Use of Sewage Sludge as Raw Material in the Manufacture of Soft-Mud Bricks

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Abstract: This article assesses the use of sewage sludge as a raw material in the ceramic industry, specifically in the manufacture of soft-mud bricks, to determine the maximum incorporation of sludge that results in technically sound and environmentally friendly bricks. The results obtained confirm that there was no alteration in the odor of the bricks, even at high proportions of sludge; however, high concentrations of sludge had a negative influence on certain properties, such as mechanical strength and absorption. Compressive strength was significantly diminished with the addition of sludge: the bricks with 5% sludge lost an average of 45% of the strength obtained by the control brick; the bricks manufactured with 15 and 20% lost around 70% of maximum strength; however, they still met minimum strength standards. For the specified conditions of this study, it was concluded that 20% was the maximum proportion of sludge that could be incorporated into a ceramic mass and still meet technical and environmental requirements. DOI: 10.1061/(ASCE)MT.1943-5533.0000239. © 2011 American Society of Civil Engineers.

CE Database subject headings: Sludge; Bricks; Sustainable development; Construction materials; Recycling.

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Introduction

Residue recycling is increasingly seen as a sustainable, technical, and environmentally correct solution. The largest amount of sludge is produced in sewage and water treatment plants. Despite exhibiting highly variable characteristics, depending mainly on the origin and type of treatment, sewage sludge can be considered a residue with high recycling potential in the construction industry.

To this end, the use of sludge as raw material in the ceramic industry has been studied by a number of writers (Meneses et al. 2002; Acchar et al. 2006; Alves and Holanda 2005; Okuno et al. 2004; Tay 1987; Santos 2003; Jordan et al. 2005; Ingunza et al. 2006).

Weng et al. (2003) reported that the benefits of using sludge or sludge ash as an additive in bricks or tiles include the immobilization of heavy metals in the ceramic matrix postfiring, oxidation of organic material, and the destruction of pathogens during the firing process.

Herek et al. (2005) and Balasubramanian et al. (2006) assessed the use of textile sludge in the manufacture of ceramic blocks. Both studies reported that the test specimens manufactured with 10% sludge are technically adequate.

Liew et al. (2004a) tested additions of sewage treatment plant (STP) sludge in the manufacture of soft-mud sludge and concluded that a proportion of 20% meets water absorption and compressive strength standards.

Nuvolari (2002) tested soft-mud bricks with reduced dimensions (10 × 5 × 2.5 cm) and concluded that the maximum proportion of sludge that met minimum compressive strength standards was 10%. For the bricks manufactured with sludge ash, a concentration of up to 40% was technically feasible.

Accordingly, the aim of this study is to assess the use of sewage sludge in the ceramic industry, specifically in the manufacture of technically sound and environmentally friendly soft-mud bricks.

Materials and Methods

The raw materials used were two clays with different mineral content (clay A and clay B) and the sludge, drained in a dry bed, was obtained from a septic tank cleaning company, where it was treated in a stabilization pond. Table 1 shows the chemical characteristics of raw materials used.

The main difference between the clays (clay A and clay B) is the high plasticity of clay A. It has higher concentrations of Al2O3 and SiO2 and lower concentrations of CaO and KO2 compared with clay B. The sludge has the lowest concentrations of SiO2 compared with the clays used, with almost 50% less of SiO2 than clay A. The high content of iron oxide did not interfere in the color of the bricks after firing, because the clay already had high contents of iron that gave the brick red coloration.

The results obtained in the mineralogical characterization of raw materials confirm the high plasticity of clay A (predominance of kaolinite and montmorillonite). The high levels of quartz indicated good stability of the manufactured products.

Before the bricks were manufactured, the appropriate balance between the two types of clay (formulation) was determined to obtain a final raw material with adequate plasticity. The results indicated that the best formulation is 3:2 (clay A: clay B).
The soft-mud bricks, measuring 220 × 105 × 45 mm, per the Brazilian Association of Technical Standards (ABNT 1983b), were molded in a manual press in laboratory and fired in an industrial kiln, with \(\frac{5}{10}C_{0}, \frac{15}{10}C_{0}, \frac{20}{10}C_{0}, \frac{25}{10}C_{0}, \frac{30}{10}C_{0}, \frac{35}{10}C_{0}, \text{ and } \frac{40}{10}C_{0}\) sludge (Figs. 1 and 2) were tested with 12 specimens per data point. For operational reasons, the bricks with different concentrations of sludge were manufactured in two batches. Therefore, to avoid any interference, two control groups of bricks without sludge were manufactured, one for each batch. Bricks containing 10, 20, 30, and 40% sludge have control group 1, and bricks containing 5, 15, 25, and 35% sludge have control group 2.

The bricks were assessed according to the following criteria (ABNT 1983b):

1. Identification of systematic defects, such as breaks, uneven surfaces or deformations;
2. Dimensional changes: the aforementioned norm allows maximum variations of ±3 mm in all three dimensions; and
3. Percentage mass loss (ML): is given by Eq. (1), in which \(M_{bf}\) and \(M_{af}\) are brick mass before and after firing, respectively.

\[
ML = \frac{M_{bf} - M_{af}}{M_{af}} \times 100
\]  

There are no normative reference values, but this parameter was used to evaluate the influence of sludge concentration in the bricks.

4. Percentage of water absorption (WA): recommended to be between 10 and 18% (Petrucci 1998); calculated by Eq. (2), in which \(M_{wet}\) and \(M_{dry}\) = brick mass after 24 h immersion in cold water and after 24 h of kiln drying at 105°C, respectively.

\[
WA = \frac{M_{wet} - M_{dry}}{M_{dry}} \times 100
\]  

5. Compressive strength (CS): the assay was established by NBR 6064 (ABNT 1983a); it is given by Eq. (3), in which \(F\) is the force observed in the equipment to break the prism, in Kgf, and \(A_p\) is the mean of the areas of two surfaces of the ceramic prism, in square centimeters.

\[
CS = \frac{F}{A_p} \times 10
\]  

For this work it was assumed that the bricks must meet the minimum strength value of 1.5 MPa, according to Brazilian standards.

6. Determination of environmental risk: NBR 10004 (ABNT 2004c) classifies solid residues as:

a. Class I residues: Dangerous; and
b. Class II residues: Nondangerous:
   1. Class II A: Noninert; and
   2. Class II B residues: Inert.

The bricks were classified as class I or II according to the lixiviation test (ABNT 2004a); the distinction between classes IIA and B was made using the solubilization test (ABNT 2004b).

Results and Discussion

Technical Assessment

The bricks showed no significant alteration in color or odor. However, the esthetic finish was visibly affected by the increase in sludge concentration: at a concentration of 25% or higher, the bricks exhibited cracks, fragile corners and flawed edges. The bricks manufactured with 35% sludge were very brittle, and those with 40% fractured as they were removed from the kiln. The bricks with these last two concentrations were broken up manually. Therefore, these concentrations were excluded, given that they would not achieve the compressive strength required by the norm.

Table 2 shows the mean dimensional changes of the bricks, considering that the ideal size is 220 × 105 × 45 mm. The values that

### Table 1. Chemical Composition of Raw Materials Used in the Manufacture of Soft-Mud Bricks

<table>
<thead>
<tr>
<th>Element</th>
<th>Clay A</th>
<th>Clay B</th>
<th>Sludge</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>68.68</td>
<td>55.32</td>
<td>33.89</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>23.01</td>
<td>20.47</td>
<td>16.24</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>3.12</td>
<td>7.4</td>
<td>12.89</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.42</td>
<td>5.82</td>
<td>1.50</td>
</tr>
<tr>
<td>CaO</td>
<td>0.99</td>
<td>5.54</td>
<td>14.56</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.97</td>
<td>0.78</td>
<td>2.87</td>
</tr>
<tr>
<td>Others</td>
<td>0.39</td>
<td>3.40</td>
<td>16.59</td>
</tr>
</tbody>
</table>

### Table 2. Dimensional Changes of Bricks

<table>
<thead>
<tr>
<th>Variation (mm)</th>
<th>CB-1</th>
<th>CB-2</th>
<th>5%</th>
<th>10%</th>
<th>15%</th>
<th>20%</th>
<th>25%</th>
<th>30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Δ Length</td>
<td>-3</td>
<td>1</td>
<td>2</td>
<td>-3</td>
<td>0</td>
<td>-3</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Δ Width</td>
<td>-4</td>
<td>0</td>
<td>1</td>
<td>-3</td>
<td>0</td>
<td>-1</td>
<td>2</td>
<td>-1</td>
</tr>
<tr>
<td>Δ Height</td>
<td>-7</td>
<td>-1</td>
<td>-1</td>
<td>-5</td>
<td>1</td>
<td>-3</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Note: CB-1 and CB-2: Control bricks.
bricks with 10 and 25% sludge showed excessive dimensional changes. However, control brick 1 (CB-1) also showed values that exceed the maximum variation allowed by the norm. The results indicate the dimensional changes do not depend directly on sludge concentration, but rather on the production method used to manufacture the bricks.

Fig. 3, which shows mean brick weight grouped by manufacturing stage, demonstrates that weight is inversely proportional to sludge concentration. Considering that maximum brick weight at each manufacturing stage would be the weight of the control brick, this graph shows that bricks manufactured with 30% sludge lost an average of 45% of their mass, whereas bricks with 5% lost an average mass of 6%.

Tests conducted by Weng et al. (2003) came to a similar conclusion; bricks manufactured with between 10 and 30% of sludge lost around 12 and 38% of mass, respectively, at a firing temperature of 1,000°C.

Based on the data obtained, the addition of sludge results in a significant loss of brick mass; however, this change is not significant at 5% sludge or when there is an increase from 10 to 20% sludge.

Fig. 4 shows the mean water absorption of bricks manufactured with different sludge concentrations. Bricks manufactured with 20, 25, and 30% sludge are above the limit proposed by Petrucci (1998). At all concentrations, the absorption of bricks with sludge was greater than that of the control brick.

The results obtained by Weng et al. (2003) demonstrated that bricks with a concentration greater than or equal to 30% also exhibited an absorption percentage above 18%.

Fig. 5, which shows percentage of water absorption increase of each brick compared with its respective control, demonstrates that bricks with different sludge concentration absorbed more water than control brick. Bricks with 25% sludge absorbed an average of 160% more than the control brick.

Fig. 6 shows the mean strength values of the bricks manufactured with different sludge percentages. It can be observed that the bricks manufactured with 25 and 30% sludge did not meet minimum strength standards. The other concentrations showed values above the minimum required by the norm.

The results indicate a significant reduction in brick strength with an increase in sludge concentration; this phenomenon is not observed when there is an increase from 10 to 20% of sludge.

Fig. 7 shows the percentage of compressive strength loss of each brick compared with its respective control. Even the bricks manufactured with 5% sludge lost an average of 45% of the strength obtained by the control brick. The bricks manufactured with 15 and 20% lost around 70% of strength; however, they still attained the minimum strength required by the norm. The highest
concentrations (25 and 30%) lost around 90% of the strength obtained by the control brick.

There is a significant reduction in brick strength, even in bricks with low sludge concentrations. There is not a linear relationship between porosity and strength. Some factors such as shape, size, and distribution of pores can modify the behavior of brick, resulting in a significant strength decrease of each brick compared with its respective control. Moreover, the sludge used in this study is not calcined but dried, and the organic matter content should influence the properties of brick. Therefore, this reduction in brick strength may owe to the volatilization of the large amount of organic material present in the sludge. Moreover, the study was conducted in full scale. The literature cited small-scale experiments which show major strength values, but whose results cannot be compared directly on the concentration of sludge, but rather depends on the method used to manufacture the bricks; the addition of sludge results in significant loss of mass in the bricks; however, this change is not significant when only 5% of sludge is added to the ceramic mass and when there is an increase from 10 to 20% of sludge; water absorption is significant and directly linked to an increase in sludge concentration: the bricks manufactured with sludge, at all concentrations, absorbed more water than the control brick; compressive strength was significantly diminished with the addition of sludge: the bricks with 5% sludge lost an average of 45% of the strength obtained by the control brick; the bricks manufactured with 15 and 20% lost around 70% of maximum strength; however, they still met minimum strength standards; the highest concentrations (25 and 30%) lost around 90% of the strength obtained by the control brick and, therefore, are not technically acceptable; and both the control bricks of the two manufacturing stages and those manufactured with 15 and 20% sludge, are characterized as Class II residue—nondangerous.

Thus, for the specified conditions of this study, it is concluded that the maximum concentration of sludge that can be incorporated into ceramic mass, meeting both the technical and environmental requirements, is 20%.

Environmental Assessment

In this phase of the assessment only the samples of bricks manufactured with the two largest concentrations that were approved in the previous evaluation (15 and 20%) were analyzed, in addition to the respective control bricks.

All the samples had lower concentrations than the limit established by the norm. As a result, all the bricks, both those manufactured with and without sludge, were characterized as Class II A residues—nondangerous and inert.

Conclusions

Soft-mud bricks, measuring 220 × 105 × 45 mm were molded in a manual press in laboratory and fired in an industrial kiln, with 5, −10, −15, −20, −25, −30, −35, and −40% sludge. Were tested 12 specimens per data point.

The following conclusions can be drawn about soft-mud bricks manufactured with sludge:

• There was no change in odor, even at high sludge concentrations;
• The bricks manufactured with 35% sludge were very brittle, without any mechanical strength and those with 40% broke up as they were being removed from the kiln;
• Of the concentrations tested, bricks with 10 and 25% of sludge showed higher dimensional changes than the limit established by the norm. However, this phenomenon does not depend directly on the concentration of sludge, but rather depends on the method used to manufacture the bricks;
• The addition of sludge results in significant loss of mass in the bricks; however, this change is not significant when only 5% of sludge is added to the ceramic mass and when there is an increase from 10 to 20% of sludge;
• Water absorption is significant and directly linked to an increase in sludge concentration: the bricks manufactured with sludge, at all concentrations, absorbed more water than the control brick;
• Compressive strength was significantly diminished with the addition of sludge: the bricks with 5% sludge lost an average of 45% of the strength obtained by the control brick; the bricks manufactured with 15 and 20% lost around 70% of maximum strength; however, they still met minimum strength standards;
• The highest concentrations (25 and 30%) lost around 90% of the strength obtained by the control brick and, therefore, are not technically acceptable; and both the control bricks of the two manufacturing stages and those manufactured with 15 and 20% sludge, are characterized as Class II residue—nondangerous.

Thus, for the specified conditions of this study, it is concluded that the maximum concentration of sludge that can be incorporated into ceramic mass, meeting both the technical and environmental requirements, is 20%.

References


Fig. 7. Strength loss as a function of sludge percentage


