Research & Reviews: Journal of Material Sciences

Valorization of Lateritic Nodules in Concrete: State of The Art and Perspectives

Paulin Djimonnan*[1], Yvette S . Tankpinou Kiki[2], Gbènondé S.G. Milohin[1], Victor S.Gbaguidi[1] and Mohamed Gibigaye[1]

[1]Laboratory of Applied Energetics and Mechanics (LEMA), Polytechnic School of Abomey-Calavi (EPAC), University of Abomey-Calavi (UAC), Benin

[2]National Institute of Industrial Sciences and Techniques (INSTI) of Lokossa, National University of Sciences, Technologies, Engineering and Mathematics (UNSTIM) of Abomey, Benin

Review Article

Received date: 15/05/2021

Accepted date: 30/09/2021

Published date: 07/10/2021

***For Correspondence**

Paulin Djimonnan, Laboratory of Applied Energetics and Mechanics, Polytechnic School of Abomey-Calavi (LEMA), University of Abomey-Calavi (UAC), Benin.

Tel: +229 97937559

E-mail: pldjimonnan@gmail.com

Keywords: Aggregates, Mineralogy, Compressive strength, Tensile strength, Simple bend.

Abstract

The exponential needs of construction have created the scarcity of aggregates commonly used in the composition of concrete. The lateritic gravelly is one of the most widespread materials in tropical Africa. To overcome the lack of common aggregates, lateritic nodules have been the subject of studies, namely the substitution of the aggregates commonly used by lateritic nodules in concrete. Concretes have variable mechanical characteristics depending on the region but are acceptable for medium-sized structures. In fact, the compressive strength at 28 days is mostly greater than 24 MPa. The tensile strength varies from 2.42 to 3.40 MPa for a dosage of 350 kg/m^3. Lateritic nodules admit a high degree of water absorption. This compilation made it possible to identify several aspects of the study that still need to be further explored, in particular the influence of the inherent strength of the nodules and the mineralogy on the mechanical strengths of the concrete. With regard of the chemical and mineralogical composition, study reveals a dominance of iron oxides, of aluminum oxides, quartz and kaolinite

INTRODUCTION

Demographic expansion has resulted in a consequent demand for infrastructures, which in tropical Africa has resulted in the scarcity or non-availability in the vicinity of conventional aggregates commonly used for making concrete such as rolled gravel or crushed rocks. Laterites are metamorphic rocks that are red or brown in colour. They appear in the form of red earths mainly due to their iron oxide content. Ecological and available in the tropical region, lateritic soils are widely used as building materials in West Africa for rather light structural constructions according [1,2]. Laterites are widely distributed in most continents of the world, but particularly in the intertropical regions of Africa, Australia, India, Southeast Asia and South America **(Figure 1)**.

Figure 1. Distribution of laterites in the world.

Figure 2. Lateritic nodules.

Thus, most tropical African countries are covered to a large extent with laterites [3]. which may have grain sizes ranging from fines to riprap [4]. The lateritic beds are mostly gravelly and the lateritic nodules **(Figure 2).** can be obtained by screening or crushing the lateritic crust. Lateritic nodules are therefore, today, one of the most available local materials and potentially usable as aggregates in the composition of concrete in view of some of their characteristics. Their use as local materials will help protect the environment. Thus, the substitution of commonly used aggregates by lateritic nodules has been of concern to researchers and particularly to those in Africa over the past decades. The problem therefore arises of finding the necessary and complete information on the efficient use of these local materials. Indeed, knowledge on the one hand of the physical and mechanical characteristics of lateritic nodules, and, on the other hand, of the characteristics of concrete of lateritic nodules are all necessary information for the design of structures. Likewise, the durability of lateritic nodule concrete is important. Several researchers have therefore approached research on the use of lateritic nodules in concrete [5-6]. In a different way with the general aim of contributing to the enhancement of this local natural material in the habitat, with strong constructive potential in order to provide civil engineering stakeholders with technical specifications on the behaviour of lateritic nodule concrete with the aim of promoting them as local materials. This article aims to take stock through a bibliographical compilation of the results of existing studies on lateritic nodules in Africa. Indeed, the use of nodules as a construction material should be promoted, because of environmental concerns and it is urgent to synergize the various researches, to define new perspectives, in order to orient future research for mastery in faster times of this material in the manufacture of concrete. Our working method consisted of identifying the results of different researchers on the key parameters of lateritic nodules, comparing them and drawing conclusions.

Physico-mecanical characterisation of lateritic nodules

Table 1 summarizes the values obtained, for different lateritic nodules, of the apparent densities and of the real densities by several researchers [4,5, 7-12].

Apparent density (t/m^3)	1.46	1.41	1.40	1.41	1.41	1.32	1.41	1.42	1.38	1.50
Actual denisty (t/m^3)	2.56	2.58	2.74	2.75	2.78	2.65	2.66	2.66	2.71	2.68

Table 1. Apparent densities and actual densities of different lateritic nodules.

The diversity of the values of these two parameters: apparent density (1.38 to 1.50) and real density (2.56 to 2.78) as well as the inexistence of relations between them confirm the influence of the nature. of the parent rock as well as the state of alteration of the nodules on the mechanical behavior of lateritic concrete. The various laterite mixtures with a density equal to 2.56, to a range of concrete density varying between 2391 and 2591 Kg/m^3. It emerges from this research that the low density of the large aggregate could generate a high density of the concrete [10]. Also focused on the granular distribution of laterite particles and generated the granulometric curves of **Figure 3** [6].

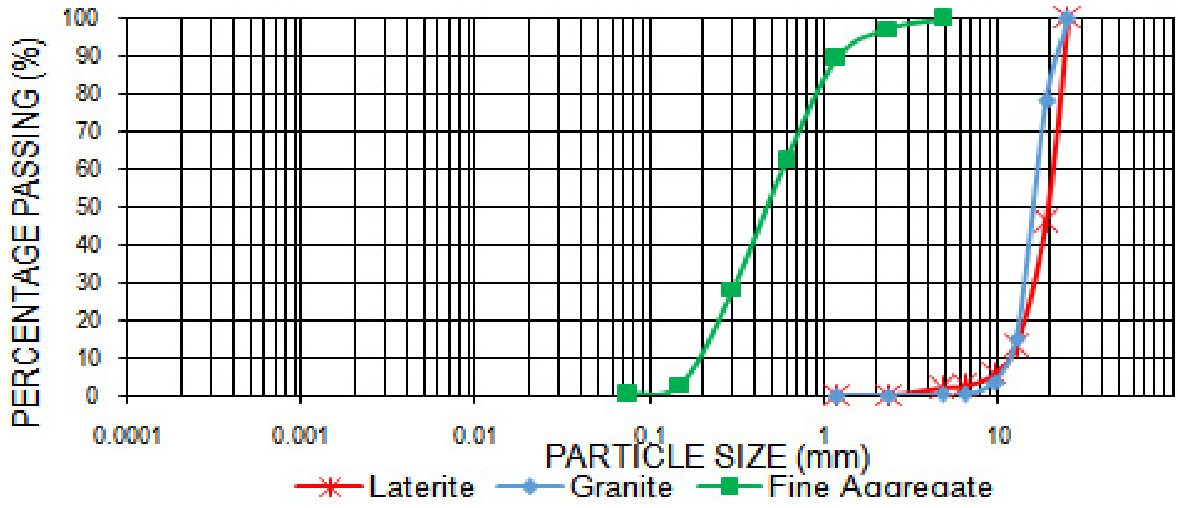

Figure 3. Particle size curves of lateritic nodules [6].

The particle size distribution of different lateritic nodules has been studied [11-12]. The grain size curves of lateritic nodules are shown in **Figure 4** and the uniformity and curvature characteristics are shown in **Table 2**.

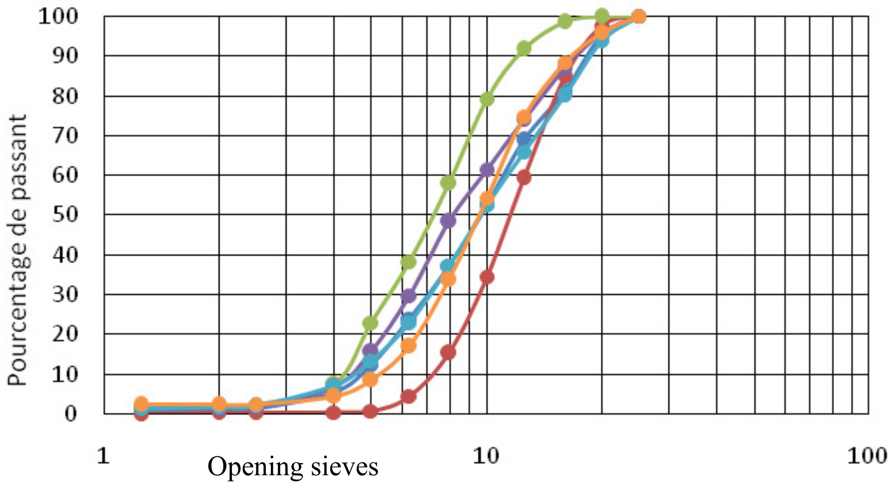

Figure 4. Particle size curves of lateritic nodules [11].

Designation	Avagoudo	Avlamè	Kika	Tourou	Logozohè	Hounkpogon
Coefficient of uniformity (Cu)	2.37	1.74	1.94	2.21	2.53	2.02
Coefficient of curvature (Cc)	0.96	1.00	0.90	0.93	1.00	1.04

Table 2. Coefficient of uniformity and Coefficient of curvature of different nodules.

The analysis of the different curves shows a granular class of 1.25-25 of the different lateritic nodules; an almost superposition of the grain size curves, a tight to very tight grain size (Cu <3) [13], according to the LPC classification, all the nodules are clean gravel with poor gradation [14]. Water absorption rates on aggregates of volcanic origin were determined [15]. Values of 13.55% and 13.60% respectively were obtained for gravel class 5-15 and gravel class 15-25. These values are high compared to the degree of water absorption of conventional aggregates which is of the order of 1%. The absorption coefficient is 7.15% for nodules and 1.07% for basalt [6]. Physic-mechanical tests were done on lateritic nodules, according to [6]. An average value of 24.9 was found for the Los Angeles hardness. **Table 3** summarizes the degree of nodule fragmentation by granular class [11].

Granular class	Los Angeles Coefficient (%)
10/14	48
6.3/10	44
4/6.3	37

Table 3. Summary of the results of the Los Angeles test carried out on the nodules.

The results are less than 50%. The lateritic nodules therefore appear resistant [11]. On the other hand, a hardness of 62 was found for the nodules and 14 for the basalt [4].

Mechanical characterization of concrete lateritic nodules

The mechanical characteristics of nodule concretes are grouped together in this section. Authors like [5], [16] performed a partial substitution while [4,11,17-18] completely used the nodules as aggregates. **Table 4.** shows the results of compressive, tensile and flexural strengths [5] on nodule concrete produced with a substitution of the common large aggregate by 25% lateritic nodules.

Substitution percentage	Compression (MPa)			Pull (MPa)	Bending (MPa)
	7 days	28 days	60 days	28 days	28 days
25	34.67	43.71	50.73	2.73	3.40
0	38.93	50.62	57.42	3.24	3.89

Table 4. Mechanical resistance of concrete with partial substitution nodules at 28 days

A drop in resistance values is noted; the values remain admissible. Values of the respective correlations have been deduced between the compressive strengths Rc_j/Rc_{28}; Rt_{28}/Rc_{28}, Rf_{28}/Rc_{28}. The correlations resulting from the results of mechanical tests obtained by [5] are innovative and are presented as follows **Table 5**.

Substitution percentage	Rc_j/Rc_{28}		Rt_{28}/Rc_{28}	Rf_{28}/Rc_{28}
	7 days	**60 days**	**28 days**	**28 days**
25	0.79	1.16	0.06	0.08
0	0.77	1.13	0.06	0.08

Table 5. Various correlation values Rc_j/Rc_{28}; Rt_{28}/Rc_{28}, Rf_{28}/Rc_{28} obtained.

For a 25% replacement of the large aggregate by lateritic nodules, the correlation values, at compression, Rc_j/Rc_{28}, are 0.79 and 1.16 for equal to 7 and 60 days of age. In addition, the correlation values between compression-traction and compression-bending at 28 days of age are 0.06 and 0.08, respectively. For the control concrete (percentage of substitution of 0% of the large aggregate by the lateritic nodules), the values obtained, at compression, Rcj/Rc_{28}, are 0.77 and 1.13 for equal to 7 and 60 days of ages. Also, the correlation values between compression-traction and compression-flexion at 28 days of age are respectively 0.06 and 0.08. It emerges from the correlations obtained **Table 5**. That the indicative values of ordinary concrete are similar to those of the concrete studied. From the study of the mechanical characteristics of the concrete with a substitution of the crushed by the lateritic nodules [16], it emerges that the compressive strength, the bending strength and the elastic modulus of the concrete thus formed decreased over time that the volume of lateritic nodules increased. Substitution of up to 30% produces concrete that can achieve a compressive strength of 30 MPa. The different breaking stresses of concrete test specimens of lateritic nodules dosed at 350 kg/m^3 are between 16.64 and 19.17 MPa [11]. The average compressive strength at 28 days of age is 16.70 MPa, which is 72.03% of the strength of rolled gravel concrete. The work of [16] reveals that the modulus of elasticity of lateritic concretes is around 17500 MPa and that lateritic nodule concrete admits a compressive strength of 90% compared to that of crushed gravel concrete. The mechanical test results obtained by [4] are more interesting and are presented as follows **Table 6.**

Variables	Resistance to compression (MPa)		Resistance to traction (MPa)	
	7days	**28 days**	**7 days**	**28 days**
Basalt (LA = 14)	16.69	24.82	2.03	2.78
Lateritic nodules (LA = 62)	15.73	24.99	1.70	2.42

Table 6. Mechanical strengths of concretes with lateritic nodules at 28 days.

Although the hardness of lateritic nodules is relatively low, the compressive strength of lateritic nodule concrete is higher than that of basalt concrete made under the same conditions. Compressive strength ratios Rc_j/Rc_{28}, compressive-tensile strength Rt_j/Rc_{28} and tensile strength Rt_j/Rt_{28} with j equal to 7 days of age have been developed. The scientific findings from these mechanical test results obtained by [4] are summarized as follows **Table 7**.

Variables	Rcj/Rc_{28}	Rtj/Rc_{28}	Rtj/Rt_{28}
	7 days	**7 days**	**7 days**
Basalt (LA=14)	0.67	0.08	0.73
Lateritic nodules (LA=62)	0.63	0.07	0.70

Table 7. Resistance ratios Rc_j/Rc_{28}, Rt_j/Rc_{28} and Rt_j/Rt_{28} with j equal to 7 days of age [4].

The correlation relations of various stresses (compression and traction), Rc_j/Rc_{28}, Rt_j/Rc_{28} and Rt_j/Rt_{28}, resulting from ordinary concrete, are 0.67; 0.08 and 0.73 for j equal to 7 days of age. The lateritic concrete correlation results obtained are 0.63; 0.07 and 0.70 for equal to 7 days of age for the different stresses (compression and traction), Rc_j/Rc_{28}, Rt_j/Rc_{28} and Rt_j/Rt_{28} respectively. The correlation values are similar for the two types of concrete: conventional and lateritic [5]. A study of the strength characteristics of concretes made with strongly, moderately and slightly indurated lateritic nodules shows that the compressive strength (19 to 42 MPa) of most lateritic concretes is comparable to the observed average strength (45 MPa) on concretes made with crushed granite as aggregates [18].

Resistance to aggressiveness of lateritic nodules concretes

The performance of lateritic nodule concrete in an aggressive environment by exposure of test pieces to sulfuric acid has been studied [10]. The concrete specimens were first poured and cured in water for 28 days before being exposed to a 2% concentration of sulfuric acid. Physical deterioration, loss of mass and loss of compressive strength were the parameters studied. The results showed that the deterioration process increases as the acid immersion period progresses. The durability of lateritic nodule concrete as a function of partial substitution (0 - 50%) of crushed granite was also studied. The specimens were immersed for 28 days in water before being subjected to the durability test [19]. The results show that the resistance of concrete to acid and corrosion decreases with increasing content of lateritic aggregates in the concrete. The characteristic parameters of lateritic nodules are in particular the chemical composition, the mineralogical composition, the physical characterization parameters and the resistance to fragmentation. The knowledge of the chemical composition of the nodules is capital for the control of the elements which could influence the mechanical behavior of the concrete of lateritic nodules. The determination of the mineralogical composition of the nodules, by the Scanning Electron Microscopy (SEM) and/or the X-ray diffraction (XRD) makes it possible to list the different minerals from the different crystalline phases. The nature as well as the quantities of minerals found by the different researchers will be compared. The values obtained for these various parameters were compared with each other but also with the current values of the characteristics of aggregate concrete in general use dosed at 350 kg/m^3. The study of concrete with nodules in an aggressive environment is also a determining parameter because it contributes to the durability of the structure.

Chemical and mineralogical composition of lateritic nodules

Table 8. Summarizes the chemical composition of the Sapouy site in Burkina-Faso, the Kakanda and Kapushi sites in the Katanga province located in south-eastern Congo and the Torodi,Oullam, Say, Fillingué, and Dosso sites in Niger. Their mineralogical composition is given in **Table 9**. From a geological point of view, the site of Soapy mainly comprises Paleoproterozoic terrains belonging to the Birimian basement. The Paleoproterozoic comprises volcano-sedimentary and plutonic belts metamorphosed to the Eburnean and plutonic intrusive formations in the belts [7]. The sites of Kakanda, Kipushi present rocky outcrops belonging to the Precambrian crystalline basement (gneiss, granite and schist) and to the sediments (mainly sandy) of the Pliopleistocene. The soils found in this region are red and yellow ferralitic, sometimes associated with lithosols on ferruginous crusts or developed on loose sandy sediments [8]. The lateritic deposits of the Torodi sites have developed on metamorphic formations (schists and micashists). The lateritic borrowings from the Ouallam and Dosso sites developed at Continental Terminal 3 and Fillingué at Continental Terminal 2 present a similar textural appearance. Say's samples were at Continental Terminal 1 [9].

Sites	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	MnO (%)	CaO (%)	Na_2O (%)	K_2O (%)	TiO_2 (%)	P_2O_5 (%)	PF (%)	Total (%)
Sapouy (Burkina-Faso)	56.19	10.10	16.09	0.05	1.68	3.24	2.01	0.07	1.39	-	8.14	99.07
Kakanda (Congo)	56.27	16.31	15.29	0.38	0.02	0.08	0.29	1.15	1.10	-	8.83	99.72
Kapushi (Congo)	66.34	15.62	8.78	0.53	0.01	0.06	0.59	1.82	1.06	-	5.01	99.82
Torodi (Niger)	52.63	20.24	14.36	0.08	0.17	0.08	0.03	0.27	1.27	0.12	10.02	99.25
Oullam (Niger)	56.46	15.91	17.44	0.04	0.11	0.12	0.05	0.14	1.05	0.11	8.92	100.35
Say (Niger)	44.40	18.19	15.84	0.03	0.06	<L.D	0.02	0.11	1.17	0.07	9.32	99.21
Fillingué (Niger)	53.70	19.65	14.90	0.02	0.10	<L.D	0.02	0.14	1.13	0.08	9.81	99.53
Dosso (Niger)	63.38	17.41	10.08	0.01	0.04	0.04	0.01	0.04	1.23	0.08	7.94	100.25

Table 8. Summary of the chemical characterization of nodules.

The chemical composition of all the lateritic nodules listed reveals, in addition to silica oxide SiO_2, a high concentration of iron oxides (Fe_2O_3) and aluminum oxides (Al_2O_3). The average Fe_2O_3 content of the sites considered is 14.10%. Ouallam and Dosso, although belonging to the same geological formation, show a noticeable difference in their Fe_2O_3 content. The average Al_2O_3 content of the sites considered is 16.68%.

Sites	Quartz (%)	Kaolinite (%)	Illite (%)	Goethite (%)	Hematite (%)	Rankinite (%)	Muscovite (%)	Anatase/Rutile (%)
Sapouy (Burkina-Faso)	42.00	26.00	-	15.00	3.00	6.00	-	-
Kakanda (Congo)	32.90	34.87	11.64	17.02	-	-	2.23	1.10
Kapushi (Congo)	45.70	19.77	16.24	-	8.78	-	4.93	1.06
Torodi (Niger)	50.30	40.60	-	3.50	2.70	-	-	1.90
Oullam (Niger)	33.60	45.60	-	7.80	3.00	-	-	1.60
Say (Niger)	56.60	58.10	-	10.30	3.20	-	-	1.00
Fillingué (Niger)	39.90	47.40	-	2.60	3.30	-	-	1.20
Dosso (Niger)	14.00	72.50	-	5.00	4.50	-	-	1.90

Table 9. Summary of the mineralogical characterization of nodules.

Kaolinite is the dominant and exclusive clay mineral for all sites except for those of Katanga which contain a high content of illite. The predominant rocks in this locality are gneiss, granite and schist. On the other hand, Ouallam and Dosso, both from continental terminal 3, are not related in mineralogical composition. The same is true of the Kapushi (Congo) and Dosso sites in Niger, although they have a similar chemical composition.

The chemical composition of the lateritic nodules shows a high content of SiO_2, Al_2O_3 and Fe_2O_3. However, the values obtained are highly diversified even for sites of the same geological formation. In addition, the chemical composition does not a priori determine the nature of the minerals or the crystalline phases that may be present in the nodules. However, once the minerals are known, by the various procedures including X-ray Diffraction and/or Scanning Electron Microscopy, it would be interesting to study the influence of their nature and their content on the physic-mechanical characteristics of the nodules, on the one hand, and on the characteristics of lateritic nodule concretes, on the other hand. The densities (apparent and real) of lateritic nodules are dependent on several parameters, including the nature of the bedrock, the degree of weathering, the nature of the minerals present. The granulometric characteristics of the lateritic nodules listed made it possible to identify them as clean gravels poorly graded according to the LPC classification. Thus, the lateritic nodules can be used as concrete aggregates formulated in the rules of the art. The possible values of the absorption coefficient of the lateritic nodules listed (7 to 14%) are relatively high compared to the average of 1% for common aggregates. Concrete formulations based on lateritic nodules must be able to take into account the absorption coefficient of water. The Los Angeles (LA) hardness of the nodules identified varies from 24 to 62 for an LA of 14 for basalt. A maximum value of 50 is often recommended for materials intended to be used for making concrete. Attention will be paid to nodules of LA greater than 50. Concretes of lateritic nodules, in partial or total substitution, generally admit good characteristics and, in terms of resistance to rolled gravel concrete, basaltic or granite aggregates are similar. The lateritic gravels, despite their relatively low hardness, have surface characteristics (roughness, absorption coefficient) which make them very good aggregates for common concrete [4]. This observation is confirmed by the results of [18] which reveal that the strength of the concrete of lateritic nodules mainly depends on the cement-aggregate bond, the mechanical characteristics of the aggregates having only a secondary importance. However, it is important to verify this remark and to really establish the part of the cement-aggregate bond, the mechanical characteristics of the aggregates or even their mineralogical composition on the final characteristics of the concrete. Lateritic nodule concretes subjected to a sulfuric acid solution exhibit greater weakness in terms of mechanical strength.

CONCLUSION

Lateritic soils are widespread in intertropical Africa and consist of lateritic nodules inserted in a clay matrix. Lateritic nodules are therefore proximity materials compared to aggregates commonly used until now. The particle size characteristics allow their use as concrete aggregates. They have been used in partial or total substitution on an experimental basis by several researchers. More porous in nature, lateritic nodules absorb a greater amount of water which must be taken into account when formulating nodule concrete. The mechanical strengths of lateritic nodule concretes are comparable with those of common concretes. For concrete dosed at 350 kg/m^3, the compressive strength is on average around 24 MPa. Thus, the strengths obtained on the whole are acceptable. However, lateritic nodule concretes show more degradation in an acid solution. Lateritic nodules could replace, depending on the size of the supporting structure, the gravel commonly used. It is therefore necessary to target the conditions for improving these resistances for use in the sizing of concrete structures. However, several aspects of the behavior of lateritic nodule concretes remain to be addressed or clarified, in particular the influence of the mineralogical composition of lateritic nodules on the physic-mechanical characteristics continue discussions on the subject in subsequent studies, with different approaches and methods, in order to contribute to evidence-based practice, provide opportunities for the effectiveness of comprehensive care for the binomial in pregnancy, childbirth and puerperium and guide actions and programs of health care, to this population sphere, which aim to reduce the indicators of low birth weight newborns.

REFERENCES

1. Nwakonobi O. Structural characteristics of laterized concrete at optimum mix proportion. Niger J Technol. 2007; 26: 12-17.
2. Nahon D. Altérations dans la zone tropicale. Signification a travers les mécanismes anciens et/ou encore actuels weathering in tropical zone. Significance through ancient and still active mechanisms. Comptes-rendus geosciences. 2003;6: 1109-1119.
3. Gbaguidi VS. Identification of the strata of lateritic soils and alterites in Benin. Int J Adv Res. 2018;6 2320-5407.
4. Laquerbe M, Cisse I, Ahouansou G. Towards a rational use of lateritic gravels and dune sands as concrete aggregates. Application to the case of Senegal. Materials and structures.1 995: 28;604-610.
5. Rao VM, Raju SRV. Strength characteristics of concrete with partial replacement of coarse aggregate by laterite stone and fine aggregate by quarry dust. Int J Eng Res Appl. 2016; 6:39-44.
6. Ephraim ME, Thankgod, GO Ezekwem. Performanc evaluation of laterite rock concrete in aggressive environment. Am J Eng. Res. 2018; 7:93-101.
7. Millogo Y, et al. Geotechnical, mechanical, chemical and mineralogical characterization of lateritic gravels of Sapouy (Burkina Faso) used in road construction. Construction and Building Materais.2008; 22;70–76.
8. Kalenda GM. Behavior of compacted lateritic soils in the embankments and retaining dykes of mining wastes in Katanga (DRC). Doctoral thesis from the Polytechnic University of Louvain.2014.

9. Fabre SI, et al. Richard Civil Engineering University Meetings. 2015.

10. Ephraim ME, Akeke GA, Ukpata JO. compressive strength of concrete with rice husk ash as partial replacement of ordinary Portland cement. Int J Eng Res Appl. 2012; 1:32-36.

11. Clement HCW. Purr wood reinforcement in the concrete of lateritic nodules: Moisture content and waterproofing for an optimal adhesion rate. PhD thesis from the University of Abomey-Calavi.2019.

12. Hode C, et al. Characterization of lateritic nodules for use in concrete and comparative study of simple compressive strengths of concretes based on different lateritic nodules. J Material Sci. 2018; 6:1-0.

13. Schlosser F. Elements of soil mechanics. Presses of the National School of Bridges and roads.1998; 26-46.

14. Hubert PB. Foundations and earthworks. Eyrolles. 2015.

15. Biryondeke BC, et al. Study of water absorption coefficient of Goma's volcanic aggregates and its influence in formulating concrete. 2016;1:141–152.

16. Khairunisa M, Kamaruzaman W, Muthusamy K. Engineering properties of concrete with laterite aggregate as partial coarse aggregate replacement. J Geotech Geoenviron. 2012; 3:47-50.

17. Savy M. Contribution to the study of the mechanical behavior of concrete with lateritic nodules: Formulation, elastoplastic resistance laws. Application to flexed beams, reinforced with steel. 3rd cycle doctoral thesis, University of Yaoundé, Cameroon. 1995.

18. Akpokodj,HP. Properties of concretionary laterite gravel concrete. Bulletin of the International Association of Engineering Geology - Bulletin de l'association internationale de géologie de l'ingénieur. 1992; 46:45–50.

19. Vesuvapateran G. Durability of concrete containing laterite aggregate as partial coarse aggregate replacement. Thesis submitted in fulfillment of the requirements for the award of the degree of bachelor of civil engineering. Faculty of civil engineering and earth resources, University Malaysia Pahang, June 2013.