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Chemical and Mineralogical Characterization of the Clayey Sands of Samo and Bingerville in the North of the Lagoon Fault, South of the Ivory Coast, In Road Construction

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Abstract

In Côte d'Ivoire, particularly in the south, the majority of paved and unpaved roads are made of clayey sand, given its availability. However, the early degradation of roads related to a strong sensitivity of this material to the environment (climate, geology and degrees of alteration) and a poor knowledge of the geotechnical properties of this one could slow down their use in road construction. It is within this framework that the work undertaken aims at determining the chemico-mineralogical nature of the clayey sands of the localities of Bingerville and Samo, in the South-East of Côte d'Ivoire. Tests were carried out taking into account the chemical and mineralogical analyses. Chemical elements were determined by atomic absorption spectrometry, colorimetry, complexometry and gravimetry. The determination of organic matter was determined using the Rock-Eval 6 pyrolysis method. The mineralogical composition was determined using a Bruker D8 ADVANCE diffractometer. The chemico-mineralogical analyses show that the clayey sands of Bingerville and Samo are more enriched in silica oxide (SiO2) but less enriched in iron oxide (Fe2O3). All the soils studied have an S/R ratio greater than 2, indicating that these soils are non-lateritic. In addition, the low TOC values between 0.1 and 0.15% by weight, which reflect the extremely low amount of organic matter in these soils, show the possibility of treating these soils with hydraulic binders. In addition, the mineralogy of the studied soils indicates that they are mainly composed of kaolinite and illite.

Keywords: Clayey sand, Characterization, Chemico-mineralogical, road, Samo, Bingerville

Introduction

In Africa, several studies conducted in the field of road construction (LBTP, 1977; AUTRET, 1983; MESSOU, 1980; BOHI, 2008; SOULEY, 2016) have shown the use of lateritic soils (SOULEY et al, 2015). However, their systematic use as road building materials is beginning to make them a scarce resource in the West African sub-region (BOHI, 2008; SAMB et al, 2013; BOUDLAL et al., 2017). The same is true in some parts of Côte d'Ivoire. Most of the roads made of lateritic soils are degrading early with a special emphasis in the coastal regions, in the particular case of the coastal, connecting Abidjan and San Pedro and in the south of the country. The evolution of the economic context and the objectives of sustainable development (SDGs) show, therefore, the need to promote alternative raw materials among which: natural materials, notably, shales and marls (BOUDLAL et al., 2017), recycled materials, concrete debris, glass debris, (BOUDLAL et al., 2017; DJOMO, 2017) and especially clayey sands. Clay sands, given their availability and abundance in the terrains encountered in the south of Côte d'Ivoire (LBTP, 1977; SODEMI, 2010), could constitute a new approach that integrates the Sustainable Development Goals (SDGs). These have sometimes been used in the design of roads. However, the use of clayey sands in road works in their natural state, with or without treatment with appropriate mixtures of hydraulic binders often poses problems from both chemical and mineralogical points of view (DJEDID, 2020).

The early degradations of roads made with natural clayey sands are recurrent and are due to its plastic state, the volume swelling, the organic matter and the clay of this raw material. DIOP (2002) reveals that during the construction of the Dakar-Thies highway, the presence of swelling clayey soils was observed in the area connecting the two localities. It is within this framework that the work undertaken aims at determining the physico-chemical and mineralogical nature of the clayey sands of the localities of Bingerville and Samo, in the South-East of the Ivory Coast, in order to better apprehend their behavior in the structures under loads such as the road infrastructures.

I- Site and experimental methods and sampling site

Reworked soils are the subject of this study. They were all taken according to the XP P 94-202 standard (1995), on sites previously identified by the Building and Public Works Laboratory (LBTP). These sites are located onshore, in the sedimentary basin, specifically in the southeastern part of Côte d'Ivoire in geotechnical region R1 according to the LPTP (1977).

Indeed, this part of the country, from a geological point of view, is characterized by three major structures that are: the lagoon fault, the Ghana-Côte d'Ivoire wrinkle and the bottomless pit (AKA, 1991; in ASSALE, 2013). The lagoon fault divides the sedimentary basin into two distinct zones: a southern zone made up of low coastal plain and low plateaus where there is a sandy cordon, and a northern zone known as the high plateaus between 50 and 110 meters in altitude. This northern zone, par excellence, is where the fine soils are located, in this case clay soils (KOUAKOU, 2005). These are, in particular, reworked soils taken from several borrow pits with a focal point around which gravitate three other sampling points within a radius of 2-3 m spread over the sites of Bingerville and Samo. That is to say a total of two (2) sampling points with the locations established with the GPS receiver below and presented in Table 1.

Table 1. Location of raw material collection sites (geographic coordinates and NTU).

Longitudes (° ' '')	Latitudes (° ' '')	Altitudes (m)	Localités
3°53'42''32 W	5°21'32''38 N	46,5	Bingerville
400 612 m	400 612 m		
3°30'53''88 W	5°17'28''19 N	51,4	Samo
278 102 m	400 612 m		

These samples were taken at variable depths ranging from 1 to 5 m, on average, over average widths of 3 to 5 m. They were placed in transparent plastic bags essentially, first, at room temperature, then, transported and conditioned in the laboratory around 25°C. The sampling or borrowing sites are shown in Figure 1 below.

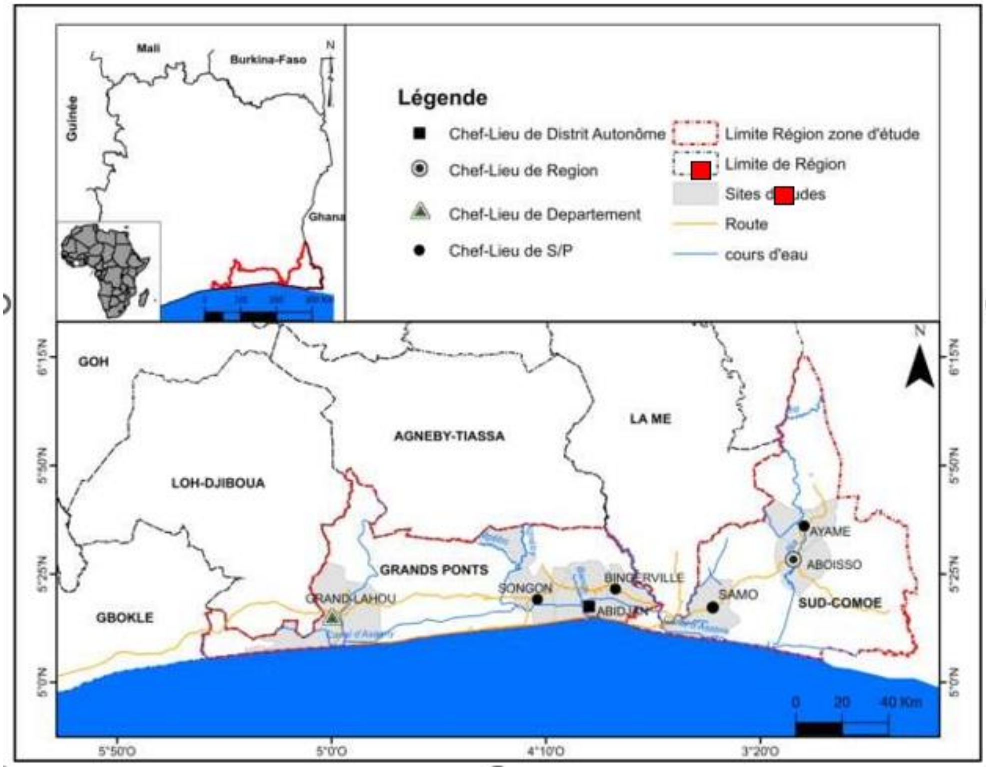


Figure 1. Location of reworked soil sampling sites

I.2. Experimental methods

I.2.1. Chemical characterization methods

The chemical composition was determined after the sample was put into solution by a tri-acid attack (sulpho-nitric mixture and hydrochloric acid according to the protocol proposed by NJOPWOUO et al. (1979). The analysis was carried out in the laboratory of the The company for the mining development of Côte d’Ivoire. Chemical elements were determined by atomic absorption spectrometry, colorimetry, complexometry and gravimetry. The spectrophotometer used is a Perkin Elmer Analyst 100 while the colorimeter used is a Jenway 6300 spectrophotometer. The determination of organic matter was done using the Rock-Eval 6 pyrolysis method at the Société Nationale d'Opération Pétrolière (PETROCI) analysis and research center. The parameter indicated by this method for the determination of the organic matter content in the analyzed samples is the Total Organic Carbon

(TOC). It allows to inform the capacity of a soil to support loads under traffic. The organic matter content will be qualified, according to ESPITALIE et al, (1977); PETERS et al, (1994) as in Table 2.

Table 2. Classification of organic matter and suitability of a soil for use under traffic in road techniques (ESPITALIE et al., 1977; PETERS et al., 1994)

TOC (weight %)	CLASSES	SOIL SUITABILITY
< 0,5	poor	suitable
0,5-1	means	suitable
1-2	good	suitable
2-4	Very good	unsuitable
>4	excellent	unsuitable

Within the framework of the design of road works, the soils suitable for use must have an organic matter content of less than 2% of good to poor classes (CEBTP,1980).

I.2.2. Mineralogical characterization methods

The mineralogical composition was determined using a Bruker D8 ADVANCE diffractometer. Sample powder ground to a particle size of less than 80µm was used for X-ray diffraction analysis. The fine fraction (<2 µm) was extracted by sedimentation according to Stokes law (Holtzapffel, 1985) in order to determine its mineralogical composition. The identification of minerals after analysis was done using the Fityk software (CANER, 2011) and is based on the positions of peaks at certain reticular distances in the (001) plane on the diffractograms (THOREZ, 1976). The analysis by DRX can be done on three types of tests which are complementary that are:

- first type of test, the normal slides (N), the recorded diffractograms of DRX are used as reference to appreciate the displacements of lines caused by the other types of test.
- second type of test, the glycol slides (EG)
- This type of test with ethylene-glycol has the effect of making the swelling minerals such as smectites contained in the sample "swell".
- Third type of test, the heated slides (CH500)

In this type of test, the slides are heated to 500°C to destroy kaolinite but this has no effect on chlorites. The minerals of the vermiculite and smectite family are irreversibly dehydrated at this temperature. This loss of water causes a shift of the 001 line from 15 to 10 Å. These clays are said to close at 10 Å after heating. This closure of minerals is a characteristic for their identification and especially for the identification of interlayers containing smectic and vermiculitic mineral sheets.

II- Results

II.1 Chemical characterization of clayey sands of Bingerville and Samo in their natural state

II.1.1. Content in oxides

The proportions of the contents in oxides realized on the clayey sands, crushed and returned in the form of powder (diameter between 75 nm and 100 nm), are consigned in table 3.

Table 3. Proportion of the contents in oxides of the various clayey sands of Samo and Bingerville

Clayey sands	Mass proportion of the measured oxides				
	% SiO_2	% Al_2O_3	% Fe_2O_3	% TiO_2	%MgO
Bingerville	60.03±0.02	12.21±0.02	8.8±0.02	1.28±0.02	0.06±0.01
Samo	62.39±0.02	9.79±0.02	12.68±0.02	1.09±0.02	0.05±0.01

This table of proportion of oxide contents shows that the clayey sands of Bingerville and Samo are more enriched in silica oxide (SiO_2) but less enriched in iron oxide (Fe_2O_3). The variation in the chemical composition of these different soils could be explained by the environmental factors that influence the process of laterization, notably: climate (temperature, water balance), topography (erosion and drainage), vegetation (organic matter, bacteria, humic acids, and parent rocks).

These clayey sands were collected in the same climatic zone, i.e. in the south of Ivory Coast in the sedimentary basin in the northern part of the lagoon fault with high rainfall alternating with sunny weather, which could lead to this variation in the proportions of oxides in these soils.

Also, the variable coloration of the soils ranging from red to yellow ochre is an indicator of different degrees of oxidation of these different clayey sands, in this case the oxidation of iron contained in the minerals of these soils such as iron oxides and/or hydroxides. The values of the degree of laterization of the various clayey sands determined by the ratio S/R are presented in table 4.

Table 4. Values of the S/R ratio of different clayey sands

Clayey sands	S/R Ratio
Bingerville	2.18
Samo	5.93

We notice that all the clayey sands present ratios of S/R superior to 2 which shows that from East-West or West to the East of the lagoon fault, we establish that the silica oxides dominate the iron oxides; and according to this classification, they are non-lateritic clayey sands. It is thus necessary to look for the content of organic matter in these different reworked soils.

II.1.2. Organic matter content

Table 5 below presents the results of the values of organic matter contents, in the different clayey sands studied, expressed in total organic carbon.

It can be seen in this table that the values of Total Organic Carbon (TOC) of the clayey sands samples studied vary between 0.10 and 0.15% by weight. It appears that the organic matter content is low, in other words, the quantity of organic matter is low in the clayey sands of Bingerville and Samo. The rate of organic matter is less than 1 (< 1%), by weight. In such conditions, the clayey sands of this study can be treated with hydraulic binders in order to be used in road base layers.

Table 5. Values of organic matter contents of the different clayey sands

Clayey sands	TOC (weight
Bingerville	0.15±0.1
Samo	0.10±0.2

II.2 Mineralogical characterization of the clayey sands Bingerville and Samo

II.2.1. Analysis of the clayey sands of Bingerville

The cross analysis of the diffractograms of the fine fraction of the clayey sands for the fine fraction of Bingerville, reveals that the clayey minerals are composed mainly of kaolinite at 96% and a small proportion of illite at 4%, below (Figure 2). Kaolinite was detected by peaks observed at reticular distances 7.1 Å (001); 3.55 Å (002) and 2.36 Å (003) on the diffractograms of the natural (N) and ethylene-glycol (EG) samples and confirmed by the absence of peaks at these same distances on the diffractogram of the heated phase (CH500) below (Figure 3 and 4) Illite was recognized from the peaks observed on all diffractograms (Figure 3 and 4) at the same respective lattice distances 10 Å (001); 5 Å (002) and at 3.3 Å (003).

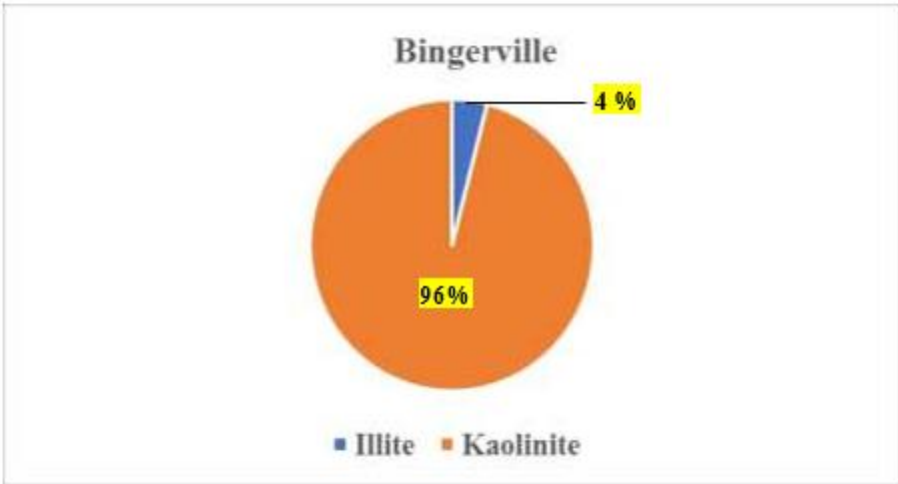


Figure 2. Mineralogical composition of the fine fraction of the Bingerville clayey sands sample

Figure 3. Diffractograms of the fine fraction of the Bingerville clayey sands sample Bingerville on normal (a) and Glycol (b) slides

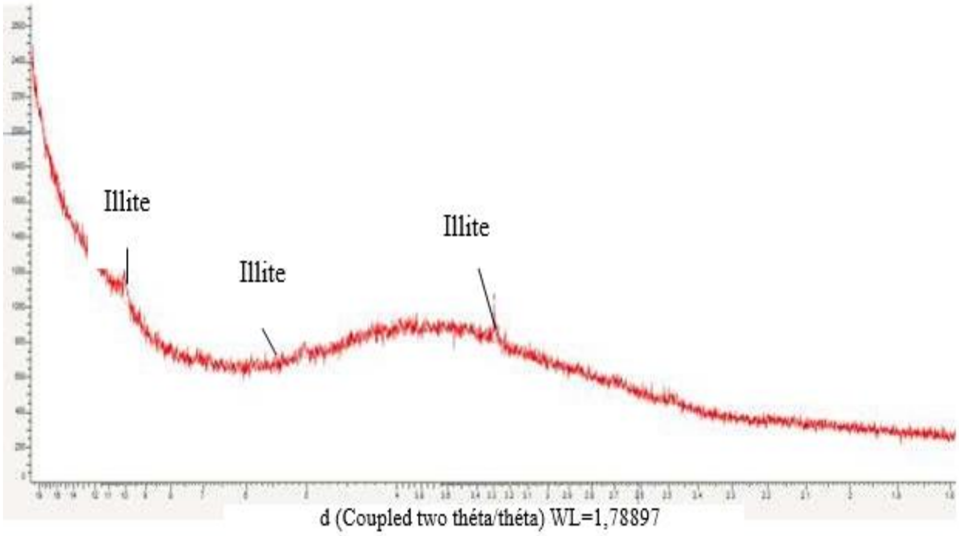
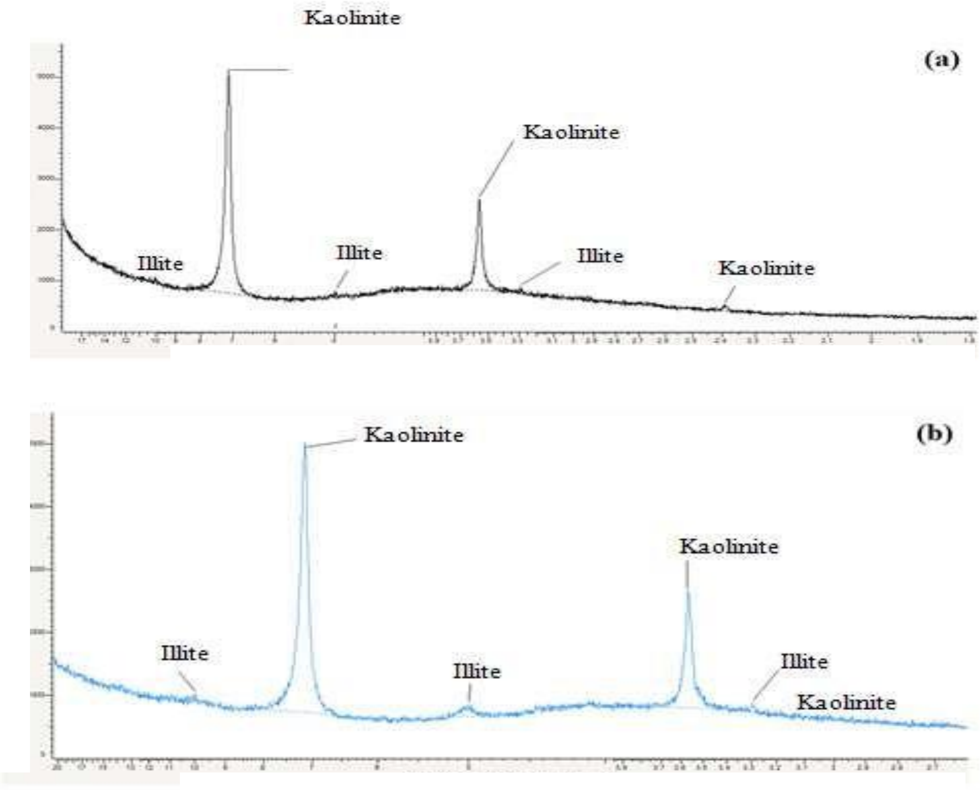


Figure 4. Diffractogram of the fine fraction of the clayey sands sample Bingerville heated

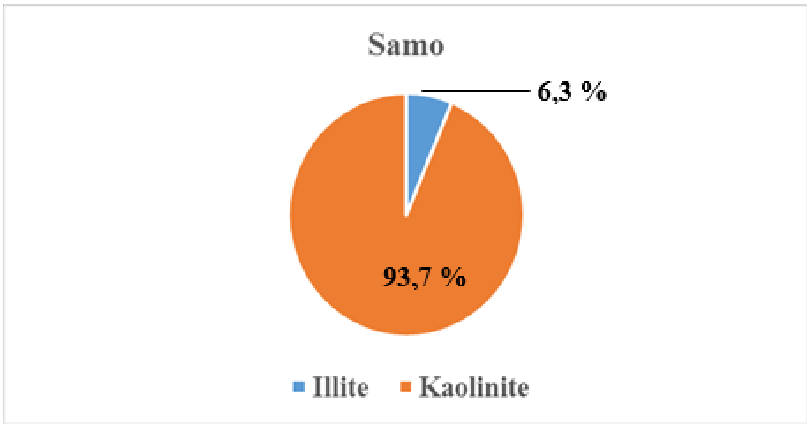


II.2.2. Analysis of the clayey sands of Samo

The clay mineralogy of the Samo sands is mainly composed of kaolinite and illite.

Indeed, the lines observed at 7.1 Å (001); 3.55 Å (002) and 2.36 Å (003) on the diffractograms of the sample carried out on normal and glycol slides indicate the presence of kaolinite which is confirmed by the disappearance of these peaks in the heating treatments. Kaolinite is dominant with a proportion of 93.7% against 6.3% of illite (Figure 5) below. The illite lines were observed at 10 Å (001), 5 Å (002) and 3.3 Å (003) on the diffractograms of the sample in normal, glycol and heated slides (Figures 6 and 7).

Figure 5. Mineralogical composition of the fine fraction of the Samo clayey sands sample



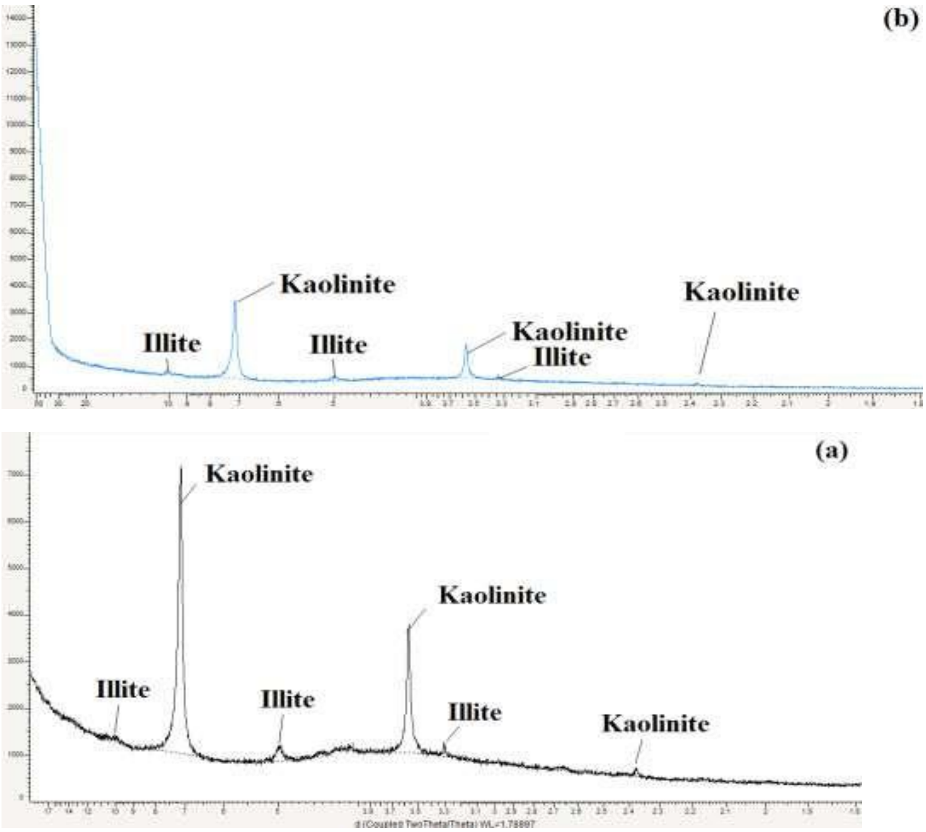


Figure 6. Diffractograms of the fine fraction of the Samo clayey sands sample performed on normal (a) and glycol slides (b).

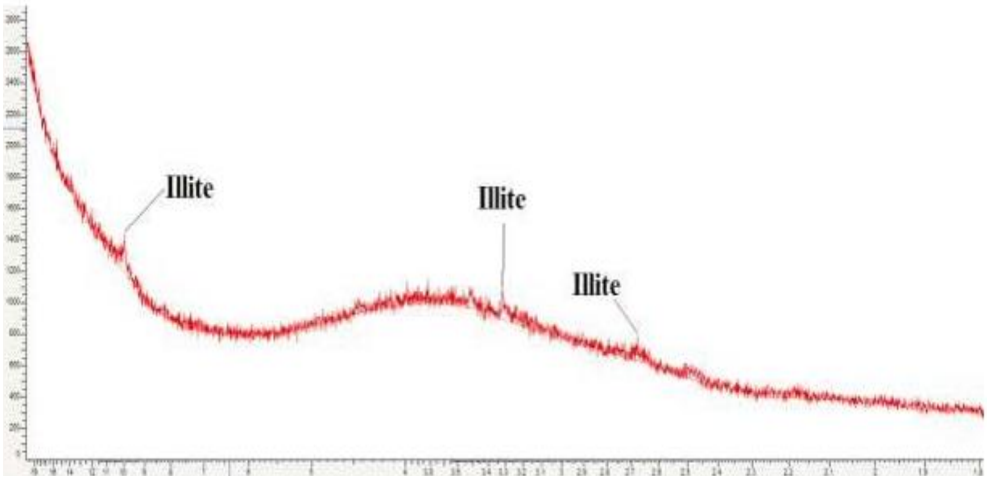


Figure 7. Diffractogram of the fine fraction of the Samo clayey sands sample on a heated slide

III- Discusion

The work of ASSALE et al (2012) showed that the clayey sands of Bingerville are enriched in quartz and signified the presence of certain minerals such as goethite, limonite, hematite which influence the coloration of the soils as well as the variation of the degree of oxidation. These results are in phase with those of our work. Regarding the mineralogy, the analysis of the soils studied by X-ray diffraction indicates that they are mainly composed of kaolinite and illite which were detected at the reticular distances corresponding to the reflections (001), (002) and (003). Our work is in agreement with that of BENZERARA (2014). For this author, the balance of crystallographic variations according to physicochemical treatments is summarized as follows:

- illite is detected by the presence of lines at 10 Å, 5 Å and 0.34 Å which correspond to the reflections (001), (002) and (003) of an illite phase unaffected by ethylene glycol treatment and heating to 550°C.
- kaolinite is highlighted by the presence of reflections (001) and (002) at 7.15 Å and 3.5 Å in the natural state, unaffected by ethylene glycol treatment, but which disappear after heating to 550°C, (dehydroxylation of kaolinite).

In addition, it should be noted that: by its physical, chemical and mineralogical characteristics, these clayey soils present aptitudes for its use in road construction. They have a relatively average content of Al_2O_3 and do not contain enough swelling clay minerals of the smectite type like montmorillonite. Also, there is a very low presence of Total Organic Carbon (TOC) in these soils. This suggests that it can be stabilized with hydraulic binders such as Portland cement (MOLARD et al. 1987; TEMIMI et al.1998). Indeed, LEROUX (1969) establishing an order of magnitude of mechanical strengths of clays stabilized with cement and lime, showed that the best mechanical strengths are obtained with kaolinite and are followed by illite. As for smectites, they are less suitable for this type of stabilization because they consume all the ca2+ ions released by the cement during its hydration, thus preventing its setting; however, AMOR (1995) reports that kaolinite only fixes two thirds of these ions.

Conclusion

The chemical analyses showed that the samples contain mainly three oxides: SiO_2, $A1_2O_3$ and Fe_2O_3. The content of oxides shows that the clayey sands of Bingerville and Samo are more enriched in silica oxide (SiO_2) but less enriched in iron oxide (Fe_2O_3). Also, the low values of TOC between 0.1 and 0.15% by weight which reflect the extremely low amount of organic matter in these soils show the possibility of treating these soils with hydraulic binders (Lime and cement).

As far as mineralogy is concerned, these clayey soils are suitable for road construction. The analysis of the soils studied by X-ray diffraction indicates that they are mainly constituted of kaolinite and to a lesser extent of illite.

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