Mechanical Performance Improvement of a Gypsum Tuff with a Sodium Hydroxide Treatment

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Abstract:

This work is part of the valorization of local Saharan materials intended for road construction. It aims to improve the mechanical performance, particularly the resistance to simple compression, of a tuff encrustation from the Ouargla region, initially possessing poor mechanical properties. This improvement is achieved through chemical treatment with a sodium hydroxide solution at different pH levels. The obtained results demonstrate that the chemical treatment of tuffs with an alkaline solution of sodium hydroxide improve their resistance to simple compression, and the concentration of the solution and the conservation mode of the specimens have an effect on this improvement. The maximum value of resistance (1.18 MPa) was achieved for specimens treated with a sodium hydroxide solution at a concentration of 2.4×10^{-1} (mole/l) with a pH of 13.38 and conserved under laboratory conditions (mode1).

Keywords: Tuff, chemical treatment, NaOH solution, simple compression resistance, conservation method**.**

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I. Introduction :

Tuff crust is one of the most widespread local natural resources in arid regions, especially in the Ouargla region (Southeast of Algeria) [1],[2]. However, its relatively poor technical characteristics sometimes limit its use[3]. As a result, road project managers resort to using so-called "noble" materials brought in from distant regions, which has a negative impact on project costs.

Tuff is known for its hardening property, primarily resulting from dissolution in the presence of water, followed by crystallization during water evaporation , which provides it with a certain level of stability [3],[4],[5],[6]. However, some varieties, particularly gypsum tuffs, remain relatively weak compared to the required technical specifications [7]. This calls for finding alternative solutions to overcome this limitation.

The idea of chemical treatment for tuff could be a solution to bring its properties in line with the required technical specifications [8]. The objective of this work is to improve the mechanical performance of tuff crust, particularly its resistance to simple compression (Rc), which is considered one of the selection criteria for tuffs used in Saharan road construction, by subjecting it to chemical treatment with an alkaline sodium hydroxide (NaOH) solution at two different concentrations.

After an experimental phase focusing on the characterization of the base material "tuff," simple compression tests were conducted on cylindrical specimens (H10Ø5 cm) made from untreated tuff and tuff treated with two sodium hydroxide solutions with concentrations values of $C_1=3.5 \times 10^{-5}$ (mol/l) and $C_{2=}$ 2.4×10^{-1} (mole/l). The duration and conservation

II. Materials And Methods

II.1- Materials

The base material in this study is tuff, sourced from the Ouargla region (southeast Algeria).

Figure.1 tuff of Ouargla region

Figure .2 Map of Algeria, showing the Ouargla region [9].

- **Basic chemical analysis**

A basic chemical analysis (Figure 1), was conducted to determine the levels of insolubles, sulfates, carbonates, and salt content [10]. This analysis revealed the predominance of sulfates (CaSO4), confirming the gypsum nature of our material [11].

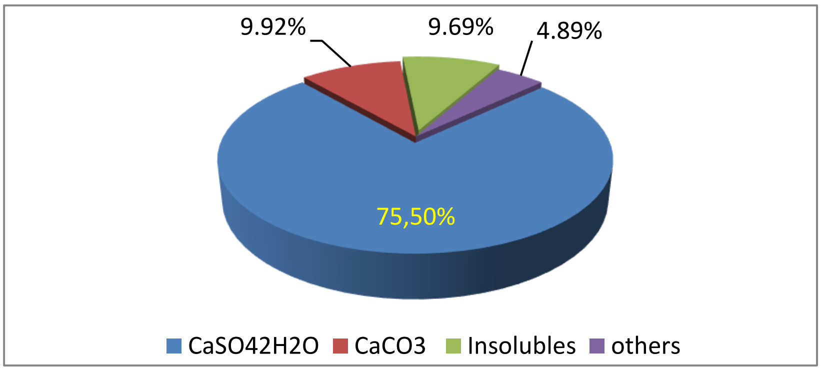

Figure 3. Chemical composition of the tuff.

- **Granulometric analysis**

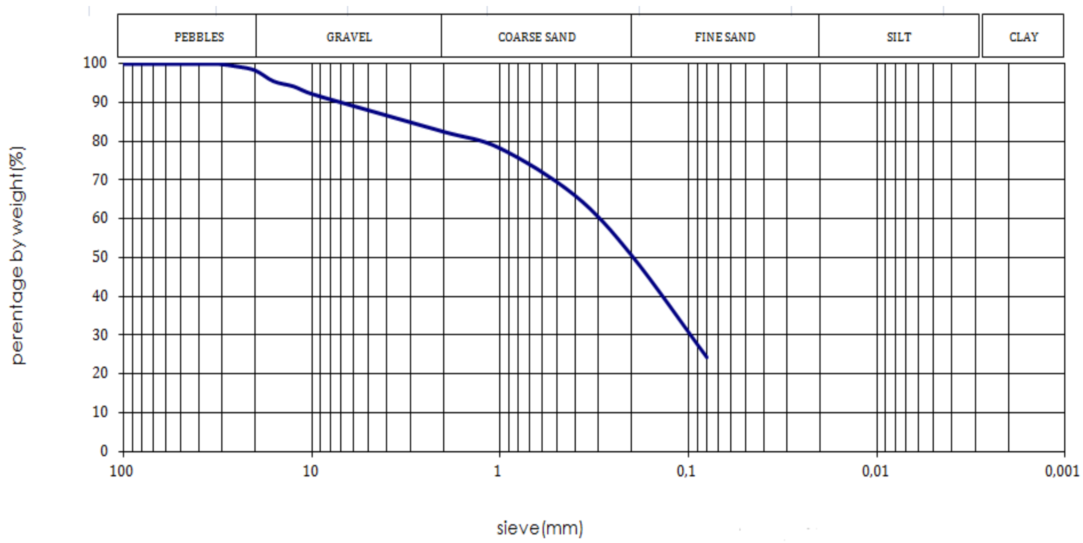

Figure .4 Tuff granulometric curve[12].

- **Compaction parameters**

The compaction parameters are determined through the modified Proctor test, where the maximum dry density (ɣd) is determined, as well as the corresponding optimal water content (wopm) [13].

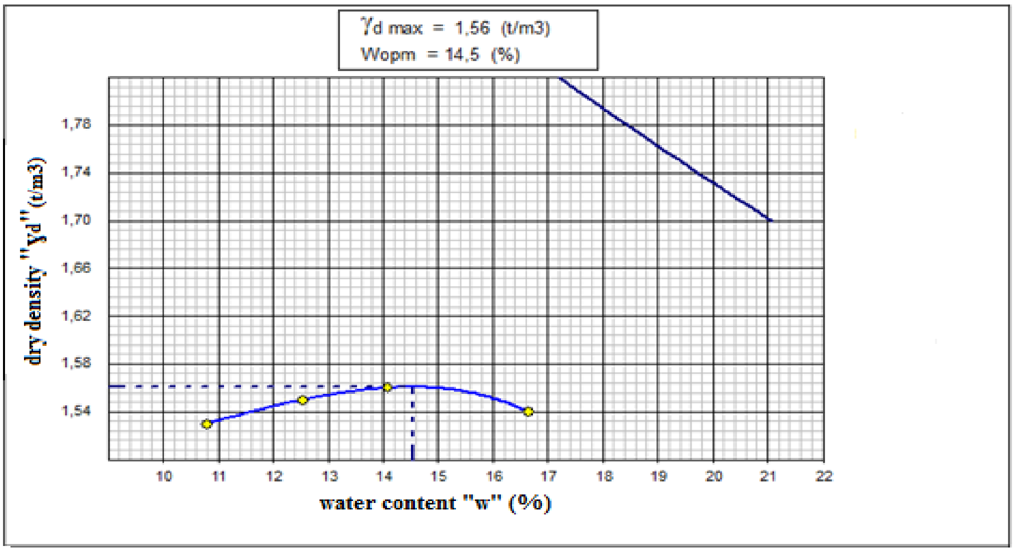

Figure.5 Modified Proctor Curve.

Table .1 Summary of characterization test results

Maximum diameter D_{max} (mm)	**50**
Elements <2mm (%)	73
Elements <0,80 mm (%)	24
Maximum dry density (t/m3)	1.56
Optimum water content (W_{opm}) (%)	14.5
Value of methylene blue VBS	0.50
Immediate CBR index	32.11
CBR index after immersion	16.52
Simple compression strength at 28 days (MPa)	0.55

According to the Road Earthworks Guide (GTR, 1992), and based on the clay activity (VBS) and granulometry with a maximum diameter less than 50 mm and a percentage of fines (passing 0.080 mm) account for approximately 24%, the studied material belongs to class B2 where it is considered as a fine soil (Figure 3), [14],[15],[16].

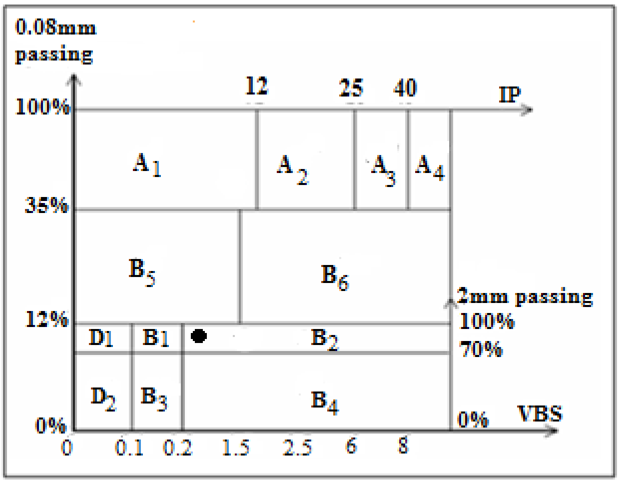

Figure .6 Classification chart (GTR, 1992).

The second material used in this study is sodium hydroxide(NaOH).
Sodium hydroxide was chosen due to its low cost, and its availability .
The preparation of the sodium hydroxide solution was done by dissolving the dry Sodium hydroxide powder in distilled water with specific weights to obtain the desired concentrations, using the following relation:

m= M×C×V .[17]

m: mass (g)

M: molar mass (M_{NaOH} =40g/mole)

C: molar concentration (mole/l)

V: water volume (l)

Two sodium hydroxide solutions were prepared, one with law concentration (C_1=3.5 × 10^{-5} (mol/l) , pH_1 = 9.55), and the other with high concentration ($C_{2=}$ 2.4×10^{-1} (mole/l) , pH_2 = 13.38) .
The real pH of the two solutions was determined using a pH- meter.

II.2- Methods:

The study of the simple compression strength (RC) is conducted on cylindrical specimens (Ø = 5cm, H = 10cm) that are statically compacted and prepared as follows:

Untreated tuff **(TNT)** , where distilled water was used.

Treated tuff **(TT1)** with a NaOH solution, used during specimen preparation, with a concentration of **C_1=3.5 × 10^{-5} (mol/l)** and **pH_1 = 9.55.**

Treated tuff **(TT2)** with a NaOH solution with a concentration of **$C_{2=}$ 2.4×10^{-1} (mole/l)** and **pH_2 = 13.38.**

The specimens are conserved under two different modes for 7, 28, and 60 days :

Mode 1: The specimens are conserved under laboratory conditions at a temperature of 25±5°C.

Mode 2: The specimens are conserved under laboratory conditions but are enclosed in plastic bags to prevent water evaporation.

It should be noted that the static compaction was performed at the optimum water content of modified Proctor "**wopm=14.5%**", and a compaction of 95% (95% of maximum dry density"**γ_d=1.56t/m^3**").

The specimens are crushed using a hydraulic press at a speed of 1.27mm/min.

Figure.7 molds for making the specimens

Figure.8 crushing hydraulic press used to measure the compressive strength of the specimens.

Figure.9 specimen after crushing

III. Results and Discussions:

III.1- Influence of the sodium hydroxide solution concentration on the simple compression strength (Rc).

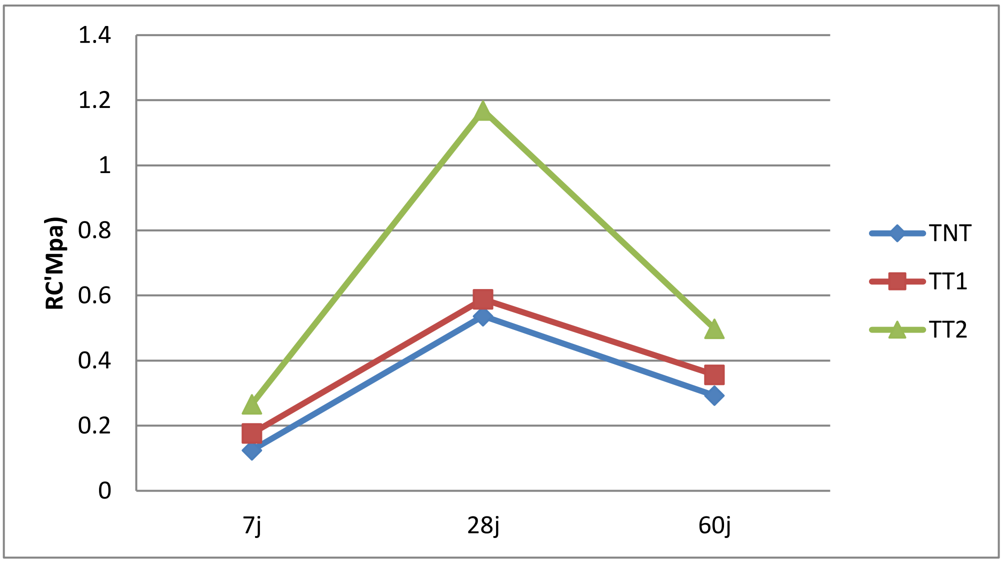

Figure.10 compressive strength evolution of treated and untreated tuffs with age in mode 1.

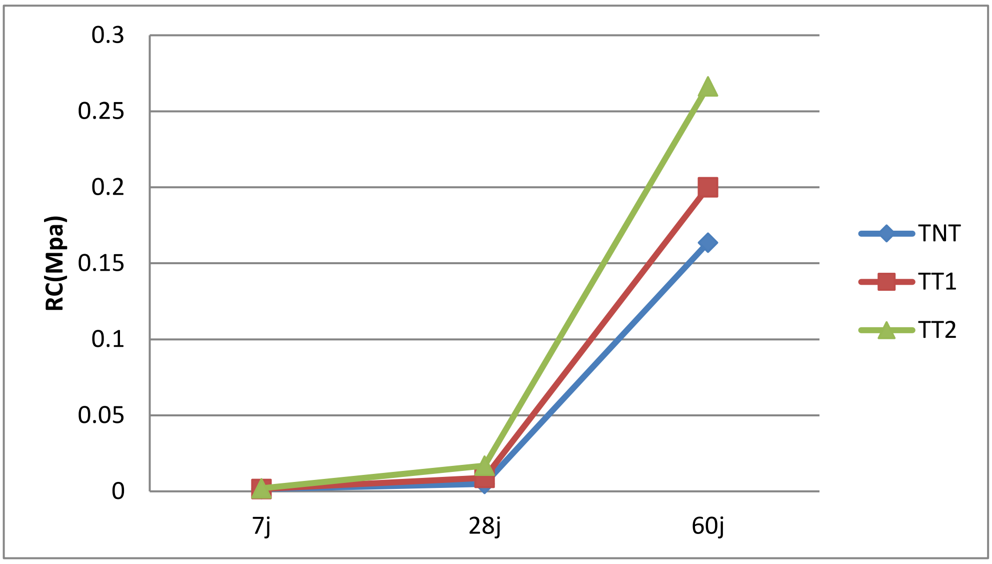

Figure.11 compressive strength evolution of treated and untreated tuffs with age in mode 2.

Figures 10 and **11** shows the evolution of the compression strength of tuffs (treated and untreated) with age, respectively for conservation modes 1 and 2.

In mode 1

The results reveal that the strength of the treated tuffs (TT1 and TT2) is higher than that of the untreated tuff (TNT) for all ages. The maximum value is obtained at 28 days for TT2 (pH=13.38) with a value of approximately 1.2 MPa. At 60 days, the strength of both treated and untreated tuffs shows a certain decrease compared to the value obtained at 28 days. This is likely due to the excessive disintegration of the specimens, which hinders the possible interaction between the components of the tuff, mainly gypsum and the sodium hydroxide solution.

In mode 2

At 7 and 28 days, the strength of both treated and untreated tuffs is almost zero. However, at 60 days, the strength shows a remarkable increase. This can be explained by the fact that confining the specimens in plastic bags provides a suitable environment for the reaction between sodium hydroxide (NaOH) and gypsum (CaSO4 2H2O) to take place. This reaction produces sodium sulfates (Na2SO4), known as thenardite, and calcium hydroxide (Ca(OH)2), known as portlandite, according to the following chemical equation:

CaSO4 • 2H2O + 2NaOH → Na2SO4 + Ca(OH) [18], This results in cohesion between the particles of the tuff and consequently an increase in compression strength. The increase in compression strength with an increase in the concentration of the sodium hydroxide solution is due to the fact that the higher concentration of NaOH can accelerate the reaction and promote faster dissolution of gypsum. This is attributed to the increased presence of hydroxide (OH^-) and sodium (Na^+) ions in the solution, which enhances the chances of collision with sulfate ($SO4^{2-}$) ions present in gypsum.

III.2- Effect of conservation mode on simple compression strength (Rc).

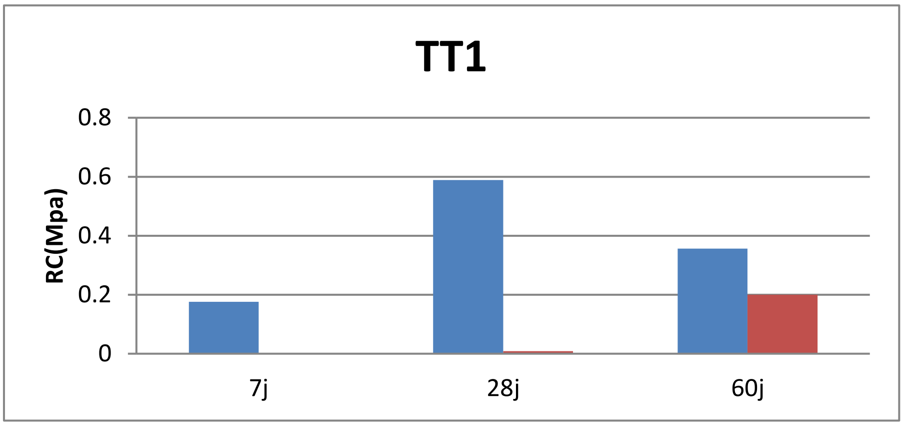

Figure.12 Comparison of the compressive strength evolution of untreated tuff (TNT), between the conservation modes 1 and 2

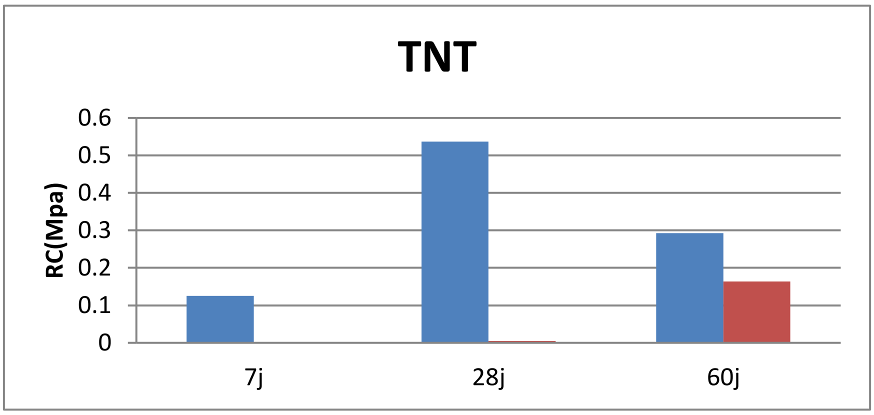

Figure.13 Comparison of the compressive strength evolution of treated tuff (TT1), between the conservation modes 1 and 2

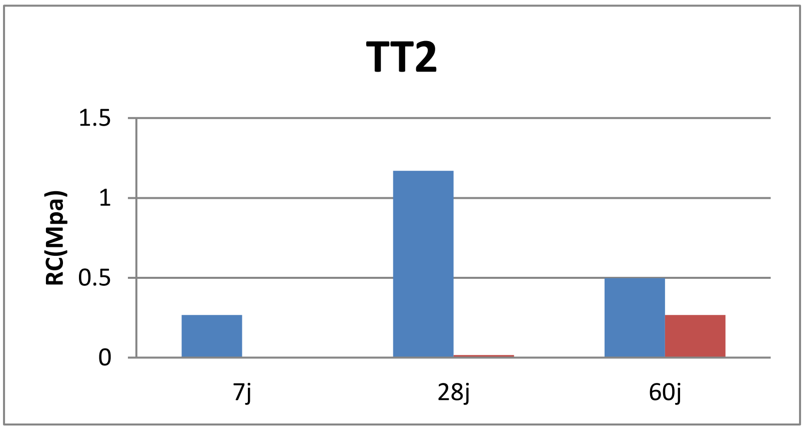

Figure.14 Comparison of the compressive strength evolution of treated tuff (TT2), between the conservation modes 1 and 2.

Figures 12,13 and **14** shows the compressive strength evolution of treated and untreated tuffs under the effect of conservation modes.

Overall, the same trend in compressive strength evolution was observed for both treated and untreated tuff.

The strengths in mode 1 are higher than those in mode 2. The compressive strength increases with age, reaching its maximum value at 28 days (RC_{TNT}=0.55 MPa, RC_{TT1}=0.58 MPa, RC_{TT2}=1.18 MPa) in mode 1, then decreases at 60 days. This is due to the rapid evaporation of water, which inhibits various reaction processes, leading to a decrease in compressive strength.

The compressive strength is low to nearly zero at 7 days and 28 days in mode 2. This is because the prevention of water evaporation is a crucial factor in the various dissolution-recrystallization reactions [4]. These reactions require more time to occur and subsequently harden the tuff, which becomes evident after 60 days when a significant increase in compressive strength is observed for all cases.

The highest value of Rc is obtained for the tuff treated with a sodium hydroxide solution at a concentration of 2.4×10^{-1} (mole/L) and pH =13.38.

IV. Conclusion:

The obtained results allow us to draw the following conclusions:

- Treatment of tuff with an alkaline solution improves its compressive strength. The strength increases with the pH of the alkaline solution.
- The conservation conditions of the specimens influence the rate of different reactions leading to cohesion and hardening of the tuff.
- Treatment of tuff with a sodium hydroxide solution at a concentration of 2.4×10^{-1} mole/l (pH=13.38) with conservation of the specimens in mode 1 (laboratory conditions) yielded the highest compressive strength, reaching(1.18 MP) after 28 days of conservation.

V. References:

[1] Djili K, Daoud Y, Ayache N, *analysis of the vertical and spatial distribution of limestone in the soils of northern Algeria* ,1999.

[2] Guettouche MS, Guendouz M,Boutiba M, *sur l'existence d'un modèle-type d'encroutement des sols arides et semi-arides en Algérie : étude comparative entre la Tafna (Algérie, nord-occidentale) , et les hauts plateaux, journal des sciences pour l'ingénieur 6,65-80*,2006.

[3] Alloul B, *étude géologique et géotechnique des tufs calcaires et gypseux d'Algérie en vue de leur valorisation routière* ,1981.

[4] Morsli M, *contribution to the valorization of encrustation tuffs in Saharan road engineering* ,PhD thesis, 2007.

[5] Ameraoui F, *étude hydro chimique des nappes de Témara et de Chaoui côtière (Meseta marocaine*, bulletin de l'institut scientifique,22,71-80, 2000.
[6] ben dhia MH, *les tufs et encroutements calcaires dans la construction routière*, Thèse doctorat, Paris 6(FRA),1983.
[7] Struillou L, Alloul B, *Road valorization of encrustation tuffs in Algeria, Bulletin of Engineering Geology and the Environment*, International Symposium on Aggregates ,1984.
[8] Goual I, Goual M S,*traitement physique et chimique du tuf d'encroutement calcaire de l'atlas saharien :application en technique routière*,dec 30,2014.
[9] Sadine S A, Bissati S , Idder M A ,*diversity and structure of scorpion fauna from arid ecosustem in algeria septentrional sahara* (2018).
[10] *Standard NF P15-461*, determining chemical characteristics of cements.
[11] HAFSI.M, LTPS Ouargla*, Les Tufs Gypseux et Calcaires en Zones Arides Essais et Critères de Sélection*, National Seminar on Road and Traffic Safety 29 & 30 Nov 2010, UKM Ouargla, p 02,03.
[12] *Standard NF P94-56*, determination of soil particle size distribution.
[13] *Standard NF P94-093*, determination of compaction references for a material.
[14] ASTM D. 2487-06, *Standard Practice for Classification of Soils for Engineering Purposes, Unified Soil Classification System* ,2006.
[15] SETRA, *Technical Guide, Construction of embankments and subgrade layers*, LCPC Guides ,2000.
[16] NF P. P 11-300, *Classification of materials used in the construction of embankments and subgrade layers for road infrastructures*, Execution of earthworks ,1992.
[17] Mathé S, PhD in Chemistry from INSA Toulouse, *livre chimie des solutions* ,2017.
[18] Le Roux A, Orsetti S, *sulfatic reactions: formation conditions, structure, and expansion of secondary sulfate minerals* ,2000.