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CHARACTERIZATION AND EVALUATION OF THE POTENTIAL USE OF SLUDGE FROM STP AND WTP IN PAVING

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LEDA C. LUCENA[1], JOSÉ F. T. JUCA[2], JORGE B. SOARES[3], SUELLY H. A. BARROSO[4], MANOEL G. PORTELA[5]

ABSTRACT: Water and sewage treatment plants (STP and WTP) generate as byproduct a significant amount of sludge with environment harmful elements. Sending to landfills or depositing on the ground or rivers are respectively expensive and dangerous alternatives. In this scenario, the use of this waste in paving processes is a promising alternative for disposal thereof. In this study, we focused on characterizing sludge and evaluating its use in paving, which showed satisfactory results for use in base and sub-base floors.

KEYWORDS: stabilization, chemical constituents, soil

CARACTERIZAÇÃO E AVALIAÇÃO DO POTENCIAL DE USO DE LODO DE ETE E ETA EM PAVIMENTAÇÃO

RESUMO: As Estações de Tratamento de Água (ETA) e de Esgoto (ETE) sanitários geram como subprodutos de sua operação uma quantidade significativa de lodo, que contém elementos danosos ao meio ambiente. As soluções usuais de enviá-lo para aterros ou depositá-lo em terreno ou nos rios, são soluções, respectivamente, caras e perigosas. Neste cenário, a política que envolve a aplicação desse resíduo na pavimentação, apresenta-se como alternativa promissora à destinação final de tais resíduos. O presente trabalho teve por objetivo caracterizar e avaliar o uso do lodo na pavimentação, tendo apresentado resultados satisfatórios quanto ao uso destes em base e sub-base de pavimentos.

PALAVRAS-CHAVE: estabilização, constituintes químicos, solo.

INTRODUCTION

In Brazil, the generation of solid waste reaches significant amounts, since there are few solutions for final disposal. The water and sewage treatment plants are largely responsible for environmental damages due to the amount and toxicity of the waste produced in sludge form. Unused solid materials form such residues during wastewater treatment process.

The sanitation in this country is still precarious. According to estimates by the IBGE - Brazilian Institute of Geography and Statistics (IBGE, 2010), only 30% of households have water supply and sewage services. Hence, in the coming years, the amount of sludge produced every day tends to increase due to the implementation of new service stations. There are no accurate data on total domestic production of sludge, but it is estimated that it exceeds three hundred thousand tons per year for each type of sludge.

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[1] Engº Civil, Prof. Doutor, Departamento de Engenharia Civil, Universidade Federal de Campina Grande/Campina Grande – PB, Fone: (83) 2101-1158, ledach@uol.com.br

[2] Engº Civil, Prof. Doutor, Departamento de Engenharia Civil, Universidade Federal de Pernambuco/Recife – PE, Fone: (81) 2126.8222, jucah@ufpe.br

[3] Engº Civil, Prof. Doutor, Departamento de Engenharia Civil, Universidade Federal do Ceará/ Fortaleza- CE, Fone: (85) 3366-9488 (R. 243), jsoares@det.ufc.br

[4] Engº Civil, Prof. Doutor, Departamento de Engenharia Civil, Universidade Federal do Ceará/ Fortaleza- CE, Fone: (85) 3366-9488 (R. 209), suelly@det.ufc.br

[5] Engº Civil, Mestrando, Programa de Pós-Graduação em Engenharia de Transporte, Universidade Federal do Ceará/ Fortaleza- CE, gualbertoportela@hotmail.com

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For a water or sewage treatment system be regarded as effective, it is required that final disposal of sludge is performed properly, since it has environment harmful elements in its composition, such as heavy metals, pathogenic microorganisms and organic pollutants. In case of improper disposal, these materials may contaminate soil and groundwater, bringing damages to the environment and population.

Sludge waste management in Water Treatment Plants (WTP) and Sewage Treatment Plants (STP) is complex and costly, accounting for about 20-60% of the operating costs of these stations (ANDREOLLI, 2001).

Among the main waste destinations in use nowadays, we may cite storage in large tanks (method that requires large areas), disposal into landfills (process considered uneconomic) and launching into waterways and the ground (environmentally incorrect). Because of the large volume of sludge produced, residue destination planning should consist of a program to guide final disposal taking into account technical, environmental and economic points of view. Thus, alternatives for disposal and application of sludge as agricultural inputs should be investigated to mitigate these issues. Therefore, reducing the volume to be disposed in landfills and applying concepts of recycling and waste minimization, it has as a major benefit, preservation of the environment (JANUÁRIO & FERREIRA FILHO, 2007).

According to CORNWELL et al. (2000), in 1999, the North American WTPs disposed sludge into landfills (20%), soil (25%), exclusive landfills (13%), public sewage system (24%), water bodies (11%) and other applications (7%) such as in degraded areas, agricultural land, industrial processes (cement and concrete) and composting. In the UK, in 1998, 52% of sludge from WTPs were disposed in landfills, 6% in exclusive landfills and 29% into public sewage system, with a small portion being launched into watercourses bodies and lakes (SIMPSON et al., 2002).

The alternatives that have been used worldwide to discard sludge from sewage treatment are burning, landfill, land farming, heavy clay ceramic industry and agricultural recycling. These solutions have as limiting factors groundwater and soil contamination (organic fertilizer and land farming), costs (landfill and incineration) and loss of mechanical strength (clay pottery and fine aggregate). In this scenario of great immediacy, new studies on sludge management are being developed; among them, there is its use as a power source, which despite being promising has not demonstrated viability yet.

Regarding the waste treatment and disposal, FONSECA (2003) points out that it is essential to reuse them instead of simply storing it temporarily due to economic, environmental and area availability causes. The most acceptable technologies are those that provide reincorporation of wastes into nature, with no harmful properties to the local flora and fauna.

In a WTP, the disposal of sludge consists in its application in heavy clay ceramic industry or as backfilling ditches. Even though promising, there are no studies indicating any economic or environmental viability of these uses, since these byproducts have resistance loss compared to those already marketed.

Adding industrial residues to the soil to make them less toxic is called stabilization of granules. It is regarded as a pre-treatment, in which hazardous constituents of wastes are processed and kept in less soluble forms, being confined in capsules, particles or blocks. According to GONDIM (2008), stabilization promotes higher soil resistance and bulk density aside from lower permeability. In this process, contaminants are trapped in a solid matrix, what decreases contaminant surface area exposed to the environment and/ or isolation of these from influences from the outside medium by particles within the soil.

The paving, for its extension and large volumes of mobilized soil, constitutes in an alternative of waste reuse, particularly those with certain potential for stabilization. Industrial waste or byproducts available near the areas where they are produced generally result in cost-effective solutions. Soil stabilization and industrial waste reuse have enabled useful applications for construction of road bases and sub-bases (CORDEIRO, 2007).

The stabilization / solidification has been studied by several authors (AGOSTINI, 2002; SHY & SPENSE, 2004; BRITO, 2007; CORDEIRO, 2007; SANTOS, 2010) in order to turn a dangerous or not inert material into an inert one.

In this study, we sought to verify the action of stabilization/solidification of sludge from WTP and STP, as well as their characterization, enabling their use in pavement bases.

MATERIAL AND METHODS

The effluent was collected from discharge decanters and filters from Botafogo Water Treatment Plant in Igarassu-PE, Brazil. Collection was performed in February 2011, is collecting around 90 kg sludge that was packed in plastic drums of 30 kg. This WTP has a nominal capacity of 2,200 L s^{-1} and flow produced of 1,600 L s^{-1}, with the following treatment units: one mixing box, three mechanical flocculators, three decanters, four rapid gravity filters and five 25-L reservoirs.

In this station, the largest sludge production occurs between May and June, which is a rainy period in Recife's Metropolitan Area; therefore, surface materials are massively carried to water bodies. Due to this fact, water turbidity and color changes, resulting in increasing levels of aluminum sulphate and sludge generation.

The STP residue used in this research was taken out of a drying bed from Cabanga STP, in Recife – PE, Brazil, after primary treatment. Sampling occurred in February 2011, collecting about 90 kg sludge and packaging in 30 kg plastic barrels.

This plant has a nominal capacity of about 80,000-m^3 sewage per day. A primary treatment is carried out on domestic sewage to remove settleable solids by decantation and part of suspended organic matter. Subsequently, sludge is treated under anaerobic digesters, followed by dehydration through sun exposure in drying beds for 15 days. Sludge production and composition vary with season and daytime. Rainy seasons tend to produce higher amounts due to water infiltration, as well as STPs near industrial parks, where treated effluent are deposited. Moreover, earlier in the day and night, productions are higher compared to other times.

Soil samples used in this study were collected in the Hélio Quarry, which is located in Mata Redonda district, in the city of Alhambra, on BR 101, km 106. Surface horizon consists of granular soil - sandy bould gravel - with a depth of around two meters. We chose a granular soil (A-2-4) given the nature of the organic residues; thus, avoiding associating certain residue behaviors with clay particles' ones.

Testing of physical and chemical characterization of materials were made and mechanical testing of soil and residue mixtures, to evaluate the potential use of these residues in pavement bases and sub-bases. For that, we followed methods proposed by the DNIT (Brazilian Department of Infrastructure and Transport), Brazilian Standards (NBR), American Society for Testing and Materials (ASTM), and the American Association of State Highway and Transportation Officials (AASHTO).

Physical properties

Assays to characterize the distribution of particle sizes by sieving and sedimentation followed NBR 7181 (ABNT, 1984). Residue density was measured in accordance with the NBR 6508 (ABNT, 1984). Yet limits of liquidity and plasticity were determined by the rules NBR 6459/84 and NBR 7180/84 of the ABNT, respectively. Sludge residue physico-chemical characterization was performed according to Standard Methods for the Examination of water and Wastewater (APHA, 1998).

Chemical analysis

Residues underwent chemical analysis by X-ray fluorescence using an EDX-720 spectrometer (Shimadzu, Kyoto, Japan).

Differential Thermal Analysis and thermogravimetry

Differential thermal analysis (DTA) and thermogravimetry (TG) were performed with the aid of a DTG-60 device in nitrogen atmosphere with alumina crucible, 1,010 mL min^{-1} flow, and 10 °C min^{-1} heating rate, with an initial mass of 10.1 mg and maximum temperature of 1,000 °C.

Residue classification

Classification of sludge waste was carried out according to the procedures proposed by NBR 10004 standard (ABNT, 2004).

Mechanical testing

Compression tests were performed through tests of California bearing ratio (CBR) and Resilience Modulus (RM) to assess potential use of the residue in base and sub-base paving. Soil stabilization was checked by mixing sludge and soil classified as A-2-4 (silty sand) by the TRB soil classification (Transportation Research Board). We added 5%, 10%, 15% and 20% relative to the total weight. Compaction tests were carried out according to Testing Method (TM) nº162/94 standardized by the DNIT within Intermediate Proctor Power. CBR trial was performed according to the TM nº049/94 and the RM test by TM nº134/2010, both from the DNIT. Soils were subjected to cyclic triaxial testing to determine RM according to T307-99 standard procedure (AASHTO, 1999).

RESULTS AND DISCUSSION

Physical properties

Figure 1 shows the particle-size distribution curves for the soil and both sludge residues (NBR 7181; ABNT, 1984). Through these curves, we could see that texture of WTP sludge and soil are similar, indicating great physical compatibility when mixed to each other whether compared to mixtures with STP sludge.

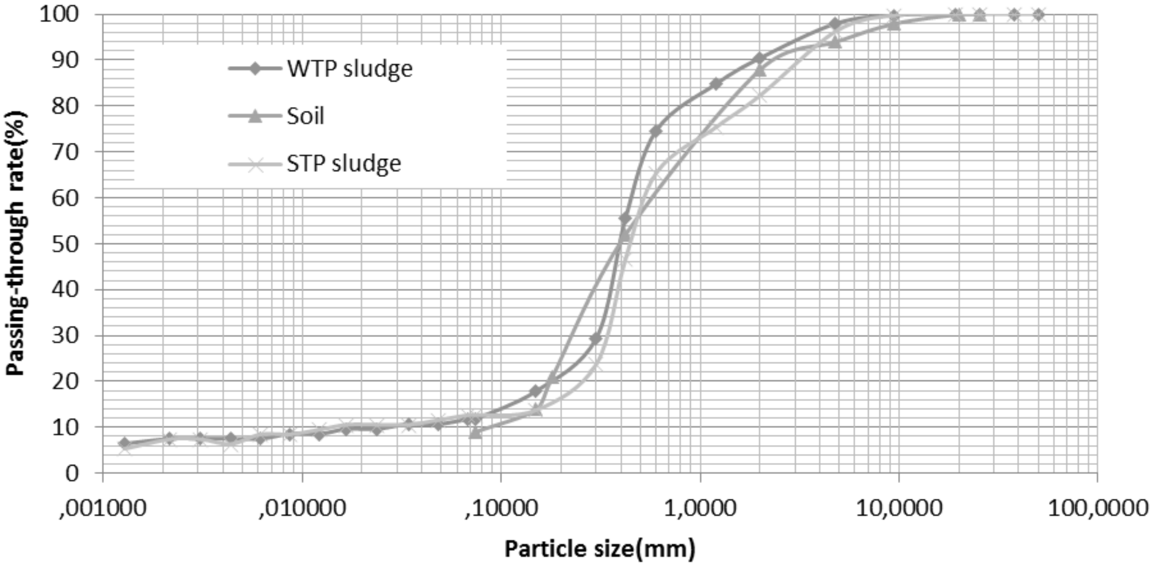


FIGURE 1. Particle-size distribution curves.

Table 1 shows the results of soil and sludge residue consistency indexes through liquidity limit (LL), plasticity limit (PL), humidity (h), density, void ratio (e) and porosity (n).

TABLE 1. Physical indexes of materials.

	LL	PL	Humidity	Density (g cm^{-3})
STP sludge	90%	77,9%	22.6%	2.11
WTP sludge	NL	NP	53.0%	2.40
Soil	23%	17%	16.0%	2.60

Based on particle-size distribution and consistency indexes, soil was classified as A-2-4 (silty sand), according to the rating system of TRB (Transportation Research Board) and as SW-SC (well-graded sand with clay) by the Unified System of Soil Classification (USSC). In compliance with the TRB rating, an A-2-4 soil type is regarded as good to excellent for paving uses.

The high LL and PL values in STP sludge samples may be derived from both water presence and organic matter burning. The aluminum sulphate added over treatment has waterproofed soil completely, reducing plasticity, what could also explain non-plasticity of WTP residues. By adding water to the residue, evaporation and repelling of water particles occur.

Chemical properties

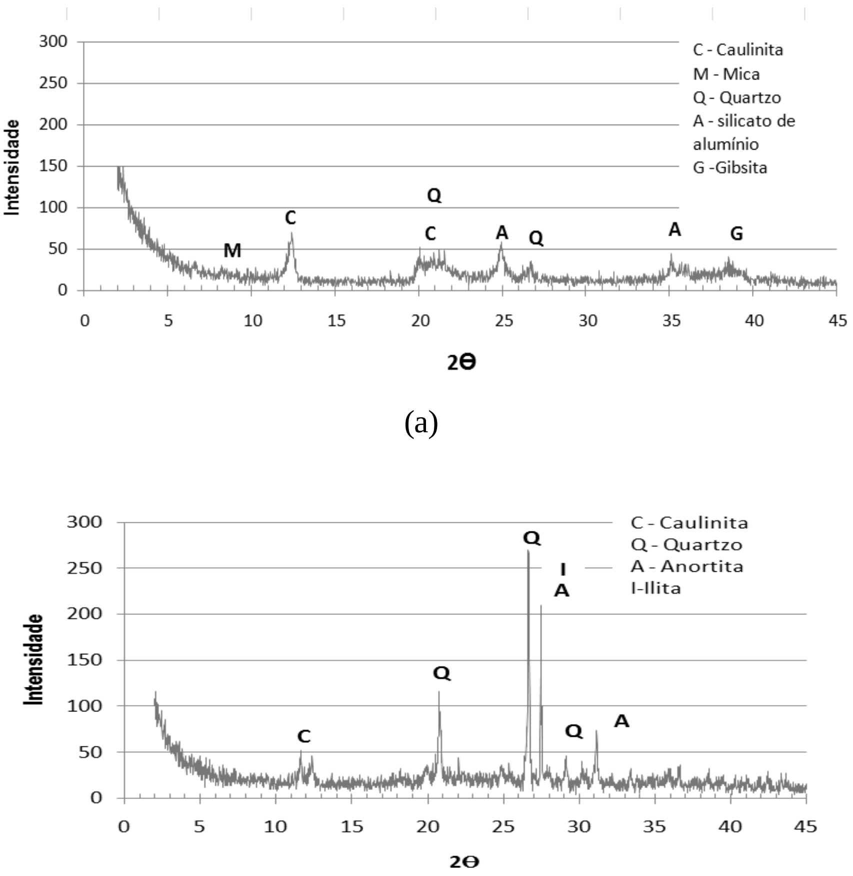
Table 2 shows the chemical composition of sludge residue from STP and WTP in their natural state. By analyzing these values, we can infer that WTP residues can be classified as alumina silicate of high silica content and significant amounts of Al_2O_3 and Fe_2O_3, with a red loss of 10.43%. According to RICHTER (2001), sludge consisting of aluminum sulphate is poorly biodegradable. This author's studies indicated that Al_2O_3 ranges from 15 to 40% of the sludge sample. The findings of HOPPEN et al. (2006) and PORTELLA (2003) showed Al2O3 contents 50% smaller than the ones found in this research. Thus, we can assert that the amount of aluminum-sulfate based coagulant added in the water treatment we assessed was higher than in other WTPs that have already surveyed in this country.

TABLE 2. Chemical composition of the STP and WTP sludge residues in natural state.

Chemical compound	STP sludge		WTP sludge	
	Without burning loss	With burning loss	Without burning loss	With burning loss
SiO_2	34.11	28.54	33.11	29.66
Al_2O_3	15.82	13.24	37.28	33.39
Fe_2O_3	13.31	11.13	26.04	23.33
SO_3	12.18	10.19	-	-
CaO	11.52	9.64	-	-
P_2O_5	6.82	5.70	-	-
Other oxides	6.238	5.219	3.57	3.20

Likewise the WTP residue, STP residue can be classified as alumina-silicate. The sample showed high silica content and significant amounts of Al_2O_3 and Fe_2O_3, with red loss of 16.33% (mostly due to a high organic load). The presence of other compounds can be explained by the presence of impurities because of the residue nature.

In Figure 2 are shown respectively the X-ray diffraction spectra of water and sewage sludge residues. Graphs showed a few well-defined peaks owning to the large amount of organic matter within the residues.



(a)

(b)

FIGURE 2. X-ray diffraction spectra of sludge residues of (a) WTP (b) STP.

Figure 2 shows the presence of kaolinite through the emergence of plane reflection at (001) 2θ ~ 13 and 18º. It is still possible to notice the presence of quartz at 2θ ~ 21 and 27º. The other reflections indicating the presence of mica at 2θ ~ 11º, aluminum silicate (Al_2SiO_3 and $Al_6Si_2O_{13}$) at 2θ ~ 25 e 35º, and gibbsite at 2θ ~ 38º. The identified minerals are compatible with standards of the International Center database for Diffraction Data (ICDD). WOLFF (2009) found similar results when studying WTP sludge from a plant in Cenibra- MG, reporting the prevalence of kaolinite [$Al_2Si_2O_5(OH)_4$] and quartz (SiO_2). The same author also reported the occurrence of other minerals such as hematite (Fe_2O_3), gibbsite [$Al(OH)_3$], goethite [$FeO(OH)$], muscovite [$KAl_3Si_3O_{10}(OH)_2$] and rutile (TiO_2) in sludge from decanters. HOPPEN et al. (2006) have also obtained a compound rich in aluminum, iron and silica residue from a WTP in the state of Paraná. The presence of Al and Si comes from using aluminum sulphate coagulants during water treatment. Moreover, the composition presented suspended materials such as sand and clayey material.

Figure 3-b shows the presence of kaolinite through the emergence of plane reflection at (001) 2θ ~ 12^o. It is still possible to notice the presence of quartz at 2θ ~ 21, 27 and 29º. The other reflections indicating the presence of anorthite [$Ca(Al_2Si_2O_8$] and illite. The identified minerals are compatible with standards of the International Center database for Diffraction Data (ICDD). ARAUJO (2008) found the same compounds aside from hematite.

Tables 3 and 4 display the chemical constituents found in leachates and extract solutions analyzed by atomic absorption spectroscopy. For both WTP and STP wastes, all constituents had concentrations below the limits set by Annex F from NBR nº 10004/2004 standard (ABNT, 2004) and by the Code Federal Register (CFR, 2003) for leachate analysis. For solubilized extracts, Table 4 shows concentrations below the limits set out in Annex G of NBR 10004/2004 standard, except for cadmium, chromium, lead, iron, manganese and nickel for STP residue, and cadmium, lead, iron, manganese, nickel and aluminum for WTP one. According to the results, both of them were classified as non-hazardous wastes at "Class II A" (non-inert). STP sludge concentration was higher than WTP one for Pb, Ni and Fe; however, the latter has Mn concentration far higher than the first had.

Nevertheless, the amounts obtained for nickel (STP residue) and aluminum (WTP residue) are above the recommended by the Ministry of Health (MH) and the Society of Environmental Sanitation Technology (CETESB). Hence, they are classified as hazardous by such organizations.

TABLE 3. Chemical composition of leachates from the assessed sludge residues.

Sample identification	Pb	Cd	Cr	As	Cu	Fe	Mg	Mn	Ni	Zn	Al
	mg L^{-1}										
STP residue	0.33	0.05	0.10	0.010	<0.10	0.12	33.20	0.32	0.21	0.41	-
WTP residue	0.40	0.05	0.10	0.010	<0.10	0.28	5.0	0.41	<0.10	0.16	1.64
Standard limit	1.000^1	0.500^1	5.000^1	1.00^1	2.0^3	0.3^3	-	0.1^2	0.02^3	5^3	0.82^2

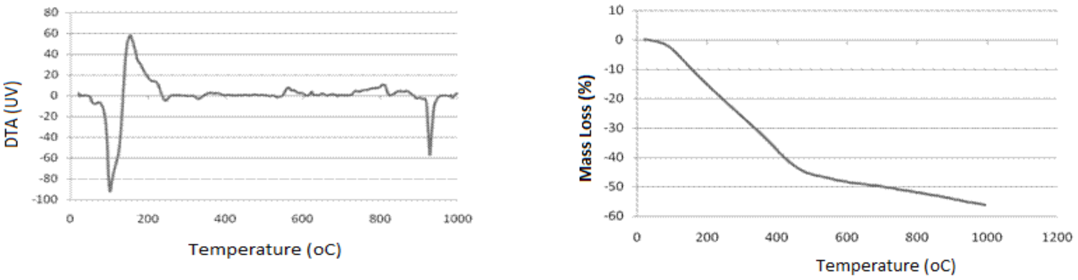
TABLE 4. Maximum Allowable Values in the Extract from the Solubilization Test.

Sample identification	As	Cd	Cr	Pb	Cu	Fe	Mn	Ni	Zn	Al	Mg
	mg L^{-1}										
STP residue	0.01	<0.05	0.1	0.39	0.10	8.52	0.77	0.35	0.48	-	43.33
WTP residue	-	0.06	0.1	0.11	0.10	0.82	3.37	0.1	0.16	1.00	2.40
Standard limit	0.01^1	0.005^1	0.05^1	0.01^1	2.0^3	0.3^3	0.1^2	0.02^3	5.0^3	0.2^2	-

Note: ^{1} Parameters and ceilings in the leachates and extract solutions as recommended by the ABNT NBR 10005 (ABNT, 2004a) and ABNT NBR 10006 (2004b), as well as by the CFR (2003). ^{2} Values based on the Ministry of Health (MH) - Executive Order N° 518 issued in 2004 (MS, 2004). ^{3} Values suggested by the Organization of Environmental Sanitation Technology (CETESB) - Executive Order N° 195 issued in 2005 (CETESB,2005)

Differential Thermal Analysis and thermogravimetry

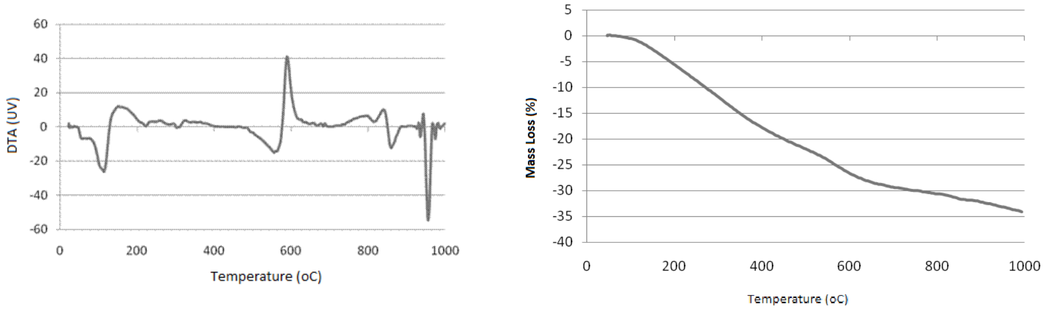
The Figures 3 and 4 show the results of differential thermal analysis and thermogravimetry for the sludge from STP and WTP, respectively.



(a) (b)

FIGURE 3. (a) Differential thermal analysis (DTA) of residues from STP; (b) Thermogravimetric analysis (TG) of the residue from STP.

The DTA profile, shown in Figure 3a, shows as intense endothermic peak between 100 and 120 ºC, which may be attributed to free water. Between 120 ºC and 200 ºC, there is an exothermic peak related to the matter burning process. Yet in Figure3b, the TG profile shows total weight loss of 60% due to the loss of free water, hydroxyl and organic matter.



(a) (b)

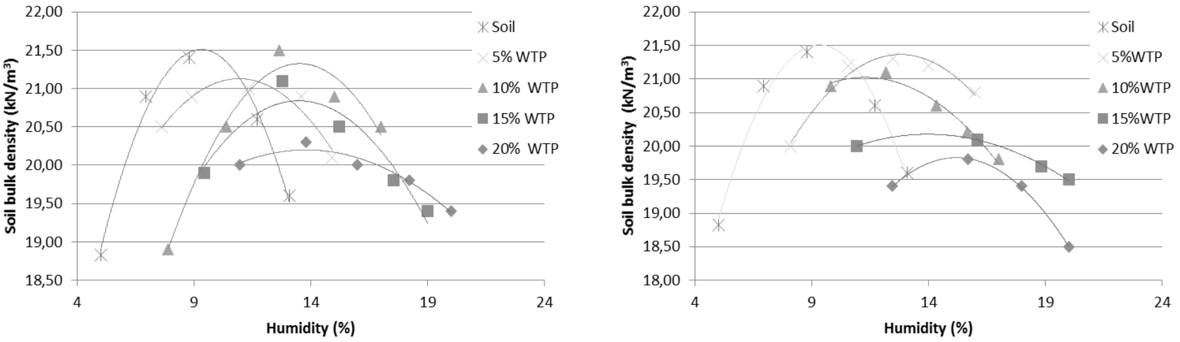
FIGURE 4. (a) Differential thermal analysis of residue from WTP and (b) Thermogravimetric analysis of residue from WTP.

From the analysis of the DTA profile, in Figure 4a, we can be inferred that between 90 ºC and 120 ºC, free water loss generates an endothermic peak; within 140 °C and 180 ° C, organic matter burning rises an exothermic peak; between 500 °C and 570 °C, the loss of structural water from kaolinite (Si2Al2O5 (OH)) starts an endothermic peak; between 570 ºC and 610 ºC, the combustion of organic matter promotes an exothermic peak; and from 940 ºC to 1,000 °C, the decomposition of carbonates fosters endothermic peak.

The TG profile, in Figure 4b, evinced mass loss of about 35% from adsorbed water, organic matter and hydroxyl losses. These values are below the references in the literature by HOPPEN et al. (2006), who found a rate of 87%. The mass loss found by the thermal characterization is above chemical analysis data, which showed burning loss of only 10%.

Mechanical testing

Compaction tests were performed at intermediate compression pressure (for soil – WTP sludge mix) and under interchanged pressures (for soil –STP sludge mix). The use of interchanged pressure in the mix with STP sludge may be justified because at an intermediate pressure, the mixture does not reach the minimum CBR required by the DNIT. Figures 5a and 5b shows the results obtained in carrying out the compaction assay, as in Figure 6 are the results of the CBR testing.



(a) (b)

FIGURE 5. Compaction curve for mixture of soil and residue from (a) WTP (b) and STP.

By graphical analysis, we found that as the amount of both residues is increased; soil bulk density (g/ cm3) decreases, increasing optimal humidity (%). This decrease was expected due to the nature of the samples, which have organic matter in their composition.

It is noteworthy the similarity of the curves, a most likely explanation for this would be that both residues have similar reactions with soil, based on their similar rate of SiO2. As the soil under study is an A-2-4 type, its behavior is related to particle size and compactness. We can hypothesize that both residues fill the voids similarly and even with same chemical compositions, the show resembling chemical and mineralogical interactions.

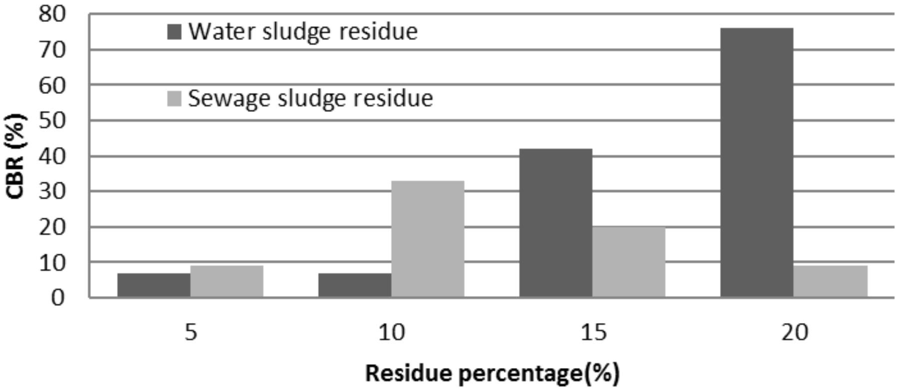


FIGURE 6. CBR testing results.

The standard DNIT ES nº 098/2007 establishes CBR values that enable soil use at a granular basis, according to the traffic request (N number) that pavement must withstand during its service life. It is noted that reference values are part of the service specifications for being used in roads with heavy traffic, i.e. when N > 5x106 (more than 5 million operations of a 8.2-tf standard axis). For intermediate base traffic, 106 < N <5x106, CBR should be greater than 60%. For N> 5x106, CBR minimum value is 80%.

Therefore, to use as pavement base, all values are lower than those recommended for heavy traffic roads are. Nevertheless, soil with 20% WTP residue can be applied in floor bases of intermediate traffic. As WTP sludge had relevant results, we performed another test incorporating 25% WTP sludge to the soil. However, CBR was lower than that obtained with the addition of 20%. This behavior indicates that most elevated concentrations of aluminum sulphate can be harmful to stabilization. The mixture soil and STP residue could be used in light traffic road bases.

Upon resilient modulus testing (RM), only 10% STP and 20% WTP withstood conditioning phase, in which plastic deformations are eliminated. Samples were deformed so that the LVDT's were not able to perform displacement measurements, interrupting testing continuity. This fact was attributed to the low resistance of mixtures of soil and residue and pure soil, causing specimen collapse before the test begins.

In order to select the RM model, classical model applicability was evaluated. The model must faithfully describe the resilient behavior of the material, assessing its deformation, accurately. The most common models relate the RM to deviation stress (σ_d), confining stress (σ_3) or stress invariants (θ), as shown in equations 1, 2 and 3.

$$RM = k_1 .\ \sigma_d^{k2} \tag{1}$$

$$RM = k_1 .\ \sigma_3^{k2} \tag{2}$$

$$RM = k_1 .\ \theta^{k2} \tag{3}$$

The modeling parameters (K1 and K2 values) and the correlation coefficients (R²) of the classical models for soil mixtures with WTP and STP sludge residues are shown in Table 5.

TABLE 5. Overview of the k_1 and k_2 values obtained by linear regression of the three models.

Sample	$RM=K_1*\sigma_3^{K_2}$			$RM=K_1*\sigma_d^{K_2}$			$RM=K_1*\theta^{K_2}$		
	K1	K2	R^2	K1	K2	R^2	K1	K2	R^2
WTP sample	946	0.268	0.36	1118	0.301	0.58	599	0.308	0.28
STP sample	340	0.134	0.90	180	-0.128	0.60	270	0.142	0.13

Analyzing the parameters of the different models, we found that the correlation coefficients for the models according to the confining stress and stress invariant were not representative for soil mixed with WTP sludge, since there is no single behavior pattern. Regarding the mixture with STP sludge, it was the best described by the model as a function of confining stress.

Since the previous models did not represent precisely resilient behavior of the studied samples, we evaluated the use of a model compound to the mixtures, represented by equation (4). The composite model relates the RM values as a function of confinement and deviation stresses, being represented by three-dimensional graph. The parameters of the compound models referring to the mixtures are shown in Table 6.

$$RM = k_1 .\ \sigma_3^{k2} .\ \sigma_d^{k3} \qquad (4)$$

TABLE 6. Overview of the k_1 and k_2 values obtained by the compound model.

Sample	$RM=K_1*\sigma_3^{K_2}*\sigma_d^{K_3}$			
	K_1	K_2	K_3	R^2
WTP sludge	1650	0.662	-0.222	0.60
STP sludge	392	0.624	-0.250	0.88

Another way to analyze the compound model is through surface graphics of RM values for a better visual assessment of variations in resilient parameters and mixtures thereof. The surfaces set by equations of the compound model for mixtures of soil with both sludge residues are shown in Figure 7. A written python program with the aid of a matplotlib (math library) plotted graph.

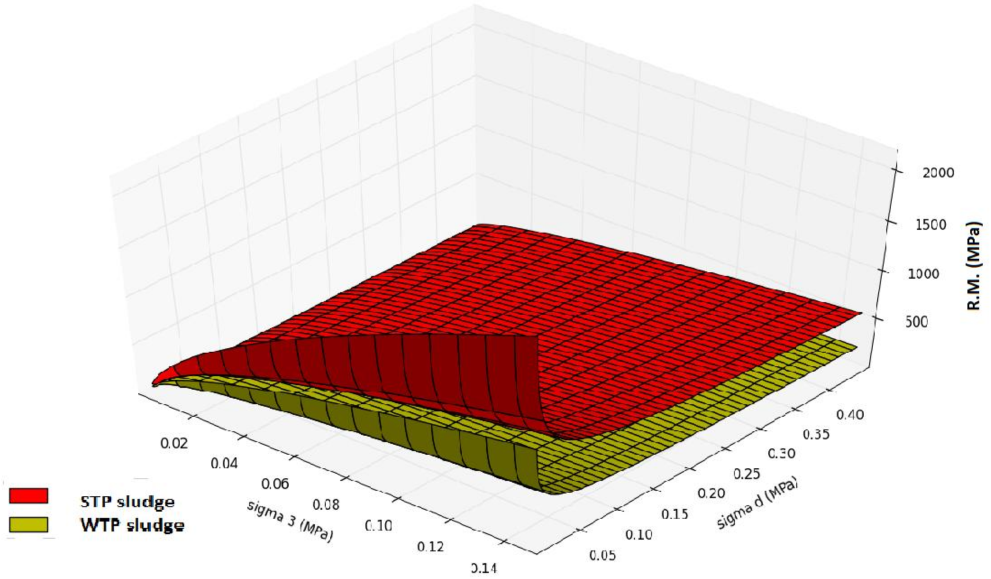


FIGURE 7. Compound model for the resilient modulus (RM) of soil mixed with WTP and STP sludge residues.

Figure 7 plots that the RM of both mixtures are susceptible to large influence of confining stress and little deviation one (except for lower deviation stress values). The average results of RM were 450 MPa for the soil with WTP, and 250 MPa with STP. These results are consistent with the findings by SOUZA JÚNIOR (2005), GONDIM (2008), and SANTOS (2009) for soils from Northeastern Brazil, as well as found in MEDRADO (2009) for those from Northern Minas Gerais state. In addition, our results also support RM values indicated by AASHTO GUIDE (2002) based on material's classification considered at an optimal moisture content for use in flooring bases (206 MPa).

The dispersion of the results may have been affected by the granular nature of the soil, which requires further care with samples during the process to avoid damages, mainly with regard to laying of the specimens into the triaxial chamber.

CONCLUSIONS

The sludge residue derived from WTPs has a great amount of quartz, kaolinite and little of hematite. These minerals are typical of material that has undergone treatment in WTPs. Chemically, the residue showed larger amounts than those found in the literature of both aluminum and iron oxides, indicating that the use of coagulants exceeded the values of other WTPs, due to impurities present in these waters.

The atomic absorption spectroscopy corroborated results found from chemical analysis since highlighted certain elements such as manganese, iron and aluminum in quantities above those permitted by the NBR No. 10004/2004 of the ABNT standard. Even though the leachate analysis has classified the residue as non-hazardous for being non-inert, care is essential with its storage and disposal, to avoid contamination of water resources and even the soil with heavy metals.

With respect to the mechanical testing, the rate of 20% WTP residue showed the best results for both CBR test and for the resilience module; this fact indicates that particle size stability allows residue use in sub-base and base of pavements of intermediate traffic.

The STP sludge residue has high organic matter content, which was confirmed by chemical analysis that found different oxides within the sample. Spectroscopy indicated the presence of heavy metals in amounts greater than the maximum limit set by standards. This result occurs because many industries discharge effluents into public sewer irregularly and unmanageably, increasing the concentration of these elements. The addition of 10% STP residue showed the best performance among the studied concentrations, being able for use in base and sub-base of low-traffic pavements.

REFERENCES

AASHTO – Mechanistic-empirical pavement design guide. American Association of Highways and Transportation Officials. Washington, D.C., 2002.

American Association of State Highway and Transportation Officials. “Determining the Resilient Modulus of Soils and Aggregate Materials.” Specification Number T307-99. Standard Specifications for Transportation Materials and Methods of Sampling and Testing: Part 2B Tests.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 10004: Resíduos Sólidos: classificação. Rio de Janeiro, 2004.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 7181: Solo: análise granulométrica. Rio de Janeiro, 1984.

ABNT - ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 10005: *Lixiviação de resíduos: procedimento*. Rio de Janeiro, 2004a.

ABNT - ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. NBR 10006: *Solubilização de resíduos: procedimento.* Rio de Janeiro, 2004b.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS. **NBR 6508**: Grãos de solos que passam na peneira de 4,8mm – Determinação da Massa Específica. Rio de Janeiro, 1984.

AGOSTINI, R.M. *Solidificação/Estabilização de resíduos sólidos oleosos de atividades de exploração e produção de óleo e gás em matrizes de cimento*. 2002. 170f. Dissertação (Mestrado em Engenharia Ambiental) - Universidade Federal do Espírito Santo, Vitória, 2002.

ANDREOLI, C.;. *Resíduos sólidos do saneamento: processamento, reciclagem e disposição*. Rio de Janeiro. 282p. Editora RiMa, ABES, 2001.

APHA - AMERICAN PUBLIC HEALTH ASSOCIATION. *Standard methods for the examination of water and wastewater.* 20th ed. Washington: American Public Health Association, 1998, 1220p.

ARAUJO, F.S.D. *Influência do lodo de STP na massa para fabricação de cerâmica vermelha*. 2008. 91f. Dissertação (Mestrado em Ciência e Engenharia de Materiais) - Universidade Federal do Rio Grande do Norte, Natal, 2008.

BRITO, A.L.F. *Protocolo de avaliação de materiais resultantes da estabilização por solidificação de resíduos*. 2007. 180f. Tese (Doutorado em Engenharia Ambiental) - Universidade Federal de Santa Catarina, Florianópolis, 2007.

CFR - CODE OF FEDERAL REGISTER. *Identification and listing of hazardous waste: Proposed Rule*. January, 14, 40 CFR Part 268, 2003. (Appendix I).

CORDEIRO, J.F.S. *Estabilização química e solidificação do resíduo oleoso gerado nas atividades de E & P de petróleo, com solo para o uso em camadas de bases e/ou sub-bases de pavimentos rodoviários*. 2007. 130f. Dissertação (Mestrado em Engenharia Civil e ambiental) – Universidade Federal de Campina Grande, Campina Grande. 2007.

CORNWELL, D.A.; MUTTER, R.N.; VANDERMEYDEN, C. *Commercial application and marketing of water plant residuals*. Denver: AWWA, 2000.

FONSECA, M.H.G.P. *Estudo do resíduo oleoso das atividades de exploração e produção de petróleo na manutenção de estradas de terra* – Enfoque ambiental. 2003. 181 f. Dissertação (Mestrado em Engenharia Ambiental) – Universidade Federal do Espírito Santo, Vitória, 2003.

GONDIM, L.M. *Estudo experimental de misturas solo-emulsão aplicado às rodovias do Agropólo do baixo Jaguaribe/Estado do Ceará*. 2008. 213 f. Dissertação (Mestrado em Engenharia de Transportes)) - Universidade Federal do Ceará, Fortaleza, 2008.

HOPPEN, C.; PORTELLA, K.F.; ANDREÓLI, C.V.; JOUKOSKI, A.; TRINDADE, E.M. Uso de lodo de estação de tratamento de água centrifugado em matriz de concreto de cimento portland para reduzir o impacto ambiental. *Química Nova*, São Paulo, v.29, n.1, p.79-84, 2006.

IBGE - INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. *Síntese de indicadores sociais- Uma análise das condições de vida da população brasileira*. Rio de Janeiro, 2010.

JANUÁRIO, G.F.; FERREIRA FILHO, S.S. Planejamento e aspectos ambientais envolvidos na disposição final de lodos das estações de tratamento de água da Região Metropolitana de São Paulo. *Revista Engenharia Sanitária e Ambiental*, Rio de Janeiro, v.12, n.2, p.117-126, abr./jun. 2007.

MEDRADO, A.W. *Caracterização geotécnica de solo da região norte de Minas Gerais para aplicação em obras rodoviárias*. 2009. 124. Dissertação (Programa de Pós-Graduação em Engenharia Geotécnica) - Universidade Federal de Ouro Preto, Ouro preto, 2009.

PORTELLA, K.F.; ANDREOLI, C.V.; HOPPEN, C.; SALES, A. BARON, O. *Caraterização físico-química do lodo centrifugado da estação de tratamento de água Passaúna* – Curitiba. In: CONGRESSO BRASILEIRO DE ENGENHARIA SANITÁRIA AMBIENTAL, 22., 2003, Joinville. Anais…

RICHTER, C.A. *Tratamento de lodos de estações de tratamento de água*. São Paulo: Edgard Blücher, 2001. 112p.

SANTOS, W.J. *Avaliação do uso de emulsão asfáltica na estabilização química de três solos de Sergipe*. 2009. 140 f. Dissertação (Mestrado em Engenharia Civil e Ambiental) - Universidade Federal de Campina Grande, Campina Grande, 2009.

SANTOS, C.B. *Utilização de resíduos oleosos provenientes das atividades de petróleo para uso em pavimentos rodoviários*. 139f. Dissertação de Mestrado em Engenharia Civil e Ambiental. Universidade Federal de Campina Grande, Campina Grande, 2010.

SHI, C.; SPENCE, R. Designing of cement-based formula for solidification/stabilization of hazardous, radioactive, and mixed wastes. *Critical Reviews in Environmental Science and Technology*, Boca Raton, v.34, n.4, p.391-417, 2004.

SOUZA JÚNIOR, J. D. *O efeito da energia de compactação em propriedades dos solos utilizados na pavimentação do Estado do Ceará*. 2005. 211f. Dissertação (Mestrado em Engenharia de transportes) - Universidade Federal do Ceará, Fortaleza, 2005.

WOLFF, E.; SCHWABE, W.; LANDIM, A.; VITORINO, M. *Caracterização do lodo gerado na estação de tratamento de água da Cenibra*. In: CONGRESSO BRASILEIRO DE ENGENHARIA SANITÁRIA E AMBIENTAL, 25., 2009. Recife. Anais…