Effect of Polymer Film Permeability on Retarding or Preventing Corrosion

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DuPont Company
Background:
Impact and Causes of Corrosion

- Economic impact of rust:
  - total corrosion worldwide costs between 1% and 5% of a nation's GDP*

- Moisture in the surrounding environment enables rust formation

- Rust (corrosion) results from electrochemical reactions at high humidity conditions where a thin film of water can form on the surface of metals

Background:
Significance of moisture vapor control

If products are wrapped, covered, or packaged in a plastic bag (or film) during shipment or storage …and the plastic film has a low water permeability…

some condensed water may be trapped inside because there is no way for water to escape

This condensed water is highly likely to initiate and accelerate corrosion

If instead…

the plastic film has high moisture permeability…

corrosion may be reduced because condensed water can quickly escape

So...

packaging in a plastic film with higher moisture permeability may prevent corrosion
Objective

- Evaluate effect of moisture permeability on corrosion under conditions of
  - Trapped moisture
  - Moisture ingress
Testing Procedure: Corrosion Resulting from Trapped Water

- **Films tested 60°C/50% RH**
- **Evaluate effect of water inside the package**
  - test apparatus keeps carbon steel coupons exposed to water vapor (100% relative humidity) but separated from liquid water
  - apparatus placed inside a bag of the test film
  - apparatus is placed in an environmental chamber to control the external temperature and humidity
- **Evaluate effect of water ingress through a permeable package**
  - Pack coupons in bags at 23°C/50% RH, store at 60°C/85% RH
- **Photographs taken of the coupons after testing**
  - amount of surface area covered by rust quantified via Adobe Photoshop
Testing Procedure: Corrosion Resulting from Water Ingress

- Coupons packaged at 23C/50% RH
- Stored at 60C/85% RH
Trapped Water Corrosion Test: Experimental set up Schematic

The experimental set up: support frame inside a plastic bag
Trapped Water Corrosion Test: Experimental set up

- wood cage
- Water-soaked sponge
- Aluminum boat
- Carbon steel coupon
Experimental: test films

<table>
<thead>
<tr>
<th>Resin</th>
<th>WVTR, g-25um/m2/day</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE (control):</td>
<td>20</td>
</tr>
<tr>
<td>Med. Perm film</td>
<td>1300</td>
</tr>
<tr>
<td>High perm film</td>
<td>4300</td>
</tr>
</tbody>
</table>

- All tested at 2 mil thickness
Trapped water: Results at 60°C/50% RH

PE Control  Med. Perm film  High Perm. film

The apparatus after the test
Note absence of fogging with high perm. film
Quantification of corroded areas using Adobe Photoshop 7
Test Coupons after exposure

Front of coupon 13% corroded

back of coupon 3.8% corroded
Test Coupons after exposure

Front of coupon 0.6% corroded

Back of coupon 0.6% corroded
Test coupons after exposure

Front of coupon 0.04% corroded

Back of coupon 0.08% corroded
Summary: Effect of permeation rate on corroded area

<table>
<thead>
<tr>
<th>Film</th>
<th>Permeation rate (g-25u/m2day)</th>
<th>Corroded area</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sample</td>
<td>Front side</td>
<td>Back side</td>
<td>Average</td>
</tr>
<tr>
<td>PE</td>
<td>20</td>
<td>1</td>
<td>2.2 %</td>
<td>3.5 %</td>
<td>5.8 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>13.8 %</td>
<td>3.7 %</td>
<td></td>
</tr>
<tr>
<td>Med. Perm film</td>
<td>1300</td>
<td>1</td>
<td>0.61 %</td>
<td>0.56 %</td>
<td>0.74 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.03 %</td>
<td>1.75 %</td>
<td></td>
</tr>
<tr>
<td>High perm film</td>
<td>4300</td>
<td>1</td>
<td>0.34 %</td>
<td>0.74 %</td>
<td>0.3 %</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>0.04 %</td>
<td>0.08 %</td>
<td></td>
</tr>
</tbody>
</table>
Summary:
Effect of WVTR on Corrosion due to Trapped Water

Corroded area vs WVTR

\[ y = -1.0694 \ln(x) + 8.9058 \]

\[ R^2 = 0.9828 \]

No corrosion if WVTR is greater than 1360 g/m2day
## Results: Water Ingress Testing

Pack at 23C/50% RH; store at 60C/85% RH

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Results: Water Ingress Testing

- Possibility of water ingress does not enable corrosion
- Moisture trapped during packaging can condense and cause corrosion under storage conditions
Results: corrosion testing

- Under conditions of trapped high humidity, a more permeable film provides better corrosion protection than a less permeable film
- The severity of corrosion is inversely proportional to film’s water permeation rate
- Water ingress through permeable film does not contribute to corrosion

What polymer chemistries can enable achieving this permeability?
# Vapor Permeability Data: commercial resins

<table>
<thead>
<tr>
<th>Material</th>
<th>$O_2$, cc-mil/m²-day</th>
<th>$H_2O$, g-25um/m²-day</th>
</tr>
</thead>
<tbody>
<tr>
<td>HDPE</td>
<td>1560-3000</td>
<td>4 – 6.4</td>
</tr>
<tr>
<td>LDPE</td>
<td>2600-7600</td>
<td>12 – 24</td>
</tr>
<tr>
<td>mPE</td>
<td>2000-21600</td>
<td>4 – 8</td>
</tr>
<tr>
<td>Styrene-butadiene</td>
<td>6400-10400</td>
<td>44 – 56</td>
</tr>
<tr>
<td>PP</td>
<td>1400-4560</td>
<td>16 – 48</td>
</tr>
<tr>
<td>Nylon 6</td>
<td>12-80</td>
<td>60 – 360</td>
</tr>
<tr>
<td>EVOH, 32/44 mole%</td>
<td>0.4/1.2</td>
<td>32/96</td>
</tr>
<tr>
<td>OPET</td>
<td>48 – 96</td>
<td>16 – 32</td>
</tr>
<tr>
<td>Polyether amide</td>
<td>8000-36000</td>
<td>12000 - 40000</td>
</tr>
<tr>
<td>Polyether ester</td>
<td>48000 – 56000</td>
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* Measured at 20 – 25 C; data from *Permeability Properties of Plastics and Elastomers*, L.K. Massey
Permeability of Commercial Resins

- Few commercially available resins with WVTR between conventional olefin copolymers (<60 g-25um/m²/day) and the very permeable polyether amides and polyether esters (8000–40000 g-25um/m²/day)
  - Few options → finding a balance of permeability and physical properties difficult

- Coextrusion of the very breathable materials with conventional resin as a way to tailor WVTR is problematic
  - permeability of a coextruded film is a weighted average of the components → coextrusion with even a very thin layer of a lower WVTR material will greatly reduce the WVTR of the coextruded structure

- **Blending to increase WVTR is also problematic:**
  - limited compatibility between the polyetheramides or polyetheresters with the moderate WVTR polymers
  - difficult to balance mechanical and optical properties
Novel Resin Technology

- Based on modified ionomer chemistry
  - Physical properties comparable to conventional ionomers
  - WVTR can be tailored by modifying composition
    - $3000 - 15000$ g-25um/m2day
Effect on Permeability of Blending Modified Ionomers with EVA

Effect of Blend Ratio on WVTR

![Graph showing the effect of blend ratio on WVTR](image)

- Blends with E/28VA
- Blends with E/15VA
- Blends with E/15VA
Effect on Permeability of Blending Modified Ionomers with EVA

Effect of Blend Ratio on WVTR

Nonlinear relationship: Influenced by morphology
## Permeability Data: commercial and developmental resins

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<tr>
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<td>2000 - 5800</td>
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Conclusions: Effect of Polymer Film Permeability on Retarding or Preventing Corrosion

- The concept that a high permeation film could be efficacious in reducing corrosion due is confirmed.

- Magnitude of the effect depends on permeability of film, temperature, and relative humidity of environment.

- Novel high WVTR resins based on ethylene copolymers fill in the spectrum of available WVTR and enable new options for protecting covered articles from corrosion.
Effect of Polymer Film Permeability on Retarding or Preventing Corrosion

Thank you

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Please remember to turn in your evaluation sheet...