
OVEN DRYING CHARACTERISTICS OF SOILS OF DIFFERENT ORIGINS

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Resubmitted: 24 January 2005
ABSTRACT

The accurate measurement of the moisture content of a soil is an important step in characterizing its engineering behavior. However, the oven-drying method can cause some chemical reaction (oxidation or loss of water of crystallization) to occur in certain soil types. The level of oxidation of the solid particles was studied over the drying temperature range of 60 to 140 °C for different soils. The period of oven drying necessary for the specimen mass to equilibrate was also examined.

The standard practice of oven drying the soil specimens at 110±5 °C or 105±5 °C over a period of 24 hours was confirmed as giving accurate moisture content values for inorganic soils. Oven drying of peat and other highly organic soils over a period of 24 hours at 80°C produced similar levels of accuracy in the moisture content measurements as that for inorganic soils at the standard oven drying temperature of 105 or 110 °C. Some oxidation of the organic fraction commenced at between 80 and 90 °C.

Key Words: Oven drying; Moisture content; Soil; Organic; oxidation

INTRODUCTION

The accurate measurement of the moisture content of a soil is an important step in characterizing its engineering behavior. In geotechnical literature, the moisture content \( w \) is defined as the ratio of the mass of the pore water \( m_w \), to the mass of the dry solid particles \( m_s \), and is expressed as a percentage.

\[
w = \frac{m_w}{m_s} \times 100 \quad (\%) 
\]

The oven-drying method (ASTM D2216 (1998) and BS1377–2 (1990)) is the standard laboratory method used for the determination of the moisture content of a soil. For many soils, the mass of the dry solid particles is equal to the equilibrium dry mass \( m_D \), corresponding to an oven drying temperature of slightly above 100 °C, which ensures complete evaporation of the pore water. ASTM D2216 (1998) recommends an oven drying temperature of 110±5 °C while BSI 1377-2[2] recommends a temperature of 105±5 °C. The equilibrium dry mass is usually taken as the mass of the test specimen recorded after an oven drying period of 24 hours. The mass of the pore water is equal to the reduction in the mass of the wet specimen, and the moisture content can be calculated as:

\[
w = \frac{m_w}{m_D} \times 100 \quad (\%) 
\]

However, oven drying at these temperatures may cause some chemical reaction (oxidation or loss of water of crystallization) to occur in certain soil types. For example, MacFarlane and Allen (1963) and O’Kelly (2004) reported that peat and other organic clays experienced some oxidation at oven drying temperatures greater than about 85 °C. Water of crystallization,
which is deemed part of the solid particles themselves for the purposes of moisture content
determinations, may also be driven off. Reductions in the specimen dry mass ($\Delta m_D$) due to
chemical reactions, cause the actual moisture content value of the soil to be overestimated
(Eq. 3).

$$w = \frac{m_w + \Delta m_D}{m_D - \Delta m_D} \times 100\% \quad (3)$$

Hence, the standards recommend that a lower temperature, typically 60 or 80°C, be used for
oven drying of peat and other organic soils. The purpose of the current study was to examine
the effect of the oven temperature on the drying characteristics of a range of different soils.
The first stage examined the period of oven drying necessary for the specimen mass to
equilibratae. The second stage examined the susceptibility of the solid particles to oxidation
for a range of oven temperatures, focusing in particular on the standard oven drying
temperatures.

INDEX PROPERTIES OF SOILS

Eight soils that comprised different particle size distributions and different proportions of
organic material, were tested. Some index properties of the soils are listed in Table 1. The
soil plasticity characteristics were assessed using the liquid limit and plastic limit tests
(ASTM D4318 (2000)), and the soils were classified using the Unified Soil Classification
System. The bulk of the solid particles in the silt and marl materials (soils 1, 3–6), were 0.002
to 0.06 mm in size, whereas the bulk of the solid particles in the clay material (soil 2), were
finer than 0.002 mm.

Loss in mass on ignition (LOI) tests were conducted by heating dry, powdered specimens of
the soils at 440 °C for a period of 24 hours. The soils are labeled 1 to 8, and are listed in order
of increasing LOI values, in Table 1. The LOI values recorded for the marl and peat materials
(soils 3–8) give reasonably accurate measures of the organic content (Skempton and Petley,
1970).

The level of biodegradation of the peat material was quantified using the von Post
classification system (Head, 1992). The scale of von Post ranges from H1 to H10, in order of
increasing levels of degradation. The peat-1 material was only very slightly degraded (H1),
and the peat-2 material was slightly degraded (H4). The marl material (soils 3–6) originated
from the dissolution of marine shells, fragments of which were still evident in the shell marl.

The specific gravity of the solid particles was measured using the small pycnometer method
(ASTM D854, 2002). Kerosene, with a density of 0.78 g/ml, was used instead of distilled
water as the fluid in the pycnometers for specific gravity measurements on soils 6–8.
Table 1. Index properties of the soils.

<table>
<thead>
<tr>
<th>Soil label</th>
<th>Soil type</th>
<th>Classification (USCS)</th>
<th>Liquid limit (%)</th>
<th>Plastic limit (%)</th>
<th>Specific gravity (g/cm³)</th>
<th>Loss on ignition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Silt</td>
<td>MH</td>
<td>65</td>
<td>32</td>
<td>2.66</td>
<td>3.0</td>
</tr>
<tr>
<td>2</td>
<td>Clay</td>
<td>CH</td>
<td>83</td>
<td>35</td>
<td>2.70</td>
<td>5.6</td>
</tr>
<tr>
<td>3</td>
<td>Marl-1</td>
<td>MH</td>
<td>116</td>
<td>95</td>
<td>2.22</td>
<td>6.7</td>
</tr>
<tr>
<td>4</td>
<td>Marl-2</td>
<td>MH</td>
<td>131</td>
<td>106</td>
<td>2.41</td>
<td>6.9</td>
</tr>
<tr>
<td>5</td>
<td>Shell marl</td>
<td>MH</td>
<td>107</td>
<td>59</td>
<td>2.35</td>
<td>10.3</td>
</tr>
<tr>
<td>6</td>
<td>Organic marl</td>
<td>OH</td>
<td>180</td>
<td>130</td>
<td>2.06</td>
<td>29.7</td>
</tr>
<tr>
<td>7</td>
<td>Peat-1</td>
<td>Pt</td>
<td>900</td>
<td>310</td>
<td>1.19</td>
<td>87.7</td>
</tr>
<tr>
<td>8</td>
<td>Peat-2</td>
<td>Pt</td>
<td>735</td>
<td>485</td>
<td>1.47</td>
<td>92.9</td>
</tr>
</tbody>
</table>

OVEN DRYING PERIOD TO ACHIEVE CONSTANT DRY MASS

Specimens of the soils were oven dried to constant mass at 60, 80 and 105 °C. These are the different oven drying temperatures recommended by the standards. Three sets of specimens, one set specific to each test temperature, were dried using a precision oven (manufactured by Memmert®), with the oven chamber temperature maintained within 1.5 °C of the set temperature value. The oven chamber had a capacity of 14 liters, which was more than adequate to accommodate all of the specimens belonging to a particular set. The wet mass of each specimen was about 40 g. The specimens were oven dried over a period of 96 hours during which the specimen masses were recorded at regular intervals. The specimens were cooled in a vacuum desiccator container to ambient laboratory temperature of 21°C before being weighed to an accuracy of 0.01 g.

Figure 1 shows the specimen masses plotted against the period of oven drying at 60, 80 and 105 °C. Since the masses of the solid particles in each of the specimens were slightly different, the specimen masses were normalized on the basis of their initial wet masses (scale 2.0), and equilibrium dry masses (scale 1.0) recorded after a drying period of 96 hours.

Figure 2 gives a direct comparison of the drying characteristics of the peat-1 material at the different oven temperatures.

The following points are concluded in relation to the period of drying from inspection of Figures 1 and 2:

- The standard practice of oven drying at 105 or 110 °C over a period of 24 hours was more than adequate for the specimen masses of the different soils to equilibrate (Figure 1c).
- Longer drying periods, although still generally less than 24 hours, were required for the specimen masses to equilibrate at the lower oven temperatures of 60 and 80 °C.
- However, the dry masses of the marl-1 and peat-1 materials only equilibrated after about 36 hours for oven drying at 60 °C (Figure 1a).
The second batch of drying tests examined the susceptibility of the solid particles to oxidation for oven drying temperatures in the range of 60 to 140 °C. The drying tests commenced at 60 °C since this is the lowest drying temperature recommended by the standards for moisture content determinations. Specimens of the soils were oven dried to constant mass at a series of oven temperatures which increased in steps over the range of 60 to 140 °C. The equilibrium condition for each oven temperature was established by recording the specimen masses at regular intervals. For example, Figure 3 shows the dry mass of the peat-2 specimen recorded for the different oven drying temperatures. After each weighing, the specimens were replaced in the same locations in the drying oven.

Figure 1. Specimen mass vs. period of oven drying.
(a) Oven drying at 60 °C

(b) Oven drying at 80 °C

(c) Oven drying at 105 °C
Figure 2. Drying of peat-1 at different oven temperatures.

Figure 3: Drying characteristics of peat-2 vs. oven drying temperature.

The level of susceptibility to oxidation was assessed in terms of the reductions in the equilibrium dry masses, expressed as percentages of the equilibrium dry masses initially recorded at 60 °C. Figure 4 shows the reductions in the equilibrium dry masses with increasing oven drying temperature for the different soils. The following points are noted in relation to the level of oxidation over the drying temperature range of 60 to 140 °C from inspection of Figure 4:

- For the silt, clay and marl materials (Figure 4a), the overall reductions in the equilibrium dry masses were less than 1.5 %, and for practical purposes these reductions do not affect the accuracy of the moisture content values.

- In general, the gradients of the different drying curves increased between 80 and 90 °C (Figure 4a, b). O’Kelly (2004) showed that the greater reductions in the specimen dry masses over this temperature range coincided with the commencement of some oxidation of the organic fraction. Small reductions in the equilibrium dry masses recorded between 60 and 80 °C were principally due to the evaporation of small residual amounts of loosely bound pore water from the void space with increasing oven temperature.
For the peat material (Figure 4b), the overall reductions in the equilibrium dry masses of 6.8% (peat-1) and 4.8% (peat-2) are more than quadruple the values recorded for the other soils. The reductions in the equilibrium dry masses of 1.7% (peat-1) and 0.4% (peat-2) corresponding to a drying temperature of 80 °C are similar to the overall reductions measured for the silt, clay and marl materials. Hence, the water content values of peat and other organic materials, calculated on the basis of the equilibrium dry mass at 80 °C, are likely to have similar levels of accuracy as those for inorganic soils, calculated on the basis of the standard oven drying temperatures of 105 °C or 110 °C.

The greater levels of susceptibility of the peat material was consistent with their higher LOI values, and the fact that the natural material was only very slightly-to-slightly decomposed (H_3 to H_4 on the scale of von Post).

Figure 4: Reduction in specimen dry mass vs. drying temperature.

(a) Silt, clay and marl materials

(b) Peat material

CONCLUSIONS

The standard practice of oven drying soil specimens at 110±5 °C or 105±5 °C over a period of 24 hours for moisture content determinations was confirmed as giving accurate moisture content values for inorganic soils.
The reductions in the equilibrium dry mass recorded for the peat material at 80 °C were similar to those recorded for the inorganic soils at the standard oven drying temperatures of 105 or 110 °C. Hence, it is recommended that moisture content calculations for peat and other organic materials are based on the specimen mass recorded after a period of 24 hour oven drying at 80°C.

There was no apparent benefit in oven drying the soil specimens at 60 °C for moisture content determinations, in fact the moisture content values were less accurate since small residual amounts of pore water remained in the void space. Longer oven drying periods of up to 36 hours were also required for the specimen masses to equilibrate.

NOMENCLATURE

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>LOI</td>
<td>Loss in dry mass on ignition</td>
</tr>
<tr>
<td>( m_D )</td>
<td>Equilibrium dry mass</td>
</tr>
<tr>
<td>( m_s )</td>
<td>Mass of dry solid particles</td>
</tr>
<tr>
<td>( m_w )</td>
<td>Mass of the pore water</td>
</tr>
<tr>
<td>( w )</td>
<td>Moisture content</td>
</tr>
<tr>
<td>( \Delta m_D )</td>
<td>Reduction in dry mass</td>
</tr>
</tbody>
</table>

ACKNOWLEDGEMENTS

The laboratory test were carried out by Martin Carney and Mairead Sayers (University of Dublin, Trinity College) and their efforts are gratefully acknowledged.

REFERENCES


