EFFECTS OF SURFICIAL SEASONAL WEATHERING ON CENTRIFUGED OIL SANDS TAILINGS

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Introduction

Mature Fine Tailings (Rowell, 2014)

30% Solids Content

Centrifuged Tailings (COSIA)

MFT Centrifugation Process (OSTC Report, 2012)

50%~60% Solids Content
Problem Statement

Challenges

- Trafficable Deposit
- Sufficient Strength
- Reasonable Time

Potential

The effect of cyclic freeze-thaw and seasonal weathering
The previous research were limited to freeze thaw cycle effect on MFT particles and the results concluded that the samples experienced the highest thaw strain in their first cycle.

The previous results suggested that the higher initial solids content (50%~60%) did not increase much upon thaw compared to MFT.

The combined effect of drying-wetting between each freeze thaw cycle have not been investigated yet.

There is a gap in conceptual theory on the effect of multiple cyclic freeze thaw and drying wetting on the stability of the tailings surface area.
Objective

The main objectives of the paper are as follows:

- To evaluate the effect of the natural conditions (repeated freeze thaw cycles, summer drying and precipitation) on the strength of existing treated tailings deposit that is filled up and waiting for reclamation.

- To establish an enhanced understanding of the volume change and the engineering behavior of the tailings deposits exposed to surficial seasonal weathering.
Concept

- Frost Depth
- Unfrozen Tailings
- Winter
- Fall and Spring
- Released Water
- Thawed Tailings
- Summer
- Surface Crust
- Unfrozen Tailings
- Rainfall
- Taifroze Settling
Methodology - Lab Test

Freeze Thaw (1st Cycle) → Drying-Wetting (1st Cycle)
Freeze Thaw (2nd Cycle) → Drying-Wetting (2nd Cycle)
Freeze Thaw (3rd Cycle) → Drying-Wetting (3rd Cycle)
Freeze Thaw (4th Cycle) → Drying-Wetting (4th Cycle)
Freeze Thaw (5th Cycle) → Drying-Wetting (5th Cycle)

Sectional Analysis
Freeze-Thaw Test
Freeze-Thaw Test Setup

(a) Freeze-thaw cell
- Attached to top cap
- Inlet for inserting thermistors
- Cooling plate at bottom
- Attached to constant temperature bath

(b) Connecting cell with temp bath

(c) Freezing cycle set up
Freeze-Thaw Test

(a) Ice lens formation during freezing
(b) Sample after thaw
(c) Sample after removal of water
(d) Sample after multiple freeze-thaw
Atmospheric Drying Test

(a) Atmospheric Drying /Evaporation Test
Drying and Wetting Test

(a) Shrinkage observed during Drying Test

(b) Wetting Test
Drying and Wetting Test

(a) Sample after re-wetting test

(b) Top surface after re-wetting test
Results-Freeze-Thaw Effect

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Total Thaw Strain (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-15</td>
<td>22.4</td>
</tr>
<tr>
<td>-10</td>
<td>22</td>
</tr>
<tr>
<td>-5</td>
<td>27.6</td>
</tr>
</tbody>
</table>
Results - Seasonal Weathering Effect

Average Solids Content (%)

-15°C (top), 0°C (bottom)
-10°C (top), 0°C (bottom)
-5°C (top), 0°C (bottom)

Shear Strength at surface (kPa)

-15°C (top), 0°C (bottom)
-10°C (top), 0°C (bottom)
-5°C (top), 0°C (bottom)
Results-Combined Analysis

Solids Content (%) vs. Shear Strength (kPa) over time for different wetting and drying cycles at temperatures of -5°C and -10°C.
Results-Combined Analysis

-15ºC

Average Solids Content (%)

Shear Strength (kPa)

Days

Wetting Event

Wetting Event

Wetting Event

Wetting Event

Wetting Event

Wetting Event

Wetting Event

1st Freeze-thaw cycle

1st Drying cycle

2nd Freeze-thaw cycle

2nd Drying cycle

3rd Freeze-thaw cycle

3rd Drying cycle

4th Freeze-thaw cycle

4th Drying cycle

5th Freeze-thaw cycle

5th Drying cycle

6th Freeze-thaw cycle

6th Drying cycle

7th Freeze-thaw cycle

7th Drying cycle

8th Freeze-thaw cycle

8th Drying cycle

9th Freeze-thaw cycle

9th Drying cycle

10th Freeze-thaw cycle

10th Drying cycle

11th Freeze-thaw cycle

11th Drying cycle

12th Freeze-thaw cycle

12th Drying cycle

13th Freeze-thaw cycle

13th Drying cycle

14th Freeze-thaw cycle

14th Drying cycle

15th Freeze-thaw cycle

15th Drying cycle

16th Freeze-thaw cycle

16th Drying cycle

17th Freeze-thaw cycle

17th Drying cycle

18th Freeze-thaw cycle

18th Drying cycle

19th Freeze-thaw cycle

19th Drying cycle

20th Freeze-thaw cycle

20th Drying cycle

21st Freeze-thaw cycle

21st Drying cycle

22nd Freeze-thaw cycle

22nd Drying cycle

23rd Freeze-thaw cycle

23rd Drying cycle

24th Freeze-thaw cycle

24th Drying cycle

25th Freeze-thaw cycle

25th Drying cycle

26th Freeze-thaw cycle

26th Drying cycle

27th Freeze-thaw cycle

27th Drying cycle

28th Freeze-thaw cycle

28th Drying cycle

29th Freeze-thaw cycle

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30th Freeze-thaw cycle

30th Drying cycle

31st Freeze-thaw cycle

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34th Drying cycle

35th Freeze-thaw cycle

35th Drying cycle

36th Freeze-thaw cycle

36th Drying cycle

37th Freeze-thaw cycle

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38th Freeze-thaw cycle

38th Drying cycle

39th Freeze-thaw cycle

39th Drying cycle

40th Freeze-thaw cycle

40th Drying cycle

41st Freeze-thaw cycle

41st Drying cycle

42nd Freeze-thaw cycle

42nd Drying cycle

43rd Freeze-thaw cycle

43rd Drying cycle

44th Freeze-thaw cycle

44th Drying cycle

45th Freeze-thaw cycle

45th Drying cycle

46th Freeze-thaw cycle

46th Drying cycle

47th Freeze-thaw cycle

47th Drying cycle

48th Freeze-thaw cycle

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68th Drying cycle

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69th Drying cycle

70th Freeze-thaw cycle

70th Drying cycle

71st Freeze-thaw cycle

71st Drying cycle

72nd Freeze-thaw cycle

72nd Drying cycle

73rd Freeze-thaw cycle

73rd Drying cycle

74th Freeze-thaw cycle

74th Drying cycle

75th Freeze-thaw cycle

75th Drying cycle

76th Freeze-thaw cycle

76th Drying cycle

77th Freeze-thaw cycle

77th Drying cycle

78th Freeze-thaw cycle

78th Drying cycle

79th Freeze-thaw cycle

79th Drying cycle

80th Freeze-thaw cycle

80th Drying cycle

81st Freeze-thaw cycle

81st Drying cycle

82nd Freeze-thaw cycle

82nd Drying cycle

83rd Freeze-thaw cycle

83rd Drying cycle

84th Freeze-thaw cycle

84th Drying cycle

85th Freeze-thaw cycle

85th Drying cycle

86th Freeze-thaw cycle

86th Drying cycle

87th Freeze-thaw cycle

87th Drying cycle

88th Freeze-thaw cycle

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100th Freeze-thaw cycle

100th Drying cycle

101st Freeze-thaw cycle

101st Drying cycle

102nd Freeze-thaw cycle

102nd Drying cycle

103rd Freeze-thaw cycle

103rd Drying cycle

104th Freeze-thaw cycle

104th Drying cycle

105th Freeze-thaw cycle

105th Drying cycle

106th Freeze-thaw cycle

106th Drying cycle

107th Freeze-thaw cycle

107th Drying cycle

108th Freeze-thaw cycle

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136th Freeze-thaw cycle

136th Drying cycle

137th Freeze-thaw cycle

137th Drying cycle

138th Freeze-thaw cycle

138th Drying cycle

139th Freeze-thaw cycle

139th Drying cycle

140th Freeze-thaw cycle

140th Drying cycle

141st Freeze-thaw cycle

141st Drying cycle

142nd Freeze-thaw cycle

142nd Drying cycle

143rd Freeze-thaw cycle

143rd Drying cycle

144th Freeze-thaw cycle

144th Drying cycle

145th Freeze-thaw cycle

145th Drying cycle
Results - Combined Analysis

(a) Sample at -5°C
(b) Sample at -10°C
Conclusion

- The multiple freeze thaw and drying wetting cycles are found effective to develop a surface crust with a solids content of over 83% and an associated shear strength of over 100 kPa.
- The thaw strain and subsequent undrained shear strength of the centrifuged tailings are affected by the temperature gradient, freezing rates and the number of freeze thaw cycles, provided melt water is removed.
- Drying-wetting cycles are affected by the meteorological parameters in the field.
- The shear strength remained unaffected by the re-wetting test once the solids content exceeded approximately 82% and it started behaving like a soil.
Acknowledgement

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• Canada’s Oil Sands Innovation Alliance (COSIA)
• Alberta Innovates – Energy and Environment Solutions (AL-EES)
• University of Alberta Geotechnical Centre
Thank You
### Results-Index Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content, $w$ (%)</td>
<td>89</td>
</tr>
<tr>
<td>Solids content, $s$ (%) $^1$</td>
<td>53</td>
</tr>
<tr>
<td>Bitumen content, (%)</td>
<td>5.7</td>
</tr>
<tr>
<td>Specific gravity, $G_s$</td>
<td>2.24</td>
</tr>
<tr>
<td>Material finer than 0.044 mm (%)</td>
<td>87</td>
</tr>
<tr>
<td>Material finer than 0.002 mm (%)</td>
<td>52</td>
</tr>
<tr>
<td>Liquid limit, $w_l$ (%)</td>
<td>57</td>
</tr>
<tr>
<td>Plastic limit, $w_p$ (%)</td>
<td>26</td>
</tr>
<tr>
<td>USCS classification</td>
<td>CH</td>
</tr>
</tbody>
</table>

1. $s = 1 / (1 + w)$

### Diagram

- [Particle Diameter (mm) vs. % Finer](chart)
## Results-Solids Mineralogy

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minerals (% weight)</td>
<td>Non-clay: Quartz (40); Siderite (3); Potassium Feldspar (2); Pyrite (2); Dolomite (1)</td>
</tr>
<tr>
<td>Bulk and Clay</td>
<td>Clay: Kaolinite (36); Illite (15) = total clay (52%)</td>
</tr>
<tr>
<td>Clay fraction (%)</td>
<td>50</td>
</tr>
<tr>
<td>From MBI</td>
<td></td>
</tr>
<tr>
<td>Specific surface area (m²/g)</td>
<td>38</td>
</tr>
<tr>
<td>Exchangeable cations (cmol(+)/kg)</td>
<td>Ca²⁺ (10); Na⁺ (4.4); Mg²⁺ (2.6); K⁺ (0.4)</td>
</tr>
<tr>
<td>Total CEC (meq/100g)</td>
<td>17.4</td>
</tr>
</tbody>
</table>
## Results - Pore Water Chemistry

<table>
<thead>
<tr>
<th>Property</th>
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<tr>
<td>pH</td>
<td>8.69</td>
</tr>
<tr>
<td>Electrical conductivity (µs/cm)</td>
<td>3560</td>
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<tr>
<td><strong>Dissolved ions (mg/L)</strong></td>
<td></td>
</tr>
<tr>
<td>Cations:</td>
<td>Na⁺ (780); K⁺ (14.6); Mg²⁺ (15.9); Ca²⁺ (36.5)</td>
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<td>Anions:</td>
<td>HCO₃⁻ (1207); Cl⁻ (446); SO₄²⁻ (17.7); PO₄³⁻ (48); CO₃²⁻ (3.5); F⁻ (2.47); Br⁻ (0.53); NO₃⁻ (0.26);</td>
</tr>
<tr>
<td>TDS:</td>
<td>2573</td>
</tr>
<tr>
<td>Ionic Strength (mol/L)</td>
<td>0.039¹</td>
</tr>
<tr>
<td>SAR (ESR)</td>
<td>27²(0.41)</td>
</tr>
</tbody>
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1. Ionic strength, \( I = \frac{1}{2} \sum n_0 v^2 \); where, \( n_0 \) = ion concentration, \( v \) = valence

2. \( SAR = \frac{[Na^+]}{\sqrt{Ca^{2+}+Mg^{2+}}} \)

3. As received MFT

4. Bitumen-free MFT
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2. \( \text{SAR} = \frac{[\text{Na}^+]^{1}}{\sqrt{[\text{Ca}^{2+}] + [\text{Mg}^{2+}]}} \)

3. As received MFT

4. Bitumen-free MFT
Results - Closed vs Open

-5°C (top), 0°C (bottom), closed
-5°C (top), 0°C (bottom), open

Thaw Strain (%)

<table>
<thead>
<tr>
<th>Freeze-Thaw Cycle</th>
<th>Cycle 1</th>
<th>Cycle 2</th>
<th>Cycle 3</th>
<th>Cycle 4</th>
<th>Cycle 5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10.7</td>
<td>1.6</td>
<td>8.9</td>
<td>9.2</td>
<td>7.7</td>
</tr>
</tbody>
</table>

Average Solids Content (%)

-5°C (top), 0°C (bottom) closed
-5°C (top), 0°C (bottom) open
**Results- Closed vs Open**

- **Shear Strength at surface (kPa)**
  - -5°C (top), 0°C (bottom) open
  - -5°C (top), 0°C (bottom) closed

- **pH**
  - -5°C (top), 0°C (bottom) open
  - -5°C (top), 0°C (bottom) closed

(a) Sample after open testing freezing