédimentaire côtier du Dahomey et du Togo. Mémoires du Bureau de Recherches Géologiques et Minières.
9. OBEMINES (1984). Carte géologique à 1/200.000 feuille Djougou-Parakou- Nikki et sa notice explicative. Office Béninois des Mines.
10. OBEMINES (1989). Carte géologique à 1/200.000 feuilles Malanville. Kandi, Porga, Karimama et leur notice explicative : Mémoire n°2. Office Béninois des Mines.
11. OBEMINES (1989). Carte géologique à 1/200.000, feuilles Lokossa- Porto-Novo. Abomey, Zagnanado, Pira-Savè et leur notice explicative : Mémoire n°3. Office Béninois des Mines.
12. OBEMINES (1995). Carte géologique à 1/200.000, feuilles Sansanné-Mango. Natitingou, Bembéréké, Dunkassa et

leurs notices explicatives : Mémoires n°4 et 5. Office Béninois des Mines.

13. AFNOR N. (1995). Sols: reconnaissance et essais. *Détermination de la teneur en eau pondérale des matériaux - Méthode par étuvage*, NF P 94-050.

14. AFNOR N. (1996). Sols: Reconnaissance et essais. *Analyse granulométrique. Méthode par tamisage à sec après lavage*, XP P 94-056.

15. AFNOR N. (1992). Sols: reconnaissance et essais. *Analyse granulométrique des sols - Méthode par sédimentation*, NF P 94-057.

16. AFNOR N. (1993). Sols: reconnaissance et essais. *Détermination des limites d'Atterberg - Limite de liquidité à la coupelle - Limite de plasticité au rouleau*, NF P 94-051.

17. AFNOR (1999). Sols: reconnaissance et essais. *Détermination des références de compactage d'un matériau - Essai Proctor normal. Essai Proctor modifié*, NF P 94-093.

18. AFNOR (1992). Classification des matériaux utilisables dans la construction des remblais et des couches de forme d'infrastructures routières. *Exécution des terrassements*, NF P 11-300.

19. LCPC-SETRA (2000). Guide des Terrassements Routiers, Réalisation des remblais et des couches de forme (GTR). Fascicules I et II.

20. Magnan J.P. (1997). Description, identification et classification des sols. Techniques de l'Ingénieur.

21. Ramamurthy T.N. and Sitharam T.G. (2010). Geotechnical Engineering (Soil mechanics). 3rd Edition. S. Chand and Company Ltd, 7361. ISBN : 81-219-2457-X.

22. Beinish H. (1999). Granulat reconstitué dont la courbe entre dans un fuseau donné. CERIB. Fiche 17.

23. AFNOR (2016). Méthodes d'essais des ciments - Partie 1 : Détermination des résistances. NF EN 196-1.