Use of Sludge Ash as a Stabilizing Additive in Soil-Cement Mixtures for Use in Road Pavements

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Abstract: This paper presents a study evaluating the use of sludge ash as a stabilizing additive to soil-cement mixtures for use in base and subbase road pavements by investigating the mechanical behavior of these mixtures. The methodology consisted of materials testing, including the geotechnical characterization of the soil and the mechanics of the soil-cement and the soil-cement-sludge ash mixtures. An unconfined compression test evaluated the mechanical behavior of soil-cement mixtures with cement contents of 3, 6, and 9% compressed with normal, intermediate, and modified pressures. The sludge ash contents added were of 5, 10, 20, and 30%. The results indicate increasing strength for all ash levels studied. The largest gain in strength was for a mixture with 20% sludge ash, which increased the strength by 26% compared with the mixture without sludge ash. DOI: 10.1061/(ASCE)MT.1943-5533.0001168, © 2014 American Society of Civil Engineers.

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Introduction

Sewage treatment plants produce a residue known as sewage sludge. The most common form of treatment is to incinerate this residue, which significantly reduces its volume. There is a global need for the development of methods used to recover the waste sludge. The search for environmentally friendly and economically viable solutions for the final disposal of waste sludge is a challenge. Currently, a major concern for environmental managers is eliminating this waste correctly and reducing its storage costs. One solution is to use the sewage sludge ash as a construction material. Sludge ash is considered by the Federal Highway Administration (FHWA), U.S. Department of Transportation as a byproduct material in pavement construction [FHWA RD-97-148 (FHWA 2008)]. Several research studies have used sludge ash as raw material, such as the following:

1. Addition of ash sludge to concrete: Tay (1987), Monzó et al. (1996), Fontes (2003), and Geyer et al. (1998);
2. Cement produced from sludge ash: Morales (1994), Onaka (2000), and Tay and Show (1991);
3. Addition of sludge and sludge ash in paving: Brosch (1975), Al Sayed et al. (1995), Durante Ingunza et al. (2013b), and Feitosa (2009); and

In this context, this paper evaluates the use of sludge ash from a sewage treatment plant as an additive for soil-cement mixtures for base and subbase layers of pavement.

Materials and Methods

The soil used in this study is a fine, red-colored soil often found on the Brazilian northeastern coast. According to the Unified Soil Classification System (USCS), the soil classification is ML, i.e., silt of low compressibility. A AASHTO classifies this soil as A-4, with an index group of 5.3 California Bearing Ratio (CBR); tests performed according to ASTM D1883-07e2 (ASTM 2007) presented values less than 6% CBR and 0.05% expansion, indicating a low support capacity for use in pavement bases and subbases. Thus, the use of such a soil as a construction material for pavement layers is only possible through a chemical stabilization.

The stabilizer used was ordinary portland cement. The sludge ash was produced from sludge dredged on an anaerobic lagoon system for domestic wastewater stabilization. The fresh sludge was classified as a Class II-A waste (not inert and nonhazardous) according to Brazilian standards [Associação Brasileira de Normas Técnicas (ABNT) 10:005 2004a, b] based on international standards. Compression tests considered three energy levels: normal [ASTM D698-12 (ASTM 2012a); 600 kN · m/m³ of applied pressure], intermediate, and modified [ASTM D1557-12 (ASTM 2012b); 2,700 kN · m/m³ of applied pressure]. The intermediate energy test followed the same steps as the modified energy test, except for the number of strokes per layer, which was 25 strokes, resulting in energy of 1.260 kN · m/m³.

The tests used soil and soil-cement mixtures with cement contents of 3, 6, and 9%.

The test used cast specimens with cement contents of 0, 3, 6, and 9% for three compaction modes of the unconfined compression test. The test calculated the cement content relative to the dry soil mass. The specimens were cured for 28 days in a humidified chamber. The unconfined compression tests followed the procedures recommended by ASTM D2166-06 (ASTM 2006).

To evaluate the effect of the sludge ash additive, the study performed unconfined compression tests on samples with sludge ash additive levels of 5, 10, 20, and 30% relative to the solid-state weight. The mixture selected to perform the study was the soil-cement mixture with 9% cement, using an intermediate energy test for the specimens. Table 1 provides the characteristics of the studied materials. For each condition indicated in Table 1, the study includes three experiments to evaluate the variability.
Results

Mechanical Characterization Testing of Soil and Soil-Cement

This study expressed the compaction test results in terms of the compaction effect on the maximum dry weight and the optimum moisture content. Fig. 1 shows that for the same compaction energy, the specific maximum dry weight increases with increasing cement content, and that for a given cement content, the dry weight increases with increasing compaction energy. Fig. 2 shows that for a given compaction energy, the optimum moisture content decreases with increasing cement content, and that for given cement content, the optimum moisture content decreases with increasing compact energy. In the compaction curves, a shift toward the left and above was observed, which means a dry unit weight increases and optimum moisture content decreases, as expected. The increase of the dry unit weight is because the cement has a higher dry unit weight value than the soil.

Fig. 3 shows the results of the unconfined compression tests in terms of the variation of the compressive strength with the cement content and the compaction effort. As shown in Fig. 3, the strength increases with the compaction effort and, for a given compaction effort, the strength increases with increasing cement content. According to the specifications of the Brazilian standards, soil stabilization with cement should provide a minimum strength of 2.1 MPa. The data in Fig. 3 show that in the intermediate energy, this value is reached with the maximum cement content (9%). In the modified energy, the specification is reached with lower cement content (3%).

Brazilian pavement specifications are based on standards and procedures of the National Department of Transport Infrastructure (DNIT) and the standards of the Brazilian Association of Technical Standards (ABNT) using the specifications of ASTM as main regulatory compliances.

Mechanical Characterization Testing of Soil-Cement-Sludge Ash Mixtures

To study the addition of sewage sludge ash to the soil-cement mixture, the trace chosen after the compression test was 91% soil + 9% cement, molded at the intermediate energy. This trace has a strength of 2.261 MPa, which meets the minimum reference value (2.1 MPa) defined by the Brazilian standard [DNIT 143/2010 (DNIT 2010)] for pavement base materials. The experiment added sludge ash contents of 5, 10, 20, and 30% of the solid weight to the selected trace (91% soil + 9% cement). Fig. 4 shows the unconfined compressive strength results of the sludge ash blends. The addition of sludge ash at all weight percentages tested increased the strength of the soil-cement mixtures. The greatest strength was with 20% sludge ash, resulting in a 26% increase in strength compared to the control mixture.

Table 1. Identification of Analyzed Materials

<table>
<thead>
<tr>
<th>Identification</th>
<th>Soil (%)</th>
<th>Cement (%)</th>
<th>Ash (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S100</td>
<td>100</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>S97C3</td>
<td>97</td>
<td>3</td>
<td>—</td>
</tr>
<tr>
<td>S94C6</td>
<td>94</td>
<td>6</td>
<td>—</td>
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<tr>
<td>S91C9</td>
<td>91</td>
<td>9</td>
<td>—</td>
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<td>86</td>
<td>9</td>
<td>5</td>
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<td>81</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>S71C9A20</td>
<td>71</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>S61C9A30</td>
<td>61</td>
<td>9</td>
<td>30</td>
</tr>
</tbody>
</table>

Fig. 1. Effect of compaction energy and cement content on the maximum dry unit weight in the compaction tests

Fig. 2. Effect of compaction effort and cement content on the optimum moisture content in the compaction tests

Fig. 3. Test results of unconfined compression strength of soil-cement mixtures
to the control trace (without sludge ash). Monzó et al. (1996) obtained similar results. The samples were molded with the optimum moisture content obtained in sample S91C9, which corresponds to 18.3%. Fig. 5 shows the dry specific weight values after applying the intermediate compaction energy. The results show that the dry specific weight decreases with the increase in sludge ash because sludge ash is less dense than soil.

Conclusions

The results of this study confirmed the feasibility of using sludge ash as a stabilizing additive for soil-cement mixtures, and indicate that it is possible to incorporate up to 30% sewage sludge ash content to a soil-cement mixture (91% soil and 9% cement) compressed at an intermediate energy to produce a strength increase. The largest gain in strength was with a 20% sludge ash content, which increased the strength by 26% compared with the mixture without sludge ash.

To assess the correct use of sludge ash as a stabilizing additive in soil-cement mixtures, it is necessary to evaluate the consequences in terms of life-cycle cost analysis of the pavement. Research carried out in the last decade shows the economic, technical, and environmental feasibility of the use of sludge in civil construction. Nevertheless, to implement in real scale, a further study shall be performed with a life-cycle cost analysis (LCCA), as related by Praticò et al. (2011).

References


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