Accelerated ageing of a stabilised/solidified contaminated soil at elevated temperatures

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consultants architects engineers

thinking in all dimensions

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Outline

- West Drayton site
- Short-term laboratory tests
- Accelerated ageing
- Experimental Results
- Conclusion
Introduction

- Limited field long-term performance data
  - Prediction of long term behaviour at the design stage – saves time and cost.
- Sustainability
  - Long term effectiveness validation is paramount to success and sustainability of any remediation technology.
- Accelerating the ageing process
  - Link short-term laboratory results to real time long-term field results.
- Accelerating methods
  - Elevated temperatures
  - Carbonation
West Drayton site

- Site - 2m of made ground overlying 3-4m of natural sands and gravels.
- Contaminated with heavy metals and petroleum hydrocarbons. Contaminants in sand & gravel:

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Concentration (mg/kg dry soil)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead</td>
<td>2800</td>
</tr>
<tr>
<td>Copper</td>
<td>1300</td>
</tr>
<tr>
<td>Nickel</td>
<td>105</td>
</tr>
<tr>
<td>Zinc</td>
<td>1600</td>
</tr>
<tr>
<td>Cadmium</td>
<td>9</td>
</tr>
<tr>
<td>Total Sulphate</td>
<td>2000</td>
</tr>
<tr>
<td>Mineral Oil</td>
<td>570</td>
</tr>
</tbody>
</table>
Site treatment

- Site treated in 1995 by in-situ S/S using 7 cement grouts and implemented using a mixing auger.

- Mix E:
  
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 : 8.0 : 0.4 : 0.42 : 1 : 3.5 : 1</td>
</tr>
</tbody>
</table>

- Site cored at 2 months to 5 years.
  - Unconfined compressive strength (UCS)
  - Leachability and leachate pH
  - Permeability
  - Durability – freeze-thaw and wet-dry
Laboratory samples

- Model soil - Gravel (50%), sand (37%), silt (6.5%) and clay (6.5%).
- Spiked with Pb(NO₃)₂, CuSO₄, Ni(NO₃)₂, ZnCl, Cd(NO₃)₂ and mineral oil.
- Cast into moulds 100mm x 50mm diameter.
- Some degree of setting before subjecting to heat treatment.
- Sample curing:
  - Elevated temperature only - oven, wax coated.
  - Oven for 1 week followed by 20% carbonation in an incubator at 90% RH.
- Samples cured for 28, 60 and 90 days
- Tested in triplicate for UCS, duplicate for NRA leachate pH.
Accelerated ageing

Elevated Temperatures

- Degree of hydration increases with curing time and temperature.
- The Arrhenius equation used to account for compressive strength development.

\[ k = A \cdot \exp\left\{-\frac{E_a}{RT}\right\} \quad \text{Equation 1} \]

- It can be shown that the equivalent time \( t_e \), which represents the time required at the reference temperature \( T_o \) to obtain the same strength (UCS) as that obtained at an elevated temperature \( T \) in time \( t \), is:

\[ t_e = t \cdot \exp\left\{-\frac{E_a}{R} \left(\frac{1}{T} - \frac{1}{T_o}\right)\right\} \quad \text{Equation 2} \]
Accelerated ageing

Carbonation

- A slow natural process leading to formation of CaCO$_3$ and silica gel from C-S-H or just CaCO$_3$ from Ca(OH)$_2$.
- The mechanisms and kinetics of carbonation are complex.
Results – Elevated temperatures

Figure 1

NRA leachate pH

<table>
<thead>
<tr>
<th>Temperature</th>
<th>21°C</th>
<th>45°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 month</td>
<td>11.7</td>
<td>10</td>
<td>9.0</td>
</tr>
<tr>
<td>3 months</td>
<td>11.6</td>
<td>11.1</td>
<td>10.9</td>
</tr>
</tbody>
</table>
Results – elevated temperatures + carbonation

Figure 2

<table>
<thead>
<tr>
<th>Temperature</th>
<th>21°C</th>
<th>45°C</th>
<th>60°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 month</td>
<td>11.7</td>
<td>10.5</td>
<td>10.5</td>
</tr>
<tr>
<td>3 months</td>
<td>10.0</td>
<td>8.4</td>
<td>8.4</td>
</tr>
</tbody>
</table>
Time-temperature superposition

- Plot the UCS vs. time results on a natural log-log scale.
- Adopt results at room temperature as the reference $T_o$.
- Shift all other results along the x-axis relative to $T_o$.
- Obtain shift factors ($a_T$).

Figure 3 Plot of the shifted curves for temperature alone data
Temperature alone

- Plot the shift factors ($a_T$), previously obtained against $(1/T_o - 1/T)$, the slope of the curve is $-E_a/R$.

Figure 4 Plot of shift factors against difference in temperature reciprocals
Time-temperature superposition

- $E_a$ is the only unknown in;

$$t_e = t \cdot \exp \left\{ -\frac{E_a}{R} \left( \frac{1}{T} - \frac{1}{T_o} \right) \right\} \quad \text{Equation 2}$$

- Therefore $t_e$ can be evaluated.
- Similar shifting and plotting of shift factors was carried out for the elevated temperatures and carbonation combination.

**Equivalent time $t_e$, after 3 months curing**

- Elevated temperature: 2.9 years
- Elevated temperatures + carbonation: 5.2 years
Time-temperature superposition

Correlation between site and laboratory results

<table>
<thead>
<tr>
<th>Property</th>
<th>Site</th>
<th>Elevated temperatures</th>
<th>Elevated temperatures + carbonation</th>
</tr>
</thead>
<tbody>
<tr>
<td>UCS (MPa)</td>
<td>4</td>
<td>10.6 (extrapolated)</td>
<td>2.6</td>
</tr>
</tbody>
</table>

- Direct comparison not possible due to differences
- Site soil vs. freshly spiked model soil
- More chemicals in site soil
- Densities different
- Better correlation when similar soil was used.
- $E_a/R$ obtained for the temperature + carbonation case 24% higher than that for temperature alone.
- More carbonation resulted in less UCS.
Conclusion

- UCS followed the trend; elevated temperature mix > site mix > elevated temperature + carbonation mix.
- Suitable scenario - longer initial temperature curing followed by a short carbonation period.
- Arrhenius equation was shown to be applicable to both elevated temperatures and temperature + carbonation.
- A much better correlation obtained when same materials were compared.
- Close to site combination of conditions (level of carbonation, chemicals etc) would give better comparison with site.