

1 **Citation:**

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3 O'Kelly B.C. 2005. Oven-drying characteristics of soils of different origins.  
4 Drying Technology, Vol. 23, No. 5, 1141–1149.

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10 **OVEN DRYING CHARACTERISTICS OF SOILS OF DIFFERENT ORIGINS**

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23 First submission: 21 June 2004.

24 Resubmitted: 24 January 2005

25 ABSTRACT

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27 The accurate measurement of the moisture content of a soil is an important step in  
28 characterizing its engineering behavior. However, the oven-drying method can cause some  
29 chemical reaction (oxidation or loss of water of crystallization) to occur in certain soil types.  
30 The level of oxidation of the solid particles was studied over the drying temperature range of  
31 60 to 140 °C for different soils. The period of oven drying necessary for the specimen mass to  
32 equilibrate was also examined.

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

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

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44 INTRODUCTION

45

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

50

51 
$$w = \frac{m_w}{m_s} ( \times 100 ) \quad ( \% ) \quad (1)$$

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53

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

63

64 
$$w = \frac{m_w}{m_D} ( \times 100 ) \quad ( \% ) \quad (2)$$

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67 However, oven drying at these temperatures may cause some chemical reaction (oxidation or  
68 loss of water of crystallization) to occur in certain soil types. For example, MacFarlane and  
69 Allen (1963) and O'Kelly (2004) reported that peat and other organic clays experienced some  
70 oxidation at oven drying temperatures greater than about 85 °C. Water of crystallization,

71 which is deemed part of the solid particles themselves for the purposes of moisture content  
72 determinations, may also be driven off. Reductions in the specimen dry mass ( $\Delta m_D$ ) due to  
73 chemical reactions, cause the actual moisture content value of the soil to be overestimated  
74 (Eq. 3).  
75

$$76 \quad w = \frac{m_w + \Delta m_D}{m_D - \Delta m_D} \quad (\times 100) \quad (\%) \quad (3)$$

77  
78  
79 Hence, the standards recommend that a lower temperature, typically 60 or 80°C, be used for  
80 oven drying of peat and other organic soils. The purpose of the current study was to examine  
81 the effect of the oven temperature on the drying characteristics of a range of different soils.  
82 The first stage examined the period of oven drying necessary for the specimen mass to  
83 equilibrate. The second stage examined the susceptibility of the solid particles to oxidation  
84 for a range of oven temperatures, focusing in particular on the standard oven drying  
85 temperatures.  
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## 88 INDEX PROPERTIES OF SOILS

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90 Eight soils that comprised different particle size distributions and different proportions of  
91 organic material, were tested. Some index properties of the soils are listed in Table 1. The  
92 soil plasticity characteristics were assessed using the liquid limit and plastic limit tests  
93 (ASTM D4318 (2000)), and the soils were classified using the Unified Soil Classification  
94 System. The bulk of the solid particles in the silt and marl materials (soils 1, 3–6), were 0.002  
95 to 0.06 mm in size, whereas the bulk of the solid particles in the clay material (soil 2), were  
96 finer than 0.002 mm.  
97

98 Loss in mass on ignition (*LOI*) tests were conducted by heating dry, powdered specimens of  
99 the soils at 440 °C for a period of 24 hours. The soils are labeled 1 to 8, and are listed in order  
100 of increasing *LOI* values, in Table 1. The *LOI* values recorded for the marl and peat materials  
101 (soils 3–8) give reasonably accurate measures of the organic content (Skempton and Petley,  
102 1970).  
103

104 The level of biodegradation of the peat material was quantified using the von Post  
105 classification system (Head, 1992). The scale of von Post ranges from H<sub>1</sub> to H<sub>10</sub>, in order of  
106 increasing levels of degradation. The peat-1 material was only very slightly degraded (H<sub>3</sub>),  
107 and the peat-2 material was slightly degraded (H<sub>4</sub>). The marl material (soils 3–6) originated  
108 from the dissolution of marine shells, fragments of which were still evident in the shell marl.  
109

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

113 Table 1. Index properties of the soils.

114

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

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118 **OVEN DRYING PERIOD TO ACHIEVE CONSTANT DRY MASS**

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

130

131 Figure 1 shows the specimen masses plotted against the period of oven drying at 60, 80 and  
 132 105 °C. Since the masses of the solid particles in each of the specimens were slightly  
 133 different, the specimen masses were normalized on the basis of their initial wet masses (scale  
 134 2.0), and equilibrium dry masses (scale 1.0) recorded after a drying period of 96 hours.  
 135 Figure 2 gives a direct comparison of the drying characteristics of the peat-1 material at the  
 136 different oven temperatures.

137

138

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

141

- 142 • The standard practice of oven drying at 105 or 110 °C over a period of 24 hours was  
 143 more than adequate for the specimen masses of the different soils to equilibrate  
 144 (Figure 1c).
- 145 • Longer drying periods, although still generally less than 24 hours, were required for  
 146 the specimen masses to equilibrate at the lower oven temperatures of 60 and 80 °C.
- 147 • However, the dry masses of the marl-1 and peat-1 materials only equilibrated after  
 148 about 36 hours for oven drying at 60 °C (Figure 1a).

149 LEVEL OF OXIDATION OF SOLIDS AT DIFFERENT DRYING TEMPERATURES

150

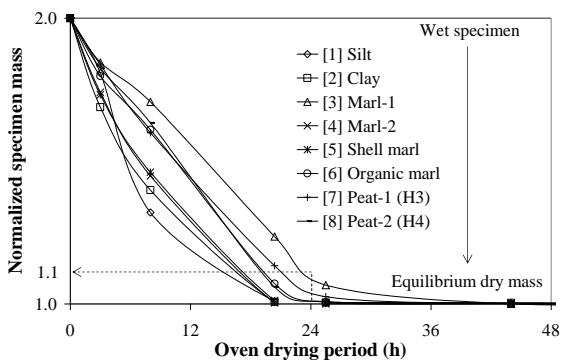
151 The second batch of drying tests examined the susceptibility of the solid particles to oxidation  
 152 for oven drying temperatures in the range of 60 to 140 °C. The drying tests commenced at 60  
 153 °C since this is the lowest drying temperature recommended by the standards for moisture  
 154 content determinations. Specimens of the soils were oven dried to constant mass at a series of  
 155 oven temperatures which increased in steps over the range of 60 to 140 °C. The equilibrium  
 156 condition for each oven temperature was established by recording the specimen masses at  
 157 regular intervals. For example, Figure 3 shows the dry mass of the peat-2 specimen recorded  
 158 for the different oven drying temperatures. After each weighing, the specimens were replaced  
 159 in the same locations in the drying oven.

160

161

162 Figure 1. Specimen mass vs. period of oven drying.

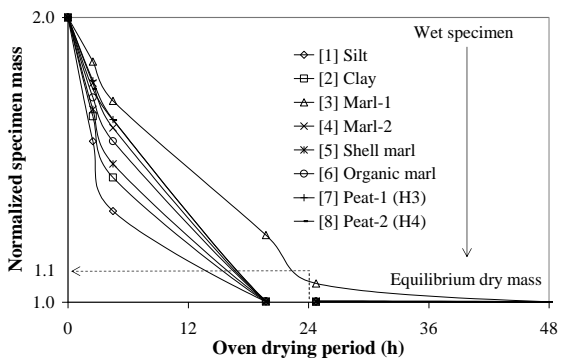
163 (a) Oven drying at 60 °C



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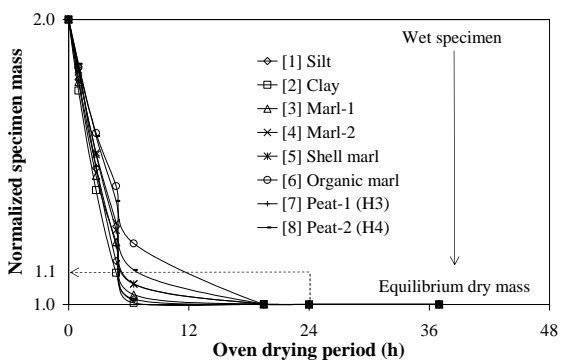
166 (b) Oven drying at 80 °C



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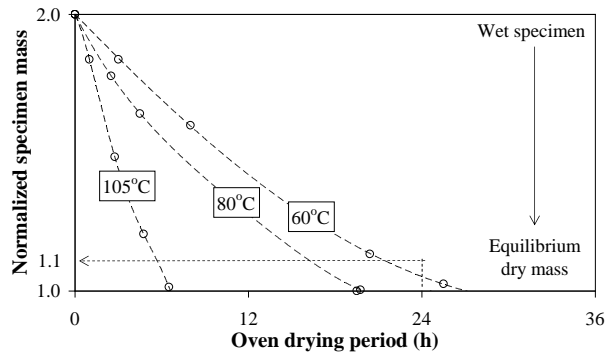
169 (c) Oven drying at 105 °C



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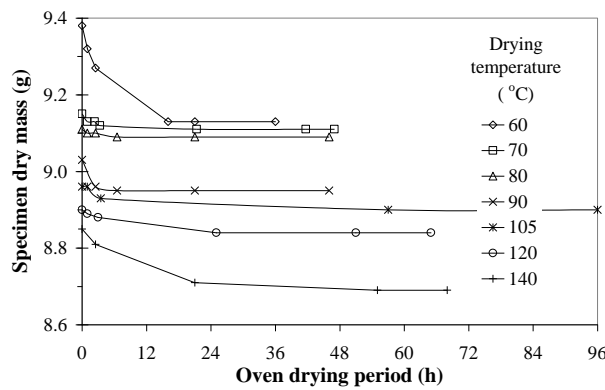
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Figure 2. Drying of peat-1 at different oven temperatures.



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



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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.

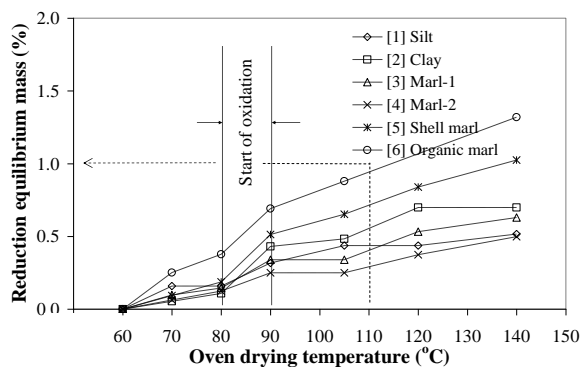
200 • For the peat material (Figure 4b), the overall reductions in the equilibrium dry masses  
 201 of 6.8 % (peat-1) and 4.8 % (peat-2) are more than quadruple the values recorded for  
 202 the other soils. The reductions in the equilibrium dry masses of 1.7 % (peat-1) and 0.4 %  
 203 (peat-2) corresponding to a drying temperature of 80 °C are similar to the overall  
 204 reductions measured for the silt, clay and marl materials. Hence, the water content  
 205 values of peat and other organic materials, calculated on the basis of the equilibrium  
 206 dry mass at 80 °C, are likely to have similar levels of accuracy as those for inorganic  
 207 soils, calculated on the basis of the standard oven drying temperatures of 105 °C or  
 208 110°C.

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 210  
 211 The greater levels of susceptibility of the peat material was consistent with their higher LOI  
 212 values, and the fact that the natural material was only very slightly-to-slightly decomposed  
 213 (H<sub>3</sub> to H<sub>4</sub> on the scale of von Post).

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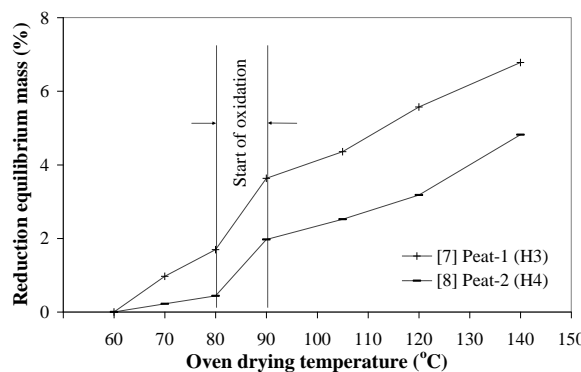
216 Figure 4: Reduction in specimen dry mass vs. drying temperature.

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 218 (a) Silt, clay and marl materials



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221 (b) Peat material



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225 **CONCLUSIONS**

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227 The standard practice of oven drying soil specimens at 110±5 °C or 105±5 °C over a period  
 228 of 24 hours for moisture content determinations was confirmed as giving accurate moisture  
 229 content values for inorganic soils.

230

231 The reductions in the equilibrium dry mass recorded for the peat material at 80 °C were  
232 similar to those recorded for the inorganic soils at the standard oven drying temperatures of  
233 105 or 110 °C. Hence, it is recommended that moisture content calculations for peat and other  
234 organic materials are based on the specimen mass recorded after a period of 24 hour oven  
235 drying at 80°C.

236  
237 There was no apparent benefit in oven drying the soil specimens at 60 °C for moisture content  
238 determinations, in fact the moisture content values were less accurate since small residual  
239 amounts of pore water remained in the void space. Longer oven drying periods of up to 36  
240 hours were also required for the specimen masses to equilibrate.

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## 243 NOMENCLATURE

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245 *LOI* Loss in dry mass on ignition

246  $m_D$  Equilibrium dry mass

247  $m_s$  Mass of dry solid particles

248  $m_w$  Mass of the pore water

249  $w$  Moisture content

250  $\Delta m_D$  Reduction in dry mass

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252

## 253 ACKNOWLEDGEMENTS

254

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

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## 259 REFERENCES

260

261 ASTM D854, 2002, Standard Test Method for Specific Gravity of Soil Solids by Water  
262 Pycnometer, American Society for Testing and Materials, Philadelphia.

263

264 ASTM D2216, 1998, Standard Test Method for Laboratory Determination of Water  
265 (Moisture) Content of Soil and Rock by Mass, American Society for Testing and Materials,  
266 Philadelphia.

267

268 ASTM D4318, 2000, Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity  
269 Index of Soils, American Society for Testing and Materials, Philadelphia.

270

271 BS1377–2, 1990, Methods of Test for Soils for Civil Engineering Purposes, Classification  
272 Tests, British Standards Institution, London.

273

274 Head, K.H., 1992, Manual of Soil Laboratory Testing: Soil Classification and Compaction  
275 Tests, Pentech Press, London, 388 pp.

276

277 MacFarlane, I.C. and Allen, C.M., 1963, An Examination of Some Index Test Procedures for  
278 Peat, Proc. Ninth Muskeg Research Conference, National Research Council of Canada.

279



- 280 O'Kelly, B.C., 2004, Accurate Determination of Moisture Content of Organic Soils using the  
281 Oven Drying Method, *Drying Technology*, 22(7) pp. 1767–1776.  
282
- 283 Skempton, A.W. and Petley, D.J., 1970, Ignition Loss and other Properties of Peats and Clays  
284 from Avonmouth, King's Lynn and Cranberry Moss, *Geotechnique*, 20(4) pp. 343–356.