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COLLEGE OF ENGINEERING | School of Civil and Construction Engineering

Microbially Induced Corrosion: Mechanisms and a Discussion of Standardized Testing Uses and Limitations

Ali Erbektas, Ivan Zaw, Burkan Isgor and Jason Weiss

March 28th, 2021

American Concrete Institute

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Microbially Induced Corrosion of Concrete

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- Corrosion of concrete in sewer infrastructures is a worldwide concern. Although the mechanism of this corrosion was discovered in the middle of last century, it was not a universal concern until the late 1990s. Since then, research has confirmed that the cause of this corrosion is a biogenic acid attack. Solutions for mitigation and testing processes for assurance have been developed. This session is for anyone interested in knowing exactly what causes sewer corrosion and what methods of mitigation are available.
- Learning Objectives:
- (1) Describe the biological mechanism that is responsible for the deterioration of concrete in some sewer infrastructures;
- (2) Explain the how biological corrosion differs from traditional chemical and physical attack;
- (3) Summarize mitigation methods to reduce the rates of degradation to concrete exposed to the effects of microbially induced corrosion;
- (4) Identify methods to simulate the biological mechanism.

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Description

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- Description: This presentation discusses microbially induced corrosion (MIC) of concrete products. Specifically, it outlines that this is a three-stage process and discusses recent developments of a standard guide and laboratory test methods for determining the resistance of concrete to MIC. The three-stage process includes the reduction in pH (Stage I) (e.g., pH > 9-10), the attachment of biofilms which further lowers the pH (stage II) (e.g., 9-10 > pH > 4-6) and eventual deterioration due to biogenic acid exposure (Stage III) (e.g., < ~4 pH). Although the guide is intended for concrete products, it also covers specialized products. The presentation will discuss coming tests as well as limitations of tests.

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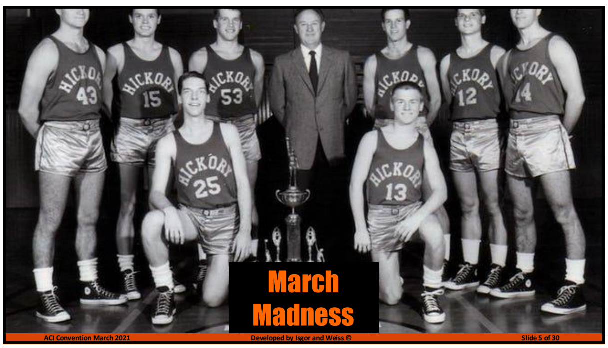

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You May Think B-Ball, but Progress and Plumbing

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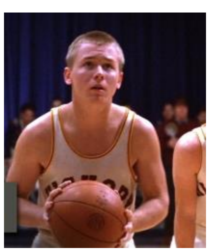
"Progress... progress is electricity, school consolidation, church remodeling, 2nd farm tractors, 2nd farm cars, hay bailers, corn pickers, grain combines, field choppers, and indoor plumbing." - Ollie



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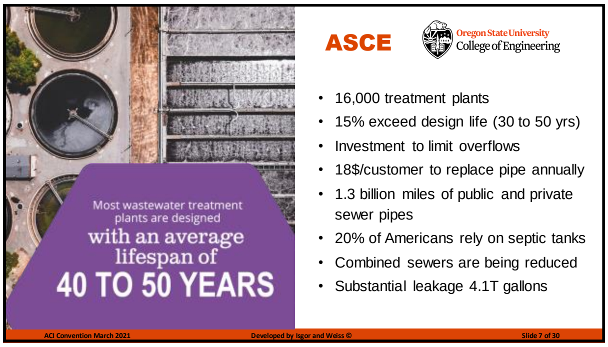
Most wastewater treatment plants are designed
with an average lifespan of
40 TO 50 YEARS
ASCE
Oregon State University College of Engineering
• 16,000 treatment plants
• 15% exceed design life (30 to 50 yrs)
• Investment to limit overflows
• 18$/customer to replace pipe annually
• 1.3 billion miles of public and private sewer pipes
• 20% of Americans rely on septic tanks
• Combined sewers are being reduced
• Substantial leakage 4.1T gallons
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Concrete Has Been a Choice for Wastewater Infrastructure
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Sewer pipes
Manholes
Lift stations
cpm-group.com
hudsoncivil.com.au
hudsoncivil.com.au
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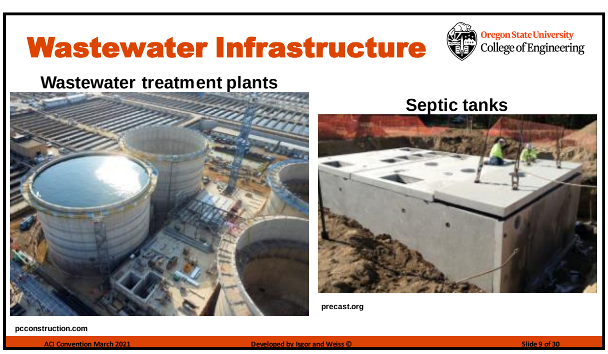
Wastewater Infrastructure
Oregon State University College of Engineering
Wastewater treatment plants
Septic tanks
precast.org
pcconstruction.com
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However, Some Forms of Damage Can Occur

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conseal.com

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- Currently – ACI is Silent on this Major Issue
- This is problematic as it lets others do the talking
- A Task Group has been Established by ACI 201; however, documentation and leadership is needed

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Microbially Induced Corrosion (MIC)

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- Some bacteria reduce sulfate
- In doing, they produce hydrogen sulfide, which escapes
- Acidothiobacillus thiooxidans produce sulfuric acid and can damage concrete
- Ferrobacillus ferrooxidans oxidizes iron to iron oxides and forms rusticles
- Not Metallic Corrosion


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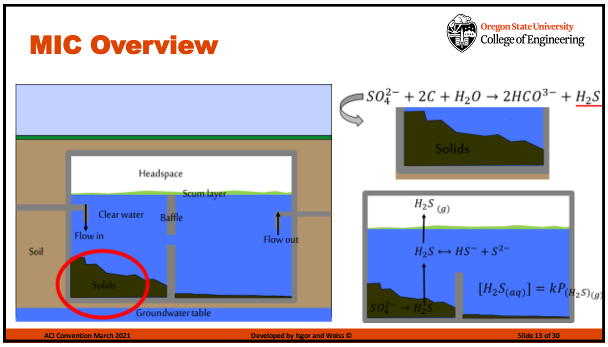
MIC Overview
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College of Engineering
$SO_4^{2-} + 2C + H_2O \rightarrow 2HCO^{3-} + H_2S$
Solids
Headspace
Scum layer
Clear water
Baffle
Flow in
Flow out
Soil
Solids
Groundwater table
$H_2S_{(g)}$
$H_2S \leftrightarrow HS^- + S^{2-}$
$[H_2S_{(aq)}] = kP_{(H_2S)(g)}$
$SO_4^{2-} \rightarrow H_2S$
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MICC In Concrete
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TZ
concrete
deterioration layer
Courtesy of Sam Lines, Concrete Sealants Inc.
Grengg et al., 2017
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COLUMBIA PICTURES CORPORATION
presents
THE THREE STOOGES
MOE
LARRY
CURLEY

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Three Stages

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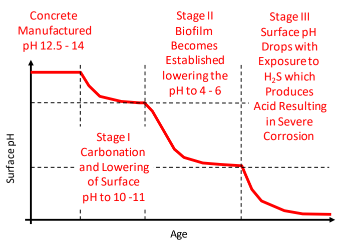

Photo 107644641 © Sutiponmm | Dreamstime.com

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Stage I: Carbonation

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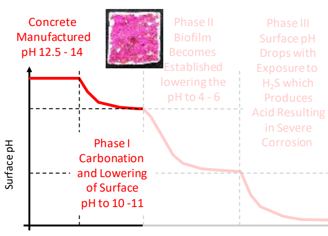
- Carbonation:
  - Dissolution of CH with fluid movement,
  - Movement of CO_2 through pore solution and reaction with Calcium Hydroxide
- CH maintains pH
- Not classic carbonation, its about surface issues



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Stage II - Attachment

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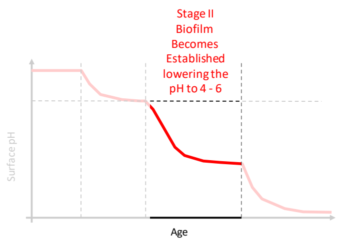
- Rate of attachment and succession depends on bacteria's "happiness"
  - Temperature
  - Surface texture
  - Moisture
  - Availability of nutrients
- Antimicrobials are discussed as altering this mechanism



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Stage III: Deterioration

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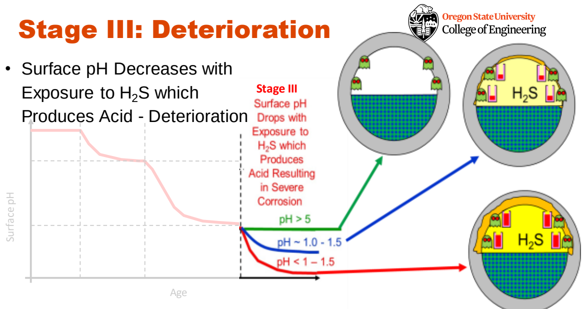
- Surface pH Decreases with Exposure to H_2S which Produces Acid - Deterioration



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Now What Do We Know

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- We may have a problem with sewer damage - MICC
- Its a three-stage problem
  - pH reduction
  - Attachment
  - Deterioration
- **Is there a test for this ?**

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ASTM Activities

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- Tip of the cap to ASTM C13 for stepping up
- Committee has been very active to bring some of the first standards forward
- Three Standards
- ASTM C1894-19 (Guide)
- ASTM C1904-20 (Biogenic Acidification)
- ASTM C1898-20 (Chemical Acidification)
- Needs – B3B; Chemical Acidification

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Guidance Document

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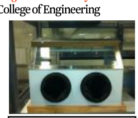
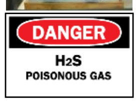
- Guide discusses MIC of concrete products
- Discusses test methods for resistance to MIC
- Sets the stage for testing and to discuss which tests are applicable for which circumstances
- Specifically, it discusses where some of the exposure chambers or other tests exist like the biogenic chamber
- Refines where Test Methods for Chemical Acid Resistance are and are not applicable





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ASTM C1904-20

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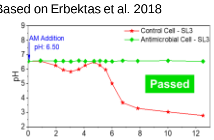
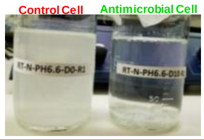
- Option A – Solution
- Option B1 – Paste/Mortar (Proportion Defined)
- Option B2 – Paste/Mortar (Alternative Proportion)
- Option C – Paste/Mortar (Driven through Biogenic to Chemical Acidification)
- Based on Erbektas et al. 2018



Biogenic acidification

Control Cell Antimicrobial Cell



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Testing on Paste and Mortar

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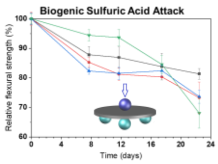
- Biogenic acid attacks the cement paste portion of concrete.
- B3B is a flexural strength testing.
- More sensitive to deterioration.



Diameter: 2 in.
Thickness: 2.65 ± 0.15 mm

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ASTM C 1904-20

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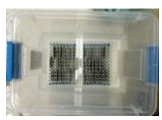
- The goal of this test is to provide a relatively simple, rapid and reliable test to simulate biogenic acidification
- We want to capture the attachment phase
- We want to capture the biogenic acidification, bacteria consumes sulfur or thiosulfate, no H_2S gas is needed
- Want to be able ti evaluate antimicrobial additives
- We create conditions for both Stage II & Stage III.
- Bio-safety Level I bacteria, "special" biological safety precautions are necessary.



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ASTM C 1898-20

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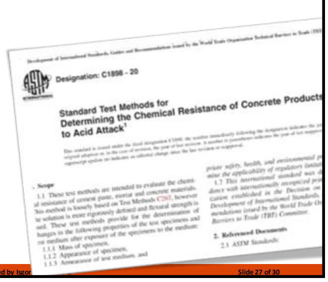
- The goal of this test is to provide a revised acid resistance testing
- This is 'revising the current C267' standard to make it more consistent
- We want to capture the chemical acidification
- Does not directly evaluate antimicrobial additives


Designation: C1898 – 20

Standard Test Methods for Determining the Chemical Resistance of Concrete Products to Acid Attack

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Phase III: Chemical Acidification (House et al. 2014; ASTM C267)

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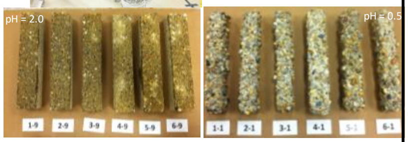
ASTM 1898-20

Parameters:

- Solution-to-sample volume 4:1
- 7 day exposure cycles
- Acid solns replaced every 7 days

Performance measures:

- Acid consumption
- Mass loss
- Cross section thickness
- Relative dynamic modulus
- Visual inspection



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ASTM – C1898-20

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- House et al. (2014) examined ASTM C267
- This is developed from C267 with modifications to reduce gray areas
- Specifically
  - Fix volume, single/multiple mixtures
  - pH can change during the test; improvements are needed Zaw (2021) performing strong work in this area
  - We need to understand what Stage we are examining (Stage III)
  - We need to understand what pH can and should be used

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Conclusions

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- Substantial work underway to better understand and predict biogenic acidification
- Clear evidence has been shown for a three stage process: 1) "Carbonation", 2) Attachment, 3 Degradation (Note pH is the key issue)
- Specifically, OSU has worked with NPCA/ACPA and ASTM C13 to develop new standards
  - ASTM C1894-19 "Standard Guide to MICC"
  - ASTM C1904-20 "Biogenic Acidification", "product qualification"
  - ASTM C1898-20 "Chemical Acidification" (Revised ASTM C267)
- Substantial changes to how this degradation process will be viewed moving forward
- Value Added materials
  - Innovative cementitious systems and additives
  - Innovative topical treatments
  - Movement to Modeling

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