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Characteristics of sewage sludge produced from wastewater treatment plant in the Moroccan city Khouribga

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ABSTRACT

This study investigates the geotechnical characteristics, mineralogical properties and physicochemical properties of sewage sludge produced by wastewater treatment plant of the Khouribga city during the wastewater treatment process of chemical coagulation, biological and sedimentation. The main aim of this paper is to characterize the composition of sewage sludge and to assess compatibility with construction materials for reuse as an addition of sewage sludge in the manufacturing of construction materials. To characterize this sewage sludge many methods were used such as: the inductively coupled plasma atomic emission spectroscopy method, X-ray diffraction, Atterberg limits and the particle size distribution was determined by granulometry. The obtained results showed the physical properties of the sewage sludge materials. It consists of about 60% fine sand in grain size range 150–75 µm. Furthermore, it contains an important quantity of chemical components such as iron, calcium, silica, alumina and phosphate, while the main mineral constituents of sewage sludge are Al_2O_3, Fe_2O_3 and SiO_2. In addition, the results of the geotechnical characterization showed a very high value for a liquid limit of 315%, a plastic limit of 55% and the plasticity index of 260%. According to the classification of Casagrande, sewage sludge is similar behavior with of soils elastic, it is located in the group silts clays to high plasticity. Based on the physicochemical and geotechnical characterization and mineralogical composition of sewage sludge, it is indicated that sewage sludge has the potential to be utilized in various applications, such as in the manufactured brick, in the ceramic industry, into a cementitious material and in the making of cement is possible, because the main compounds of the sewage sludge is similar the properties of the raw material used in these materials.

Keywords: Wastewater treatment; Sewage sludge characteristics; Physicochemical properties; Mineralogical properties

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1. Introduction

In wastewater treatment plants, operating according to the usual treatment method (pre-treatment, chemical treatment by coagulation and flocculation, biological treatment, secondary settling) have generated a vast amount of sewage sludge. Several environmental problems are related to this sewage sludge waste such as air contaminants, water and soil. Also, it presents a real danger to public health. Therefore, is an issue in various countries due to its increasing volume and the impacts associated with its disposal; Morocco is not an exception. Morocco had produced more than 240,000 tons of sewage sludge in 2015 (the estimated production of sewage sludge from wastewater treatment plants in Morocco, more than 320,000 tons in 2025) [1]. The traditional methods for sewage sludge disposal are used in landfilling sites [2–5], has been used in agriculture as fertilizer and soil amendment, because the sewage sludge contains various elements of nitrogen, phosphorous and large rate of organic matter [6–9] but also it contains toxic heavy metals such as Zn, Cu, Ni, Cd, Pb, Hg and Cr are principal elements restricting the use of sewage sludge for agricultural purposes [3,10,11], in ocean dumping [12,13]. All these methods of managing the sewage sludge might have adverse impacts on the environment. Therefore, there is a need to develop new technologies of management solutions of sewage sludge, in terms economic and of their environmental sustainability, as a goal to be recycled these waste of sewage sludge for limit the problem of its disposal.

On the other hand in recent years, sewage sludge is used in various applications, mostly in the building materials, which was found to be ecological and sustainable in small dosages assessed through several studies carried out by various global researchers in recent years, such as an additive in the production of construction materials [14–20], as the raw material in cement and eco-cement production [21–28], in concrete [29,30], in the manufacturing of lightweight aggregate and mortar [31–36], in ceramic products [37–41], and in the production of bricks [42–44]. In Morocco, the current disposal method of sewage sludge is traditional which caused the harmful damage to the natural environment. Thereby, this novel study demonstrates the feasibility of incorporating wastewater solid waste as one of the constituents for production of sustainable building materials. Hence, the objective of this paper is to characterize the physicochemical properties, geotechnical properties and mineralogical compositions of sewage sludge and to evaluate the possibilities to reuse it in different sectors of the construction materials.

2. Materials and methods

2.1. Origin of the sewage sludge used in this study

The sewage sludge used in this study was obtained from wastewater treatment plant located in Khouribga city, Morocco, which treats the wastewater by the biological process of activated sludge. The sewage sludge sample was dried at 105°C ± 5°C for 24 h in an oven dryer before usage, for natural humidity elimination, as to perform the physicochemical, geotechnical and mineralogical analyses that are presented below.

2.2. Analytical procedures

2.2.1. Physical properties

- *Density*: the apparent and real densities were measured with 20 g samples by the displacement of an organic solvent (toluene) in a pycnometer volumeter according to NF ISO 11272, NF ISO 11508 standards [21,45].
- *Porosity*: the porosity was calculated from the results obtained by apparent and real densities, according to the following equation [21]:

$$n = \frac{1 - P_{\text{apparent}}}{P_{\text{real}}}$$

- *Particle size distribution*: this test was carried out in two phases:
  – *Granulometry by sieving*: size analysis was made by screening a 200 g sample, obtaining fractions with sieves 63; 125; 250; 500; 710; 1,000 and 2,000 μm, according to NLT 104/91 and ASTM standard method [46].
  – *Granulometry by sedimentation method*: this test supplements the first and makes it possible to quantify the fractions of particles whose diameter is lower than 63 μm for clay and silt fractions; this analysis is based on the processing of the sewage sludge sample by H_2O_2 to remove organic matter and mechanically agitating for 2 h with Na-hexametaphosphate diluted to N/1,000 [47], then transferring the mixture to a cylinder of 1,000 mL for the precipitation to occur according to the law of Stokes. To take the measurements approximately 26 s, 5 min, 1 h and 3 h.
- *Loss on ignition*: the organic fraction obtained from 1 g sample was used to conduct LOI test. Furnace temperature was increased from 550°C to 950°C for 4 h. Weight loss was calculated according to the equation below [48]:

$$\text{Weight loss}\left(\%\right) = \frac{(m_i - m_a)}{m_i} \times 100$$

with m_i as the mass of the calcination at 550°C (g) and m_a as the mass after calcination at 950°C (g).

2.2.2. Chemical compositions

The concentration of heavy metals was measured by using the inductively coupled plasma atomic emission spectroscopy equipment. After the solution of 1g sample of sewage sludge (dry weight) in 10 ml of diluted nitric acid to 10%, the mixture was heated at 95°C ± 5°C for 10–15 min without boiling. After the mixture is cooled, 5 mL of concentrated nitric acid and 10 mL concentrated hydrochloric acid were added to the mixture and then heated at 95°C ± 5°C, and then it was allowed to cool. After this step, 2 mL of distilled water and 3 mL of 30% H_2O_2 were added, then the mixture was separated by filtration, and then the volume of mixture was made up to 100 mL using distilled water [13,45].

2.2.3. Mineralogical characteristics

The X-ray diffraction (XRD) which was carried out with Bruker equipment (analytical instrumentation for elemental analysis and materials research), was used to determine the crystalline phase of sewage sludge, with 2Θ angles scanning ranges from 10° to 90° [3,45].

2.2.4. Geotechnical index properties

The characteristics of sewage sludge by geotechnical properties were carried out according to the main following tests:

- Atterberg limits of corresponding to the thresholds of the passage of the solid state in a plastic state (plastic limit W_p) and to the plastic state in the liquid state (liquid limit W_L). The interval between these two limits gives the index of plasticity (I_p) [45,46,49,50].
- The water content (W_c) of sewage sludge sample was measured after drying in the kiln at a temperature of 105°C for 24 h. The water content was calculated according to the following equation: W_c (%) = $M_w/M_s \times 100$ with M_w as the mass of water and M_s as the mass of the solid particles [51–53].
- Sand equivalent according to NLT 113/87 standard, a quick procedure for determining the percentage of fines contained in a material [50].

3. Results and discussion

3.1. Result of the physical properties

3.1.1. Particle size distribution

3.1.1.1. Granulometry by sieving The results of the physical test of sewage sludge samples of the particle size analysis are shown in Fig. 1.

The granulometry of sewage sludge sample characterize by the of particle size distribution about 63–1000 µm. Around 52% fine sand ranging between 250 and 63 µm, 30% silt and 18% clay constitute the sewage sludge. This indicates that the sewage sludge may be classified as silt or clay [3,46]. Furthermore, it was similar to that of a fine agglomerate according to results obtained by Valls et al. [6].

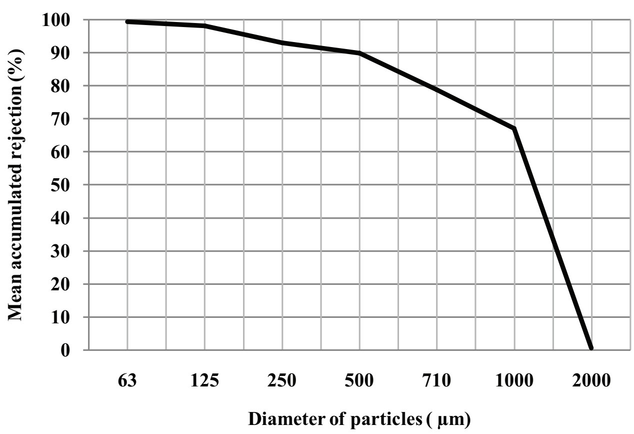

Fig. 1. Granulometric distribution of sewage sludge.

3.1.1.2. Result of the granulometry of sedimentation method The results of the granulometry sedimentation method are shown in Fig. 2.

Fig. 2 presents the fraction of fine grains less than 63 µm which were determined by the sedimentation method, shows more than 80% of fine fraction; this result demonstrates that the composition of sewage sludge is similar to the silt loam composition according to the textural triangle class by the United States Department of Agriculture.

From the result of the sieve analysis and sedimentation method, it can be concluded that the sewage sludge, principally composed of the silt loam and clay-sized particles, this outcome, is similar to the one obtained by Huang and Wang [31].

3.1.2. Density, specific gravity and porosity

Table 1 shows the results of the basic physical properties of sewage sludge such as pH, moisture content, total volatile,

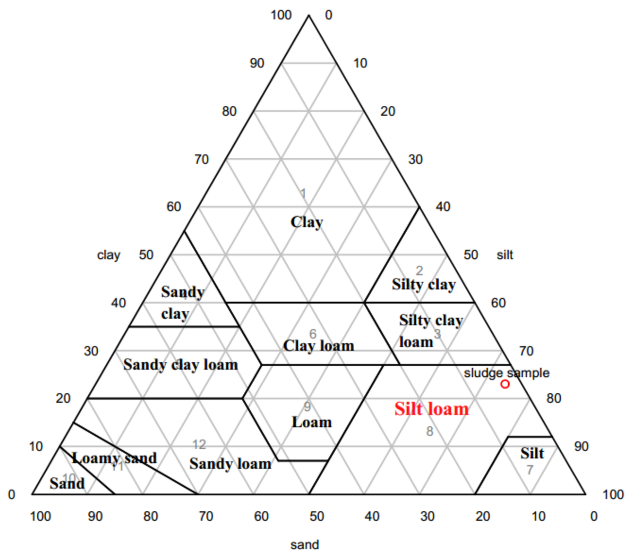

Fig. 2. Soil texture triangle, showing the sewage sludge textural class, by the United States Department of Agriculture (USDA).

Table 1
Physical properties of the sewage sludge

pH	7.07
Content of organic matter (%)	68
Densities	
Apparent	1.18
Real	2.32
Loss on ignition	6
Porosity (%)	39
Void ratio[a]	6.4
Moisture[b]	21
Volatile matter[c]	27.34

[a] $e = \frac{n}{(1-n)}$; with n as porosity.
[b] Heated at 105°C ± 5°C for 24 h.
[c] Combusted at 550°C ± 5°C for 2 h.

volatile matter solids, loss on ignition and ash content of the sludge.

The sewage sludge sample was nearly dry because the moisture content is 21%. As well as, results from pH showed that the average pH of the sewage sludge is near the neutrality at 7.07, the same result was found by the different authors [2,54]. The apparent density of the sewage sludge was found to be around 1.18 g/cm^3, which is the same order of magnitude as the densities of sand and gravel (around 1.6 and 1.7/cm^3), respectively [55,56]. On the other hand, which is much smaller than that of sand and gravel (2.60–2.75 and 2.86 g/cm^3), respectively [3,45,51]. The real density was determined in a range of 2.32 g/cm^3, which is the same order of magnitude as the densities of cement, sand and gravels (around 3.0; 2.6 and 2.7 g/cm^3), respectively, was proved by several studies [55,56]. The average porosities of the sewage sludge, as calculated from its apparent and real densities, were determined around 39% [29,31]. In addition, the volatile matter present in the sewage sludge is high as 68% indicates that the sewage sludge is organic in nature; this result approximates the result obtained from Diliunas et al. [5], as well as, the void ratio is 6.4%, meaning that the sewage sludge is very compact.

The results from weight loss showed that the total mass loss measured between 550°C to up 950°C, was very low about 6%. Was characteristic of the decomposition of volatile organic matter and combustion of complex nonvolatile organic matter [10]. Generally, the loss on ignition result in sewage sludge obtained from the literature search yielded an average value of 3.5% up to 13%, have been reported by [5,57–59].

Table 2
Chemical composition of the sewage sludge

	Elements	Content (mg/Kg)
Non-toxic elements	Fe	11,213.33
	Ca	62,120
	Mg	7,209.67
	Al	4,548.9
	K	1,407.67
	Na	1,292.3
	Mn	189.37
Toxic elements	Zn	1,386.67
	Cu	147.43
	Ba	399.4
	Pb	107.53
	Cr	27.82
	Cd	3.28
	Co	3.176

3.2. Chemical characteristics

The results of chemical analysis the toxic and non-toxic element concentrations are shown in Table 2.

The most abundant inorganic elements of sewage sludge are Ca, Fe, Mg, Na, Al and K, sewage sludge has high iron and calcium contents, due to the use of ferric salts and lime during wastewater treatment [10,45,48]. It should also be noted that many toxic components were present such as Zn, Cu, Cr, Pb, Ni and Cd, which is the result equivalent to that obtained from the studies by Lynn et al. [29] and Cyr et al. [60]. The presence of toxic elements were likely caused by materials brought by pluvial waters, cleaning of streets and erosion of the system of piping, due to domestic detergents or by the reagents added during wastewater processing [10,38,45].

3.3. Mineralogical compositions

Fig. 3 presents the XRD diagrams result of sewage sludge.

The mineralogical compositions of sewage sludge mainly are consisted of quartz (SiO_2), calcite ($CaCO_3$), hematite (Fe_2O_3), with the presence of aluminum oxide (Al_2O_3), same results which have also been found by

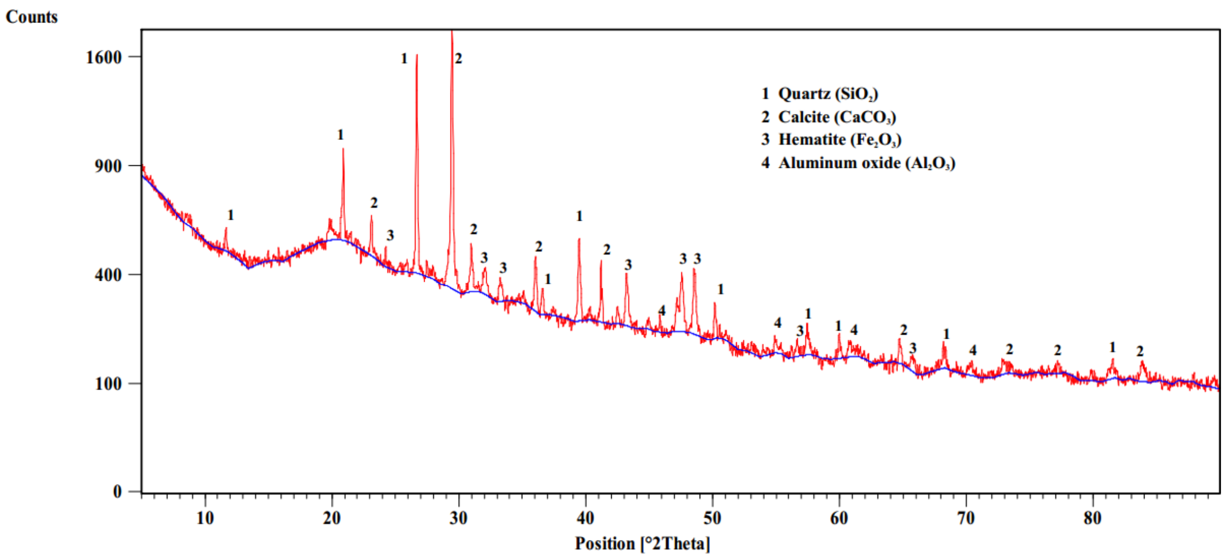

Fig. 3. X-ray diffraction pattern of sewage sludge.

Table 3
Geotechnical properties of the sewage sludge (determination of Atterberg limits by Casagrande's method)

Parameters		Mean (%)
Limits of Atterberg	Liquid limit (L_L)	191.12
	Plastic limit (P_L)	141.94
	Plasticity index (P_I)	49.18
	Liquidity index (L_I)[a]	–1.76
	Consistency index (C_I)[b]	3.22
Equivalent of sand		22
Water content (W) (%)		141.94

[a] $L_I = \frac{(W - P_L)}{(L_L - P_L)}$.

[b] $C_I = \frac{(L_L - W)}{(L_L - P_L)}$.

other authors, in particular by Naamane et al. (2014) [61], Cyr et al. [62], Naamane et al. (2013) [63], Ahmad et al. [64] and Aadraoui et al. [65]. The existence of these mineralogical compositions is very common in this type of waste of the wastewater [66,67]. The mineralogical fraction of the sewage sludge consisted is similar to those found in the silty fractions of clays, and they were, therefore, deemed suitable for manufacture direct in ceramic and brick [38,68,69], also the major mineralogical compounds of sewage sludge are compatible with some raw materials in cement production [70].

3.4. Geotechnical index properties

The results of the liquid limit (W_L) and plastic limit (W_p), index of plasticity (P_L), natural water content (W), as well as the equivalent of sand, are shown in Table 3.

The average value of the liquid limit and plastic limit for the sewage sludge were 191.12% and 141.94%, respectively. The very high values of liquid and plastic limits were consistent with the results obtained by Lo et al. [4], Diliunas et al. [5], O'Kelly [54], Zhan et al. [71], thus sewage sludge is very plastic, Therefore, the plasticity index is 49.18%. Based on those results on the classification of Casagrande, it can be concluded that the sewage sludge mostly a similar behavior within soils elastic silts and organic clay of very high plasticity [2,45]. According to the Unified Soil Classification System, it is believed that the high plasticity is related to the hydration of sewage sludge flocs and the coagulants used during wastewater treatment. Moreover, the equivalent of sand around to 22% was confirmed the sewage sludge sample is of plastic type, this result correlated with of the plastic soil, also, the liquidity index near at –1.76% was given that this sewage sludge is largely solid depending on NF P94-051, according to result of the consistency index about to 3.22%, this sewage sludge is solid.

4. Conclusion

From the above results of the physical properties, chemical analysis, mineralogical composition and the geotechnical properties, the application of sewage sludge as an additional component in construction material as lightweight aggregate production, Portland cement concrete, in brick making and in the manufacture of ceramic is feasible. Because the sewage sludge is compatible with the raw material used in the construction materials industry, this result confirmed the results by several authors in previous works. It is important to say that sewage sludge management strategies in construction materials are disposal strategies economic and sustainable, as well as the importance of sewage sludge as a valuable source of building matter. The following major conclusions may be drawn:

- The main chemical elements of sewage are Ti, Ba, Zn, Cr, Cu, Ni and Pb;
- The major mineralogical constituents of the sewage sludge are quartz, Al_2O_3 and Fe_2O_3 and calcite. Therefore, this composition can be used in the production of material such as cement, brick and ceramic;
- The geotechnical properties according to the classification of Casagrande showed that the sewage sludge consisted of high values of liquid limits and plastic limits, Hence, the sewage sludge is similar to an organic soil with a high plasticity;
- The physical properties results presented that the particle size distribution of sewage sample contain silt-size grains at a portion of 30% and clay-size grains with a portion of 45%, This indicates that the sewage sludge may be classified as silt or clay, and the density value of 2.60–2.75 is similar to that of the general soil.

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