Municipal Solid Waste
Particle Size Effects on
Compression Behavior

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Objectives

Enhance sustainable solid waste management

• Use laboratory findings to predict waste behavior

• Evaluate effects of waste processing on compression behavior

• Develop laboratory procedures for the evaluation of solid waste → move towards standard method

Hypothesis

• Large, stiff particles occupy greater continuous space, create a stiffer waste matrix
MSW Basics

- MSW annual generation in US = 250 million tons (2011)
  - 54% still disposed in landfills → need geotechnical properties
- Composition: paper, food waste, yard trimmings, wood, rubber, leather, textiles, plastics, metals, glass

Geotechnical properties:
- Shear strength and stability
- Compression
- Hydraulic conductivity

Bareither et al. (2010)
Challenges working with MSW (or any solid waste):

- Heterogeneity
- Varying
- Changes with time (decomposition)
Laboratory Testing of MSW

Challenges testing MSW:

• Scale effects: laboratory versus field
• Waste shredding
• Consistent composition
• Controlling degradation
• Non-standardized laboratory MSW evaluations
• Effective characteristic assessment for empirical estimates of model parameters
**MSW Settlement/Decomposition**

Total settlement = **Immediate** + **Time-dependent**

\[ S(t) = H_0 \left( C'_c \times \log \frac{\sigma_v + \Delta \sigma_v}{\sigma_v} \right) + H_M \left( C'_{\alpha M} \times \log \frac{t_B}{t_M} + C'_{\alpha B} \times \log \frac{t_F}{t_B} + C'_{\alpha MF} \times \log \frac{t}{t_F} \right) \]

- Immediate compression:
  \[ C'_c = \Delta \varepsilon / \Delta \log \sigma \]

- Mechanical creep:
  \[ C'_{\alpha M} = \Delta \varepsilon / \Delta \log t \]

- Biocompression:
  \[ C'_{\alpha B} = \Delta \varepsilon / \Delta \log t \]

- Final mechanical creep:
  \[ C'_{\alpha MF} = \Delta \varepsilon / \Delta \log t \]
Experimental Set-up

- Prepared MSW to replicate field waste composition
- Similar initial composition, dry unit weight, and water content
- 3 x 100-mm-diameter compression cells
  - Temperature and stress control
  - Leachate and gas management
- Varying maximum particle size
  - P25: < 25.4 mm
  - P9: < 9.5 mm
  - P4: < 4.75 mm
Operation

Stress application:

- Incremental loading to evaluate immediate compression
- Constant stress (59 kPa) phase with leachate dosing: evaluate mechanical creep and biocompression

Leachate:

- Initiated on Day 50
- Dosing: 78 L/Mg-MSW/week
- Sampled ~ twice per week: $V_{\text{EFF}}$, pH, COD

Biogas

- Collected as needed
- Volume measured in air-tight syringes

Temperature: 45-47°C,

- Even throughout heat box using electric heater and fan
Results: Immediate Compression

- R-Ratio = \( \frac{\text{compression cell diameter}}{\text{max MSW particle size}} \):
  - Smaller particle size = Larger R-Ratio
  - P25 = R-4, P9 = R-11, P4 = R-21

- Compression ratios \( C_c' = \frac{\Delta \varepsilon}{\Delta \log \sigma} \)
  - DTBE = 0.23
  - R-21, 100 mm = 0.25
  - R-11, 100 mm = 0.25
  - R-4, 100 mm = 0.17
  - R-13, 64 mm = 0.11
  - R-11*, 100 mm = 0.21
  - R-12, 305 mm = 0.18

Additional data from Bareither et al. (2012)
**Results: Immediate Compression**

- $C_c'$ increase with stress increase
- Literature shows leveling off > 100 kPa
- Laboratory Range: 0.17 – 0.25
- Varying compaction efforts between specimens

Additional data from Bareither et al. (2012)
Time-Dependent Compression

• Before dosing: increase in MSW compressibility with decrease in maximum particle size
  • Through Day 20: \( C_{\alpha}' = 0.048 \) (R-21), 0.036 (R-11), 0.025 (R-4)

• Leachate dosing on Day 50
  • Increase in compression rate for all specimens
  • Moisture-induced softening of particles (R-21, R-11) vs. biocompression (R-4)
  • Greatest rate of increased strain in R-4 specimen, behavior reflects anticipated
Results: pH, COD

- R4 specimen
- Methanogenesis indicators:
  - CH$_4$ production
  - pH increase and stabilization
  - Acid reduction
- Lowest pH measured on Day 94, coincided with peak effluent COD
- Trends consistent with anaerobic biodegradation

![Graph showing pH and COD over elapsed time](image)
Compression Comparison

- Small, stiff, particles have less impact on overall compression compared to larger, stiff particles that occupy more space.

- Finely-shredded MSW increased surface area and may lead to enhanced hydrolysis and fermentation.

P4 schematic

P25 schematic
Observations

• Greater perceived compaction effort for specified MSW dry unit weight with an increase in waste particle size

• Rate of physical MSW compression increased with a decrease in MSW particle size

• Low pH in R-21 and R-11 specimens during leachate dosing and no increased compression rates = likely acid-stuck conditions and inhibited biodegradation

• Mechanical creep and biocompression rates in 100-mm cells are low relative to rates measured on similar-sized waste in a 300-mm cell and at field scale
Conclusions

• Smaller particle size (increase in R-ratio of specimen diameter to particle size) = greater rate of physical MSW compression
  
  • Specimens with larger particles created a stiffer matrix
  
  • Small, stiff, shredded particles less of an effect than larger, stiff particles occupying more space within the specimen
  
• Finely shredded MSW may lead to enhanced initial rates of hydrolysis and fermentation → low pH levels not conducive to biocompression/methanogenesis
  
• Low mechanical creep rates→ may not be representative of field-scale behavior
Questions?
MSW Settlement/Decomposition

Total settlement = **Immediate settlement** + **Time-dependent settlement**

**Cc’ + Cα’ Model:**

\[ S(t) = H_0 \left( C'_c \ast \log \frac{\sigma'_v + \Delta \sigma'_v}{\sigma'_v} \right) + H_M \left( C'_{\alpha M} \ast \log \frac{t_B}{t_M} + C'_{\alpha B} \ast \log \frac{t_F}{t_B} + C'_{\alpha MF} \ast \log \frac{t}{t_F} \right) \]

- **S(t)** = Total settlement
- **H_0** = Initial specimen thickness
- **C'_c** = Immediate Compression ratio
- **σ'_v** = Initial vertical effective stress
- **Δσ'_v** = Change in vertical effective stress i.e. load increment
- **H_M** = Waste thickness after immediate compression
- **C'_{\alpha M}** = Mechanical creep compression ratio
- **C'_{\alpha B}** = Biodegradation-induced compression ratio
- **C'_{\alpha MF}** = Final Mechanical creep compression ratio
- **t_M** = Time for onset of mechanical creep; end of immediate compression
- **t_B** = Time for onset of biocompression; end of mechanical creep
- **t_F** = Time for onset of final mechanical creep; end of biocompression
Data from Bareither et al. 2012
Methane Generation Data

- Methane Flow Rate (mL-CH₄/g-dry MSW/d)
- Methane Yield (mL-CH₄/g-dry MSW)

Graph showing the relationship between elapsed time (d) and methane flow rate and yield.
References


