Universal Classification for the Use of Lateritic Soils in Low Cost Durable Pavements

J.K.G. Rodrigues, P. Reiffsteck, J.C. Auriol, M. Ndiaye

Abstract. The literature review of previous studies and the analysis of observations and knowledge gathered in Africa, as well as regional experience in Brazil, India and Australia on the influences of texture, grain size distribution and mineralogy conditions on the stability of materials used in pavement base have shown that the mechanical behaviour of lateritic soils is strongly influenced by their physical and mineralogical properties, we argue in this article that development of new procedures for classification of these soils as new building materials, that consider appropriate designs for the humid tropics and the nature and state parameters associated with the mechanical behaviour, can broaden the use of a higher percentage of local soils in pavement layers for low cost road compared to traditional techniques.
Keywords: lateritic soils, classification, low volume road.

1. Introduction

The difficulty in classifying tropical soils located in areas where "the laterization process" has a vital importance on their physical, chemical and mechanical properties is in the inability of traditional systems to correctly predict the mechanical behaviour of materials under the action of traffic and the environment. Classification systems such as those developed by the American Association of State Highway and Transportation Officials (AASHTO) and the Unified Soil Classification System (USCS) are not relevant when applied to some of these soils. Studies and practices have shown that recommendations based on these systems, particularly the activity of the clay fraction in the presence of water and the long term performance of gravel and sand fractions are not compatible with the results from the field and laboratory.

In this paper we analyze, from the Brazilian, Indian and Australian national experience and transnational experience on the African continent the influence of texture, grain size and mineralogy on the stability and classification of materials used in low costs pavement base. A new procedure for classification of lateritic soils is proposed.

2. Laterization Process

The laterization process includes a set of phenomena that lead to a considerable degree of weathering of bedrock soil, and an identification of items such as silica and oxide hydrates or hydroxides and metal, especially iron, aluminium, manganese and titanium (Maignein, 1966).

This process may be followed by other soil processes such as dragging hydroxides from the surface to a half-depth horizon; hardening in concretions or shells or armor of metal hydroxides previously individualized and sometimes accumulated; segregation of elements of an horizon by hydromorphy (Autret, 1983; Schellmann, 2009).

2.1. Influence factors

Factors that influence the laterization process are climate, topography, vegetation, bedrock, the dragging period with optimization by the drainage conditions (Autret, 1983).

2.2. Geographic location of lateritic soil distribution

A global census conducted by FAO shows that the lateritic soil distribution is localized in tropical regions (South America, Africa, India, Australia and South East Asia) (Fig. 1) FAO (2006). It is therefore mainly in developing countries where the issue of transport infrastructure development is vital.

2.3 Product release "lateritic systems"

Lateritic soil to be used in civil engineering is characterized by a high degree of alteration of minerals from the original rock with virtual elimination of alkaline and alkaline-earth, and partial silica; thrust decomposition of organic matter and a accumulation of more or less hydroxides and oxides of Fe, Al, Ti, Mn. To this may be added, at varying degrees, the accompanying leaching process, accumulation of organic matter and induration (Schellmann, 2009).

2.4. Chemical composition of lateritic soil

Lateritic soils contain as chemical components, a high percentage of oxides and hydroxides of Fe and Al (oxides and hydroxides of iron and / or alumina - sesquioxides) for some Gravelly lateritic soils up to near 80% of laterization process product.

J.K.G. Rodrigues, PhD, Associate Professor, Universidade Federal de Campina Grande, 58402-000 Campina Grande, PB, Brazil. e-mail: jkennedy@pq.cnpq.br.
P. Reiffsteck, PhD, Professor, Université Paris Est/IFSTTAR-LCPC, 75732 Paris, France. e-mail: philippe.reiffsteck@lcpc.fr.
J.C. Auriol, PhD, Professor, IFSTTAR-LCPC - Nantes. Address : 58, Boulevard Lefebvre - 75732 Paris Cedex 15, France. e-mail: jean-claude.auriol@lcpc.fr.
M. Ndiaye, PhD Student, Ecole Centrale de Paris, 75732 Paris, France. e-mail: massam14ba@yahoo.fr.
Submitted on August 30, 2011; Final Acceptance on April 8, 2013; Discussion open until April 30, 2014.

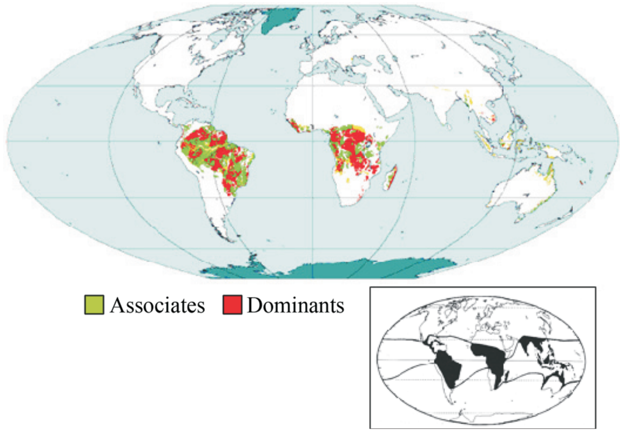


Figure 1 - Lateritic soil distribution (Ferralsols) over the world FAO (2006).

These components are generally in lateritic soils, regardless of specific behaviours, specific of clay minerals observed under tempered climate. Thus, although having a high surface area and small size, they do not present a swelling behaviour, have a significant cation exchange capacity in the pH conditions prevailing in these soils and have an excess of positive charges (not negative as in the case of clay minerals) (Villibor & Nogami, 2009).

It is possible to observe the microstructure of fine grains lateritic soils using scanning electron microscopy (SEM). The presence of relatively large flakes, caking clay particles, having the appearance of "clouds" or "popcorn" and measuring from 1 to 2 to 50 to 100 mm in their largest dimension is observed (Fig. 2).

3. Morphology of Lateritic Soils

The induration of samples depends on factors such as degree of crystallization of components, assembly of the various constituents and the degree of aging.

The extremely varied structure can be reduced to three main types: hardened elements form an consistent and continuous skeleton, indurated elements as concretions or nodules free in the middle of an earth mass and hardened elements cement the pre-existing materials.

Their pigmentation is due to iron oxides more or less hydrated and sometimes manganese. The color of the soil is mixed but generally of strong intensities. The most common colors are: pink, red, yellow, brown and ocher.

The density varies in relatively large proportions (2.5 to 3.6) and depends on the chemical composition of lateritic soil. It increases with iron content and decreases with the concentration of alumina. Oxidized forms are denser than the hydrated forms.

The evolution of rock from inner to surface is characterised by different sets overlapping each other allowing to generally distinguish a set of weathering, a intermediate set of overall accumulation of metal oxyhydroxides and clay phases and a set of washed up upper crust of residual primary minerals resistant.

4. Pedogenic Classifications

Lateritic soils can be classified in a synthetic or analytic manner. The first classification is based on genetic factors and on properties of factors or pedogenic processes. The second considers mainly morphological characters, including pedogenic concerns (Maignein, 1966). The main denominations are: Laterite, tropical soils, lateritic soils, ferruginous soils, lateritic soils, Soil Ferseallitiques, ferrisols, Ferrasol, Andosols, Oxisols, Podzols, Latossols and Plinthosols.

5. Geotechnical Classification

5.1. Particle size ditribution

The particle size distribution of lateritic soils generally has:

- A high proportion of fines (below 80 μm sieve) from 10 to 40%;
- A refusal on the 2 mm sieve from 20 to 60%;
- A variable hardness of gravels in the same deposit and this depending on the maturity of lateritic particles concretionned and the amount of sesquioxide which predominates in the aggregate;

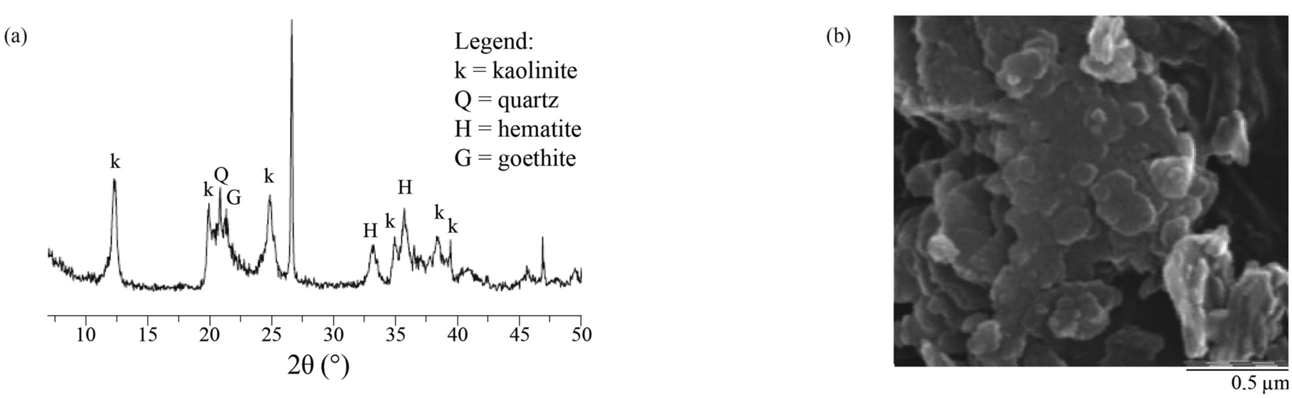


Figure 2 - Test results for lateritic soils (a) X-ray diffraction (b) SEM LNEC (2009).

- The grading curves present frequently a step or a curvature indicating the absence of certain granular fractions. This step is between 8 and 0.2 mm;
- Materials with hard aggregates, rich in iron, tend to have stable mechanical behaviour;
- In the granular fraction, the mineralogical composition of the silt fraction is generally simple, the predominance of quartz with the presence of lumps of clay appear clearly;
- The main constituents of the clay fraction (diameter less than 0.002 mm) can be classified as: clay minerals, oxides and hydroxides of iron and / or aluminium, and organic constituents.

5.2. Influence of test methodology on particle size distribution

The metastable structure of lateritic soils is sensitive to changes in levels of thermal energy and therefore its physical properties. In terms of size, drying causes an increase in the size of the particles, leading clayey fraction and silt fraction to agglomerate up to the granulometry of a sand due to the coagulation of iron oxide during heating (Terzaghi, 1958; Moh & Mazhar, 1969; Lyon, 1971).

For lateritic soils, increasing the mechanical energy results, due to its vulnerability, results in an increase of the apparent maximum dry density and content in fine sand, especially with the fraction in excess on the 80 μm sieve and for fine soils which have a low clay content and a high Fe_2O_3 content (Novais & Meireles, 1992).

5.3. Plasticity limit

The influence of sesquioxides (Al_2O_3 and Fe_2O_3) made that lateritic soils have a plastic behaviour differed from that of soils under temperate climates. During the test, an increase of the surface area is observed due to the disintegration of particles and/or breakage of granular soil structure with consequently an increase of water absorption by the sample (Moh & Mazhar, 1969; Villibor & Nogami, 2009).

5.4. Shrinkage limit

The knowledge of the shrinkage limit is important for predict whether lateritic soils, and especially their fine fractions, are unlikely to be subject, mainly in countries with well marked dry seasons, to shrinkage which could lead to cracking. It would then preferable to keep them safe from moisture changes or possibly not use them without improvement or stabilization (Fig. 3) (Autret, 1983).

5.5. Durability

The strength and durability of hardened laterite depends on their chemical composition, age and homogeneity. The iron-rich laterites hardened are harder than those that are rich in alumina (Lyon, 1971; Enuvie & Hudec, 1992).

The results of measurements of specific gravity and absorption show a relationship with the durability of coarse particles. The durability of coarse elements increases with the weight. The behaviour of fine elements can be linked with the absorption and not with density. The durability of coarse and fine elements increases when the water absorption decreases.

5.6. Compaction characteristics

Factors influencing the properties of compacted lateritic soils can be separated into two groups (Lyon, 1971). The first group of these factors is related to soil genesis, the second relates to pre-treatment methods applied prior to testing. The factors are:

- Texture: the most important genetic factor;
- The influence of the transformation of hydrated halloysite méthalloysite result of the drying in the oven;
- Position of the sample in the soil profile (depth of the sample);

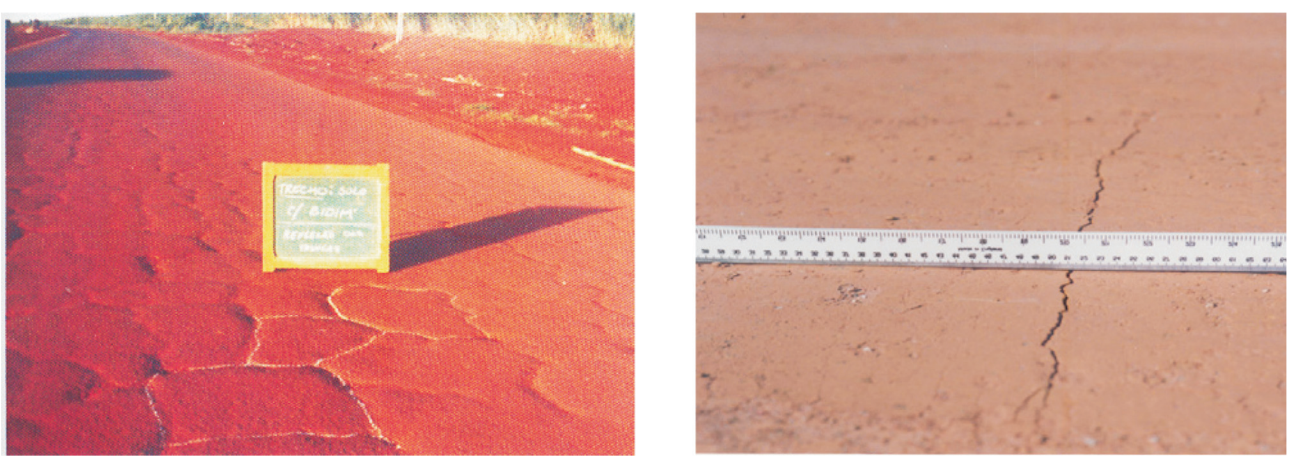


Figure 3 - Cracking on pavement made of fine and coarse lateritic soils (Villibor, 2009).

- Erosion of concretionned lateritic gravel during compaction and the degree of laterization process maturity;
- For a given energy and for lateritic fine soils more than gravelly ones, drying in the oven always gives higher maximum dry density and lower optimum moisture content, while the soils at natural water content give the lowest maximum dry density and the highest optimum water content.

5.7. Bearing characteristics

For ISTED (1990) the stability and bearing capacity lateritic soils depend on:

- The maximum grain size D;
- The sieving of 80 μm;
- The residue on the sieve of 20 mm;
- The step of the grading curve between 80 μm and 2 mm;
- Plasticity;
- The fragility of the nodules (changes during compaction) and;
- The mineral nature of fine particles.

6. Classification System for Lateritic Soils Used in Low Cost Paving Platform

Various studies show that it is possible to establish classification systems tailored to lateritic soils (Fall, 1953; Sharp *et al.*, 2001) for use in low cost pavement based on the nature and state parameters as well mechanical properties. To do this, it is important that test execution are compatible with the specificities of soil in tropical regions, with measured reference values to be adopted, being consistent with the type of traffic on pavements (Villibor & Nogami, 2009).

Figures 4 and 5 illustrates the logical sequence of a proposed classification for lateritic soils based on numerous literature reviews and using as inputs the parameters of nature and state and the mechanical behaviour measured during laboratory testing.

In this method two aspects are considered: first, the metastable structure of lateritic soils, sensitive to changes in levels of thermal and mechanical energy and secondly the physical and mineralogical properties (the influence of sesquioxides) compared to the resistance, durability and plasticity.

Soils are classified according to their plasticity and particle size (gravelly, sandy or fine soil). Finally, classes are established based on the mechanical behaviour from the test results on degradability, fragmentability, embrittlement, bearing capacity and shrinkage limit (Figs. 5 and 6).

At this stage of our study, the creation of a database of cases will allow the validation of this new classification. This will be done in the framework of an international cooperation.

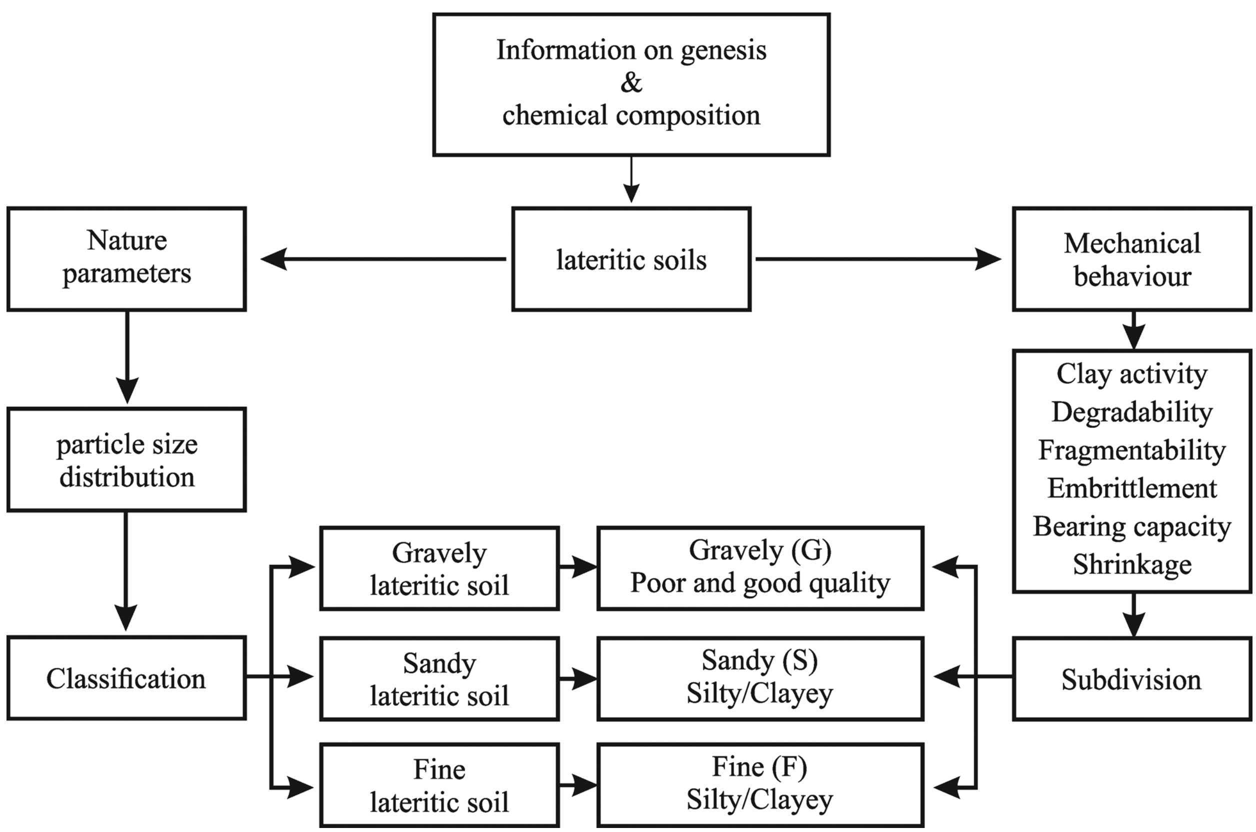


Figure 4 - Chart with the criteria for a proposed classification of lateritic soils.

7. Case Study

For the case study we choose three soil samples from the Brazilian Northeast Region, based in previous knowledge on its materials' characteristics, on geographic localization and region's.

7.1. C Reservoir - Rio Grande do Norte State

Located in the Metropolitan Region of Natal, more precisely in São Gonçalo of Amarante, the reservoir C is in the Natal's International Airport area which is used as sub-base of the airport's runway and taxi-in space.

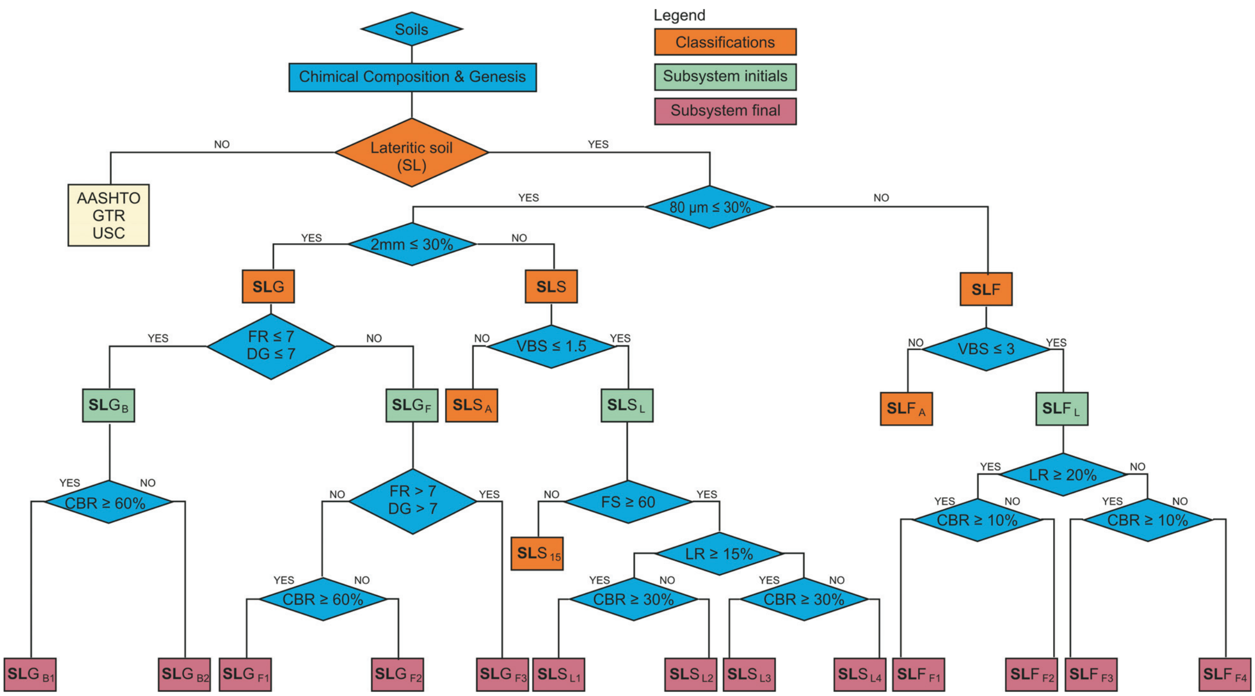


Figure 5 - Layout with the criteria for a proposed classification of lateritic soil.

<table>
<tr><td colspan="16">Lacteritic Soils (SL)
(Genesis and chemical compositions)</td></tr>
<tr><td colspan="11">80µm ≤ 30%</td><td colspan="5" rowspan="2">80 µm > 30%</td></tr>
<tr><td colspan="5">2mm ≤ 30%</td><td colspan="6">2mm > 30%</td></tr>
<tr><td colspan="5">Gravely Lateritic Soils (SLG)</td><td colspan="6">Sandy Lateritic Soils (SLS)</td><td colspan="5">Fine Lateritic Soils (SLF)</td></tr>
<tr><td colspan="2">FR ≤ 7
&
DG ≤ 7</td><td colspan="2">FR > 7
ou
DG > 7</td><td rowspan="4">FR > 7
&
DG > 7</td><td colspan="5">VBS ≤ 1,5</td><td rowspan="4">VBS > 1,5</td><td colspan="4">VBS ≤ 30%</td><td rowspan="4">VBS > 3</td></tr>
<tr><td rowspan="3">CBR
≥ 60%</td><td rowspan="3">CBR
> 60%</td><td rowspan="3">CBR
≥ 30%</td><td rowspan="3">10% ≤ CBR
≤ 30%</td><td colspan="2">FS ≤ 60</td><td colspan="2">FS ≤ 60</td><td rowspan="3">FS > 60</td><td colspan="2">LR ≥ 20%</td><td colspan="2">LR < 20%</td></tr>
<tr><td colspan="2">LR ≥ 15%</td><td colspan="2">LR < 15%</td><td rowspan="2">CBR
≥ 10%</td><td rowspan="2">CBR
< 10%</td><td rowspan="2">CBR
≥ 10%</td><td rowspan="2">CBR
< 10%</td></tr>
<tr><td>CBR
≥ 30%</td><td>CBR
< 30%</td><td>CBR
≥ 30%</td><td>CBR
< 30%</td></tr>
<tr><td>SLG_{B1}</td><td>SLG_{B2}</td><td>SLG_{F1}</td><td>SLG_{F2}</td><td>SLG_{F3}</td><td>SLS_{L1}</td><td>SLS_{L2}</td><td>SLS_{L3}</td><td>SLS_{L4}</td><td>SLS_{L5}</td><td>SLS_{A}</td><td>SLF_{F1}</td><td>SLF_{F2}</td><td>SLF_{F3}</td><td>SLF_{F4}</td><td>SLF_{A}</td></tr>
<tr><td colspan="2">No
treatment</td><td>With
treatment</td><td colspan="2"></td><td>No
treatment</td><td colspan="5">With treatment</td><td>No
treatment</td><td colspan="4">With treatment</td></tr>
<tr><td colspan="5">Base Layer (CBR ≥ 60%)</td><td colspan="6">Fondation Layer (CBR ≥ 30%; LR ≥ 15%)</td><td colspan="5" rowspan="5">Sub-Base Layer (CBR ≥ 10%; LR ≥ 20%)</td></tr>
<tr><td colspan="3">No treatment
with CBR ≥ 30%</td><td colspan="2">With treatment</td><td colspan="2">No treatment
with CBR ≥ 10%</td><td colspan="4">With treatment</td></tr>
<tr><td colspan="5">Fondation Layer (CBR ≥ 30%</td><td colspan="6" rowspan="3">Sub-Base Layer (CBR ≥ 10%; LR ≥ 15%)</td></tr>
<tr><td colspan="5">No treatment</td></tr>
<tr><td colspan="5">Sub-Base Layer (CBR ≥ 10%; LR ≥ 15%)</td></tr>
<tr><td colspan="16">Observations:
Traffic = N<10^5 P<13 Tonnes
SLG = Gravely Lateritic Soils; SLS = Sandy Lateritic Soils; SLF = Fines Lateritic Soils.
L = Silty; A = Clayey; F = poor quality; B = good quality.
FR = Fragmentability coefficient; DG = Degradability coefficient; FS = Embrittlement coefficient; LR = Shrinkage limit; VBS = Blue Methylen value.</td></tr>
</table>

Figure 6 - Proposition of a classification system for lateritic soil.

7.2. RC Reservoir - Pernambuco State

The RC Reservatoir is located in the Recife's Metropolitan Region and was used as sub-base material of a highway pavement.

7.3. PIC Reservoir- Piauí State

The third reservatoir, called *PIC*, located 70 km of Picos City, at Highway 316 borders, among the cities of Inhuma and Ipiranga.

Results from X-Rays Diffraction Analysis of soils studied are shown in Fig. 7. The peaks shown in the diffractometer for the three soil samples indicate the presence of Quartzo (SiO_2) and of Kaolinite ($2SiO_2Al_2O_32H_2O$).

According to Nogami & Villibor (1995), due to the lateritization process the clay fraction of lateritic soils is constituted essentialy by clay minerals of the Kaolinite Group and by oxides and hydroxides of Ferro and/or. Therefore results obtained with the help of diffraction tests indicate that the material we analyzed are probably lateritic soils.

The microphotographs of soils samples obtained in the Scanning Electron Microscopy (SEM) are show in Fig. 8, regarding to sample C; in the Fig. 9, regarding to sample, and int He Fig. 10, regarding to sample, with 1,000, 3,000, 5,000, 10,000 and 20,000 times magnification.

We observed typical patterns of materials which suffered the lateriticzation process, a marking characteristic of

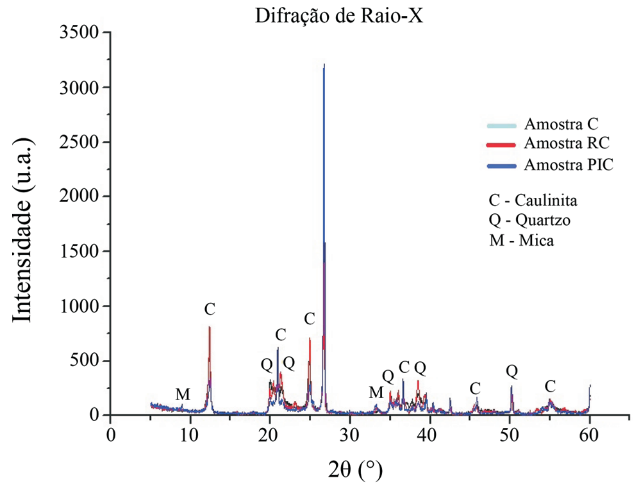
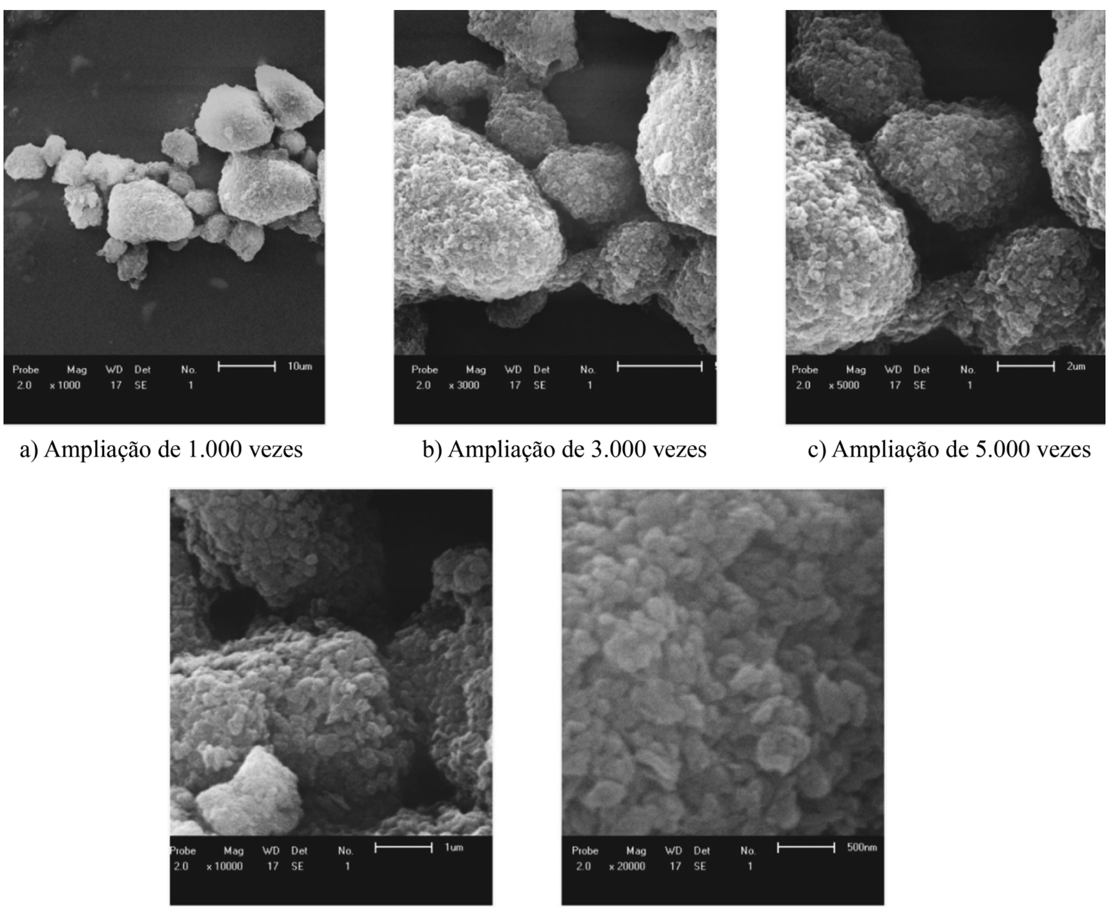


Figure 7 - Diffraction of X-rays - C Sample.



a) Ampliação de 1.000 vezes

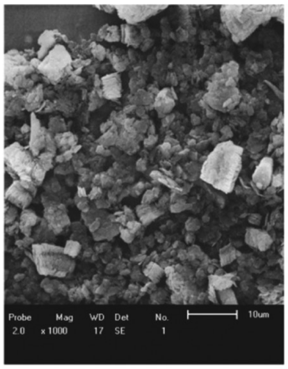
b) Ampliação de 3.000 vezes

c) Ampliação de 5.000 vezes

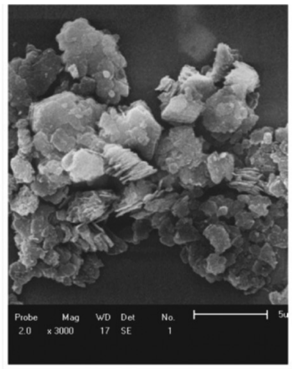
d) Ampliação de 10.000 vezes

e) Ampliação de 20.000 vezes

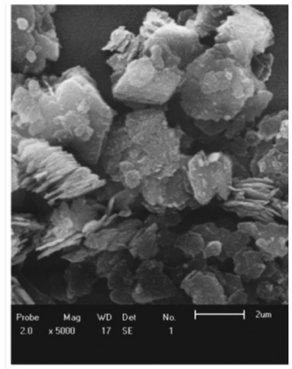
Figure 8 - Microphotographs (MEV) of the C Sample.



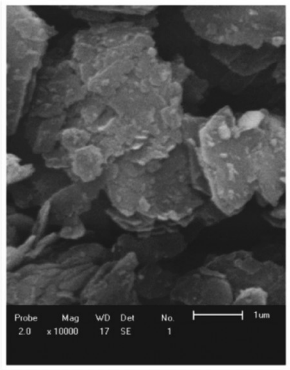
a) Ampliação de 1.000 vezes



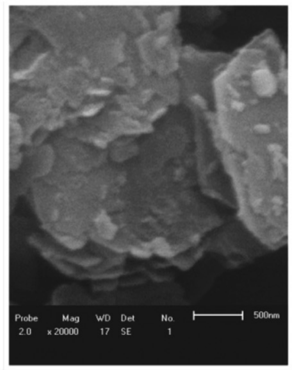
b) Ampliação de 3.000 vezes



c) Ampliação de 5.000 vezes

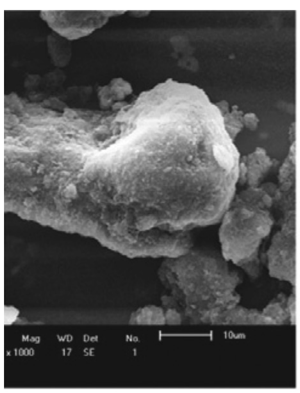


d) Ampliação de 10.000 vezes

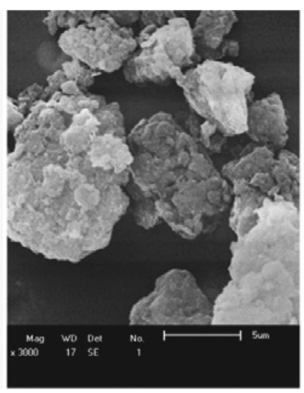


e) Ampliação de 20.000 vezes

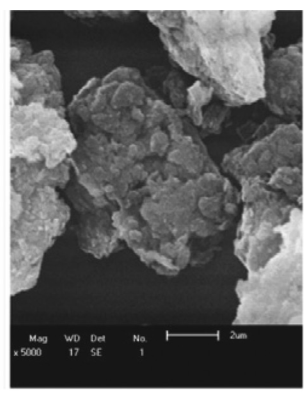
Figure 9 - Microphotographs (MEV) of the RC Sample.



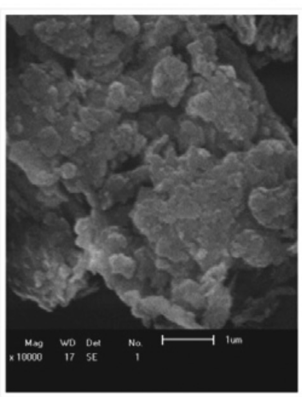
a) Ampliação de 1.000 vezes



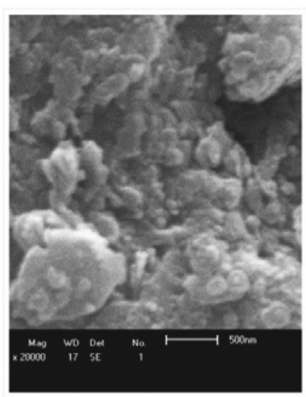
b) Ampliação de 3.000 vezes



c) Ampliação de 5.000 vezes



d) Ampliação de 10.000 vezes



e) Ampliação de 20.000 vezes

Figure 10 - Microphotographs of PIC Sample.

Table 1 - Universal soil classification parameters.

Laboratory test		C sample	RC sample	PIC sample
Brazilian standard	% < 0.08 mm	19.91	25.56	13.03
	% < 2.00 mm	98.70	99.31	62.65
French standard	% < 0.08 mm	19.85	27.17	31.52
	% < 2.00 mm	98.41	99.25	60.96
Fragmentability coefficient		—	—	—
Degradability coefficient		—	—	—
VBS (g/100 g)		2.0	1.4	2.0
Embrittlement coefficient (%)		31.8	37.4	71.7
Contraction limit (%)		27.1	24.6	35.0
CBR (%)		62.45	12.37	13.21

lateritic soils, due to its cemented appearance. There is a clear presence of quartzo and again the occurrence of an amorphous layer of Ferro and Aluminium oxides and hydroxides, involving the Kaolinite in the lateriticzation process.

Differences observed among images of C, RC and PIC samples were caused probably by soil reaction to the sample dispersion process or due to characteristics of the samples fractions we analyzed. According to the results obtained in the SEM there's no doubt the three samples have chemical composition compatible with soils whose origin is lateritic. In the RC soil one can clearly observe the Kaolinite clay mineral stacking in a hexagonal form.

8. Classifications of Soils

The Universal Soils Classification required parameters are presented in Table 1. The classification we produced is detailed in Table 2. In summary the soils we studied were classified as Sandy lateritic soils with high retraction and with middle to low bearing capacity. Therefore they need particle size or chemical in order to avoid fissures and to improve their bearing capacity when used in highways pavements as base and sub-base material.

Due to its high retraction and to its necessity of stabilization, results after stabilization procedures probably will be compatible with the demands of bearing capacity in layers of base and sub-base of low volume of traffic, being unnecessary additional costs with the increase of the compacting energy.

Table 2 - Universal soils classification.

Sample	Lateritic universal lateritic soils classification
C reservatoir	Sandy Lateritic Soil
	SLS_A
RC reservatoir	Sandy Lateritic Soil
	SLS_{S2}
PIC reservatoir	Sandy Lateritic Soil / Fine Lateritic Soil
	SLS_A / FLS_{S1}

9. Conclusion

The new classification procedure proposed takes into account the appropriate design criteria to the tropical humid climate, and the specific nature and state parameters associated with the mechanical behaviour of lateritic soils. It is expected to provide for much higher use of local soils in pavement layers. This study is part of a growth policy leading to saving resources and optimizing the lifecycle of infrastructure adapted for emerging countries.

Acknowledgments

The authors wish to thank the Laboratoire Central des Ponts et Chaussées (LCPC / France) and the Conselho Nacional de Desenvolvimento Cientifico e Tecnologico (CNPq / Brazil) for financial support for this research action.

References

Autret, P. (1983) Latérites et Graveleux Latéritiques. Phd Dissertation. Institut des Sciences et des Techniques de L'équipement et de L'environnement Pour le Développement, Laboratoire Central des Pontes et Chaussées, Paris, 120 p.

Akpokodje, E.G. & Hudec P.P. (1992) Factors controlling properties and durability of laterite gravel aggregates. Journal of Materials in Civil Engineering, ASCE, v. 4:1, p. 58-70.

Fall, M. (1993) Genèse et Formation des Sols Latéritiques. Phd Dissertation. Faculté des Sciences et Techniques-UCAD, Institut National Polytechnique de Lorraine, Nancy, 240 pp.

Food and Agriculture Organization of United Nation - FAO (2006). World Reference Base for Soil Resources, World Soil Resources Reports, Rome, 128 pp.

ISTED (1990) Utilisation des Graveleux Latéritiques en Technique Routière. Synthèses. Institut des Sciences et des Techniques de l'Equipement et de l'Environnement Pour le Développement, Centre Expérimental de Recherches et D'Études du Bâtiment et des Travaux Plubics, Paris, 203 pp.

Lyon Associates Inc. (1971) Une Etude Géotechnique pour Agence pour le Développement International, Les Sols Latéritiques et d'Autres Sols Difficiles d'Afrique, Lyon Associates, 135 pp.

Laboratório Nacional de Engenharia Civil – LNEC. (1969) Engineering properties of lateritic soils. VII International Conference on Soil Mechanics and Foundation Engineering, Mexico, 122 pp.

Maignein, R. (1966). Review of research laterites. Natural Resource, UNESCO, Paris, 142 pp.

Moh, Z.C. & Mazhar, M.F. (1972). Effects of method of preparation on index properties of lateritic soils. Proceeding of the Specialyty Session, Engineering Properties of Lateritic soils, 123 pp.

Ferreira, H.N. & Meireles, J.M.F., Influência nas Propriedades Geotécnicas de Solos Lateriticos, do Umedecimento e da Temperatura. Laboratório de Engenharia de Angola, p. 251-259.

Sharp, K.G., Vuong, B.T., Rollings, R.S., Baran, E., Foley, G.D., Johnson-Clark, J.R. & Metcalf, J.B. (2009) An Evaluation of the Field and Laboratory Properties of Lateritic Gravels.

Schellmann, W. An Introduction in Laterite, available at http://www.laterite.de/index.html.

Terzaghi, K. & Robertson, R.H.S (1958).The design and perfomance of the sasumua dam. ICE Proceedings, v. 9:4, p. 369-394.

Villibor, D.F. & Nogami, J.S. (2009) Pavimentos Econômicos: Tecnologia do Uso dos Solos Finos Lateriticos. Arte & Ciência, São Paulo, 218 pp.