Corrosion in underground metal mines

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NIOSH Research Team:
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Research Collaborators:
Hecla Mining Company
Montana Tech
Jennmar Corporation
NIOSH Mining Research Program

- Research seeks to work with industry and other collaborators to eliminate occupational diseases, injuries, and fatalities from the mining workplace

- Facilities in Spokane, WA and Pittsburgh, PA

- Spokane Mining Research Division (SMRD)
  - Focus on Western Mining safety and health
  - Metal Ground Control, Induced Seismicity, Automation Technology, and Miner Health teams
  - ~40 people split between the four groups
Outline

• Background
  • Corrosion in Mining

• Bolts and mesh
  • Field tests
  • Lab tests

• Future work
  • Pull tests
  • Non-destructive Testing
Low pH ground water
Juneau, Alaska

Some areas rehabilitated 6 months after installing ground support
Galvanic Rock Corrosion Mechanism

Galvanic Series

<table>
<thead>
<tr>
<th>Metal</th>
<th>Volts vs Cu-CuSO₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active or Anodic End</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td>-1.10</td>
</tr>
<tr>
<td>Clean Carbon Steel</td>
<td>-0.50 to -0.80</td>
</tr>
<tr>
<td>Rusted Carbon Steel</td>
<td>-0.20 to -0.50</td>
</tr>
<tr>
<td>Carbon, Graphite</td>
<td>+0.30</td>
</tr>
<tr>
<td>Nobel or Cathodic End</td>
<td></td>
</tr>
</tbody>
</table>
Field Tests

- Resistivity Measurements
- Coupons
- Time of wetness sensors
- MIC
Rock Mass Resistivity

• Electrical characteristic of the rock mass/soil/ground water which affects the ability of corrosion currents to flow through the electrolyte (rock mass, soil, groundwater)

• Function of moisture and the concentrations of ionic soluble salts – considered the most comprehensive indicator of a soil’s corrosivity in the pipeline industry

Werner Array – Rock Mass Resistivity

- Resistivity Measurement
- Four equally spaced electrodes
- C1 and C2 – Current electrodes
- P1 and P2 – Potential electrodes
- Depth of current penetration correlates to electrode spacing

\[
\text{Resistivity} = 2\pi a \left(\frac{V}{I}\right)
\]

\(a\) = electrode spacing
\(V\) = measured voltage
\(I\) = current

After ASTM D 6431: Standard Guide for using the direct current resistivity method for subsurface investigation
Rock Mass Resistivity Measurements

Measurement device designed by SMRD Electrical Engineer
Carl Sunderman
Classification system

C1: Negligible
C2: Localized
C3: Surface
C4: Advanced
C5: Very Advanced
C6: Extreme

After Dorion J.F. & Hadjigeorgiou, J. 2014
Resistivity data

![Graph showing resistivity data with two mine types: AK Mine and MT Mine. The x-axis represents Corrosion Severity, and the y-axis represents Resistivity on a logarithmic scale.]
Current Research – Field
Corrosion coupons – Alaska and Montana
Time of wetness and atmospheric monitoring in Montana mine

Sending Corrosion Sensor Data to the Cloud

Gateway (in mine)

Corrosion Sensors
Wireless Sensor Network (in mine)

Researchers Desktop/Phone

Amazon AWS

Graph showing temperature, humidity, and capacitance over time.
Microbial Influenced Corrosion

- Sulfate Reducing Bacteria (SRB) most common

- Reduction of sulfate to hydrogen sulfide leads to increased corrosion

- \( \text{SO}_4^{2-} \rightarrow \text{H}_2\text{S} \)
Lab Tests

- Laboratory tension testing of ground support
  - Multiple samples with a range of corrosion severity

- Tension bolt drip system

- Humidity room coupons
Tension Pull Tests
Wire Mesh Pull Tests

\[ y = 138.78x^{1.8527} \]
\[ R^2 = 0.8522 \]

\[ y = 0.5384e^{0.562x} \]
\[ R^2 = 0.6273 \]
Tensioned bolt drip system

Development of tensioned rock bolt testing

• Bolts donated by Jennmar
• Load Frames built in house – set out for corrosion resistant coating (Precision Dip Coating LLC)
• Frames built and scratch methodology developed at SMRD
• Tests will run for 6 months
Current Research - Lab

• Fog room bolt coupons 18 sets in 16 different rock types with 2 control sets from Alaska Mine

• Expected time of results: 3, 6, and 12 month test series
Lab coupons

- Mass loss
- Rockwell hardness
- SEM analysis
Estimation of Rock Bolt Longevity – Engineering Practice/collaborator

- Empirical study
- Estimate corrosion rate in terms of bolt capacity
- Pull bolts to failure with rock bolt pull tester
  - Bolts of different ages – install own or use mine bolts
  - Different corrosive environments (corrosion rates)
Estimation of Rock Bolt Longevity – Engineering Practice/collaborator

- Goal: produce design chart to estimate bolt life
  - Engineering tool decide use inexpensive (corrosion prone)
  - Vs. cost effective (?) to install expensive corrosion resistant bolts
  - Safety: life of bolt- better estimates of rehab schedule- reduce corrosion related fall-of-ground (FOG)

Hypothetical Empirical rock bolt lifetime estimation - high corrosion rate

\[ y = -14.095x + 14.175 \]

Hypothetical data
Non Destructive Monitoring

Circuit schematic of the half-cell potential technique

Ultrasonic measurement
Shotcrete overlay

• Shotcrete encasement of non-submerged support

• Studies of corrosion propagation through shotcrete in western underground metal mines
Thank you

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