Corrosion Issues & Test Methods

Jerry Byers
Cost of Corrosion to US Industries

- **Corrosion** is the deterioration of a material (often a metal) due to interaction with its environment.
- A study in 1998 estimated the direct cost of corrosion to be $275.7 Billion
- Represents 3.1% of the US Gross Domestic Product
- Indirect costs (lost productivity due to outages, delays, failures, and litigation) considered to be at least equal to the direct costs.
Factors that Affect Corrosion Rate

- Moisture (Humidity)
- Temperature
- Air Pollution/Contamination
- Water Quality (see photo)
- Lean MWF dilutions
- Acids/Bases/Salts
- Concentration differences across metal surface
- Crevices
- Contact between dissimilar metals
There are just over 100 known chemical elements. About 80 are metals.
Corrosion Issues – Metals Considered

- Iron
- Aluminum
- Copper
- Magnesium
- Titanium
Cast Iron & Steel
IRON (Fe)

• 90% of all mining for metallic ores is for extraction of iron.
• Its low cost and high strength make it indispensable in engineering applications such as the construction of machinery, machine tools, automobiles, hulls of ships, and structural components for buildings.
• Addition of tiny quantities of carbon to iron greatly increases its strength.
• Steel has lower carbon content than cast iron.
• The main disadvantage of most iron alloys is rust!
Rust Happens!
Rusted, Pitted Camshaft
Caused by high chlorides & high humidity
Open Face Cast Iron Cylinders
held overnight at 100% RH & Room Temp

Breakpoint: Weakest concentration that will control rust
STACKED STEEL CORROSION TEST

Stacking reduces fluid volume & excludes oxygen
Cast Iron Chip Test
## Comparison of Cast Iron Chip Methods

<table>
<thead>
<tr>
<th>ASTM D4627</th>
<th>DIN 51360-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 g chips</td>
<td>2 g chips</td>
</tr>
<tr>
<td>Filter paper: glass fiber</td>
<td>Filter paper: standard</td>
</tr>
<tr>
<td>Water hardness: 100 ppm</td>
<td>Water hardness: 340 ppm hardness</td>
</tr>
<tr>
<td>5 ml fluid</td>
<td>2 ml fluid</td>
</tr>
<tr>
<td>20-24 hr fluid contact</td>
<td>2 hr fluid contact</td>
</tr>
<tr>
<td>PRODUCT</td>
<td>ASTM D4627</td>
</tr>
<tr>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td>Syn A</td>
<td>4%</td>
</tr>
<tr>
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<td>2%</td>
</tr>
<tr>
<td>Syn C</td>
<td>5%</td>
</tr>
<tr>
<td>Semi D</td>
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</tr>
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<tr>
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<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Syn C</td>
<td>5%</td>
<td>7%</td>
<td>1%</td>
</tr>
<tr>
<td>Semi D</td>
<td>5%</td>
<td>&gt;10%</td>
<td>&gt;10%</td>
</tr>
<tr>
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<td>3.5%</td>
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<tr>
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<td>5%</td>
</tr>
<tr>
<td>Sol Oil H</td>
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The problem with metal chips

Metal chips have a very large surface area that extracts corrosion inhibitors from solution.
Microbially Induced Corrosion
Bacteria & Mold Can Cause Corrosion Problems

- Bacteria and mold are everywhere: water, air, operator’s hands, incoming parts, walls of the sump and pipes, etc.
- It is only natural that they wind up in the cutting fluid mix.
- Low levels cause no problem
- At higher levels the organisms begin to digest critical fluid components (such as rust inhibitors) and leave acidic by-products in their place. The combined effects cause corrosion problems.
Microbes & Rust
ASTM D4627 Cast Iron Chip Test
(Shown with chips removed)

5% Semi-Synthetic, Sterile
5% Semi-Synthetic with Bacteria & Mold, 1 Week
ALUMINUM (Al)
ALUMINUM

- Soft, durable, lightweight metal
- About 1/3 the density and stiffness of steel
- Vital for aerospace, and useful in other areas of transportation to help reduce fuel consumption.
- Good thermal and electrical conductor
- Remarkable for its ability to resist corrosion
- Corrosion resistance is reduced by
  - Aqueous salts
  - Combinations with other metals
Fluid Developed for Ferrous Metals, But is Bad on Aluminum
Corrosion of Aluminum

- High alkalinity or salts
  Darkening: gray to black

- Galvanic or Bimetallic
  Electrical phenomenon
  Look for outline of contact area

- White corrosion
  Alloys with high Mg or Zn content – caused by plain water
Simple Aluminum Corrosion test:
Immerse freshly ground metal strip in fluid at desired dilution for 20-24 hours.
Observe metal surface and rate.
Boeing Spec. BAC 5008 - 12.3
Aluminum “Sandwich” Test

- Prepare “sandwich” with two metal coupons and a piece of filter paper soaked with MWF.
- Test is run with both MWF concentrate and diluted mix.
- Conditions: 100º F for 8 hr and 100º F + 100% humidity for 16 hr – 7 day duration.
- Coupons: 7075 T-6 clad aluminum and 7075 T-6 anodized, (2 in. x 4 in.)
- Sizes: Coupons 2 in. x 4 in., Paper 1 in. x 3 in.
- Compare to distilled water as control fluid.
## Comparison of Results, 7075 Aluminum

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>24 Hr Strip Immersion, 5% mix</th>
<th>Boeing 12.3 Sandwich Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synthetic</td>
<td>Clean</td>
<td>• Mix Passed</td>
</tr>
<tr>
<td>Soluble Oil A</td>
<td>Clean</td>
<td>• Mix Failed</td>
</tr>
<tr>
<td>Soluble Oil B</td>
<td>Clean</td>
<td>• Mix Passed</td>
</tr>
<tr>
<td>Soluble Oil C</td>
<td>Clean</td>
<td>• Mix Failed</td>
</tr>
</tbody>
</table>
COPPER (Cu)
Formicary Corrosion

- Note pits on interior surface of copper tube (top photo).
- Formicary corrosion pattern looks like tunnels in an ant farm (bottom photo).
- Bottom photo shows branched tunnels associated with Formicary Corrosion in the evaporator tube.
Formicary Corrosion

- Some experts say Formicary Corrosion is caused by hydrolytic breakdown of drawing lubricants to form low levels of Formic Acid and Acetic Acid.

- Test Method: 90 g lube + 10 g water + 1 g alumina, reflux 48 hours. Extract with 90 g more water. **Passing result is <20 ppm formate/acetate.**

- Alternate procedure is ASTM D2619.

- **However**, even copper tubing “as supplied” shows significant interior & exterior pitting
### Formicary Corrosion - Hydrolysis Test Results for copper tube bending & forming lubes

<table>
<thead>
<tr>
<th>PRODUCT</th>
<th>Formate + Acetate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lube A</td>
<td>78 ppm (fail)</td>
</tr>
<tr>
<td>Lube A, reformulated</td>
<td>2 – 4 ppm (pass)</td>
</tr>
<tr>
<td>Lube B</td>
<td>100 ppm (fail)</td>
</tr>
<tr>
<td>Lube B, reformulated</td>
<td>10 ppm (pass)</td>
</tr>
</tbody>
</table>
MAGNESIUM (Mg)
MAGNESIUM

- Light-weight metal, 2/3 the density of aluminium
- Highly reactive
- Metal burns with a bright flame
- Chips react with water to release Hydrogen gas
- Magnesium is the third most commonly used structural metal, following steel and aluminium.
- Principal use is as an alloying additive to aluminium
- Strong and light weight, it is used for many consumer goods: “mag” wheels, engine blocks, laptop shells, mobile phones, cameras, etc.
Magnesium Reacts in Water to Generate Hydrogen

\[
\text{Mg (s)} + 2\text{H}_2\text{O( l )} \rightarrow \text{Mg(OH)}_2(\text{aq}) + \text{H}_2(\text{g})
\]

- Note hydrogen generation in test tube on the left.
- Products can be ranked by the volume of hydrogen produced, as well as by degree of stain on Mg surface.
## Magnesium Stain vs H₂ Generation

<table>
<thead>
<tr>
<th></th>
<th>Magnesium Stain</th>
<th>Hydrogen Volume, 24hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Syn A (lt. duty)</td>
<td>Heavy</td>
<td>&gt;1000 ml</td>
</tr>
<tr>
<td>Syn B (med duty)</td>
<td>None</td>
<td>60 ml</td>
</tr>
<tr>
<td>Semi C</td>
<td>Heavy</td>
<td>3.5 ml</td>
</tr>
<tr>
<td>Semi D</td>
<td>None</td>
<td>42 ml</td>
</tr>
<tr>
<td>Sol Oil H</td>
<td>None</td>
<td>0 ml</td>
</tr>
<tr>
<td>Sol Oil R</td>
<td>Trace</td>
<td>11 ml</td>
</tr>
</tbody>
</table>
TITANIUM
TITANIUM (Ti)

- Corrosion resistant
- Highest strength to weight ratio of any metal
- Can be alloyed with many metals
- Light weight strong alloys for aerospace, military, industry, medical, dental, sports
- Susceptible to stress corrosion cracking at elevated temperatures.
TITANIUM

- **ASTM F945** tests for stress-corrosion cracking of pre-stressed titanium specimens (3 in. x 0.75 in. x 0.05 in.)
- AMS 4911 & AMS 4916 Titanium Alloys
- Method A = 500°F (168 hrs.)
- Method B = 900°F (8 hrs.)
- Comparison is made to salt (NaCl) solution.
- Sometimes small changes in a formulation can make big changes in the test result.
SUMMARY & CONCLUSIONS

• Many different metals are being machined in industry.
• Each has a unique corrosion concern associated with it.
• In this talk we described some of the test methods that may be used for each metal.
• We also showed that different test methods can give different results for the same metal alloy.
• Some of these methods may be useful for monitoring the condition of used MWF, but others are too time consuming for routine use.
I want to thank the following people who helped supply the test results:

Dr. Giles Becket
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Andy Yoder