Accelerated Aging of TPO Membranes – Prediction of Actual Performance

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Prior Studies – the context

TPO Study – how today’s membrane is performing

Aging of TPO

Conclusions & Future Work
Key Takeaways:

- 116 to 138°C is a linear relationship.
- Many samples fail <50 days at 138°C.
**Key Takeaways:**

- Short projected lifetimes
- Membrane performance covers a wide range: TPOs are very different
- <116°C testing takes over a year!

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**Heat Aging: 138°C vs. 116°C vs. 93°C**

<table>
<thead>
<tr>
<th>TPO Membranes (Thickness)</th>
<th>138°C (280°F)</th>
<th>116°C (240°F)</th>
<th>93°C (200°F)</th>
<th>Predicted Years (assuming 6 hrs/day @93°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Days to Cap Cracking</td>
<td>Predicted Days to Cap Cracking</td>
<td>Factor to actual/predicted days @116°C</td>
<td>Predicted Years</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>Y</td>
<td>Y = 4.2634*X + 110.45</td>
<td>R² = 0.9358</td>
<td></td>
</tr>
<tr>
<td>A, 1.14 mm</td>
<td>20</td>
<td>212</td>
<td>196</td>
<td>941</td>
</tr>
<tr>
<td>B, 1.14 mm</td>
<td>28</td>
<td>229</td>
<td>230</td>
<td>1017</td>
</tr>
<tr>
<td>C, 1.52 mm</td>
<td>31</td>
<td>212</td>
<td>243</td>
<td>941</td>
</tr>
<tr>
<td>D, 2.03 mm</td>
<td>34</td>
<td>212</td>
<td>255</td>
<td>941</td>
</tr>
<tr>
<td>E, 1.52 mm</td>
<td>37</td>
<td>296</td>
<td>268</td>
<td>1314</td>
</tr>
<tr>
<td>F, 2.03 mm</td>
<td>40</td>
<td>296</td>
<td>281</td>
<td>1314</td>
</tr>
<tr>
<td>G, 2.03 mm</td>
<td>48</td>
<td>344</td>
<td>315</td>
<td>1527</td>
</tr>
<tr>
<td>H, 2.03 mm</td>
<td>68</td>
<td>399</td>
<td>400</td>
<td>1772</td>
</tr>
<tr>
<td>I, 1.52 mm</td>
<td>76</td>
<td>399</td>
<td>434</td>
<td>1772</td>
</tr>
<tr>
<td>J, 2.03 mm</td>
<td>80</td>
<td>475</td>
<td>452</td>
<td>2109</td>
</tr>
<tr>
<td>K, 1.52 mm</td>
<td>85</td>
<td>473</td>
<td>473</td>
<td>2100</td>
</tr>
<tr>
<td>L, 1.52 mm</td>
<td>187</td>
<td>NA</td>
<td>908</td>
<td>4032</td>
</tr>
<tr>
<td>M, 2.03 mm</td>
<td>194</td>
<td>NA</td>
<td>938</td>
<td>4165</td>
</tr>
</tbody>
</table>

**Suspected field issues**

*Engineered for high heat & solar applications*
Key issues from the 2011 work:

• Samples were single pieces from one roll per manufacturer
• Performance was very variable, but
  • Samples spanned many years
• Some membranes failed relatively early

Next Steps were seen as:

• Test recent production
• Test multiple rolls / all plants

Industry Backdrop:

• Test temperature uncertainty – 116 versus 138°C
• Failure mode definition – cracking, mechanical properties, or weight loss
The Ideal Test Report...

| ✓ | Recent product |
|   | • Produced in similar time frame |
| ✓ | Produced in all plants |
| ✓ | Multiple rolls each from a different day’s production |
| ✓ | All manufacturers |
| ✓ | Transparent – shows all data |
| ✓ | Testing by reputable firm |
In 2013, GAF retained SRI

SRI obtained all material through distribution

GAF, Firestone, Carlisle, & JM were all tested
• 5 rolls from each TPO plant
• Product was made at various times throughout 2013
• Tested over 165 samples
• All 60 mil product
What We’re Talking About...

- Manufacturer/Product
  - Plant 1
    - Roll 1
    - Roll 2
    - Roll 3
    - Roll 4
    - Roll 5
  - Plant 2
    - Roll 1
    - Roll 2
    - Roll 3
    - Roll 4
    - Roll 5
What We’re Talking About... In Context

Carlisle
- Plant 1
  - Roll 1
  - Roll 2
  - Roll 3
  - Roll 4
  - Roll 5
- Plant 2
  - Roll 1
  - Roll 2
  - Roll 3
  - Roll 4
  - Roll 5

Firestone
- Plant 1
  - Roll 1
  - Roll 2
  - Roll 3
  - Roll 4
  - Roll 5
- Plant 2
  - Roll 1
  - Roll 2
  - Roll 3
  - Roll 4
  - Roll 5

GAF 60 mil
- Plant 1
  - Roll 1
  - Roll 2
  - Roll 3
  - Roll 4
  - Roll 5
- Plant 2
  - Roll 1
  - Roll 2
  - Roll 3
  - Roll 4
  - Roll 5

GAF 50 mil EX
- Plant 1
  - Roll 1
  - Roll 2
  - Roll 3
  - Roll 4
  - Roll 5
- Plant 2
  - Roll 1
  - Roll 2
  - Roll 3
  - Roll 4
  - Roll 5

JM
- Plant 1
  - Roll 1
  - Roll 2
  - Roll 3
  - Roll 4
  - Roll 5
What We’re Talking About... In Context
Physical Property Data – no major differences

Weathering Showed Wide Performance Range ...

• All samples met 3X UV standard in D6878
  • Used QUV method

• Heat resistance...
  • Heat is known to cause issues

• SRI tested at 135°C (275°F)
Heat Aging

• The basic question – 240 or 275°F (116 vs 135°C)

• It’s basic science – every 10°C rise doubles the reaction rate
  • So, how quickly do you want to do the test?

• An ASTM Interlaboratory Study (“Round Robin”) showed:

The times to fail at the two temperatures tested are highly correlated. Thus there is little difference in the performance of the tests using either the 240° or the 275°. However, the higher temperature reached conclusion in as little as 4 weeks and in all cases ended by 13 weeks (just a little over 2 months) while tests at 240° needed as much as 52 weeks (a full year) to reach failure.

It appears that the use of 275° as a new nominal temperature is very appropriate.
Heat Aging Test Temperature for TPO

• Accelerated testing is done at unrealistic conditions – by definition!

• There has been no evidence published showing a change in aging mechanisms at higher temperatures!
Heat Aging Failure Mode...

Various Proposals:

• Surface cracking (3” mandrel bend, 7X eyepiece; ASTM D6878) ✅

• Weight loss (Tokarski and Martin) ✅

• Physical tests (ASTM D08.18 proposal) ✗
  • Impractical for large numbers of samples

Kim Deaton and Nate Martin, “Putting Membranes to the Test”, Architectural Roofing and Waterproofing Magazine, June 1, 2013
What Cracking Means...

Test Sample

Real World
Weight Loss Can Lead To...

Erosion to the scrim
Weight Loss vs Days to Cracking – not a consistent correlation

If all data is combined (C, D, E, F), there is no correlation!
No overall correlation (i.e. cannot combine C, D, E, F)

• Each manufacturer’s stabilizer choice is unique
• Weight loss and cracking need to be examined separately

• Consider weight loss first...
Oxidation Induction Time – a classic test to measure

- Amount of stabilizer
- Effectiveness of stabilizer

Graph: Oxidation Induction Time (OIT) test of polyethylene pipe grade isothermal at 210°C.
Oxidation Induction Time – a classic test to measure
• Amount of stabilizer
• Effectiveness of stabilizer
Loss of stabilizer, leading to degradation
Initial weight loss – surface moisture?
Slow weight loss – moisture migration?
Range of failure times – process/formulation variation?
TPO B – 50 mil

Maintains low weight loss for 200+ days
Maintains low weight loss for 200+ days only loses up to 2% >200 days

TPO A
Using Weight Loss as a Specification

• Potential questions:
  • Should the samples be preconditioned?
  • How do we identify onset of breakdown?

• Proposed solution:
  • Test samples without conditioning
  • Use weight loss >1.5% as the failure point
TPO Heat Aging... Proposed Specification

• Failure:
  • Time to reach >1.5% weight loss
  or
  • Surface cracking visible using 7x magnification
  • Whichever comes first

• Rationale:
  • Field failure has not occurred due to mechanical performance
  • Leaks are always the failure – cracks or erosion!
Time Before Failure Begins (>1.5% wt. loss or cracking)

- **TPO A**
- **TPO B 50 mil**
- **TPO C**
- **TPO D**
- **TPO E**
- **TPO F**

**Days to Failure at 275°F**

**Years, <160°F**
- 10
- 20
- 30
- 40

**Years, <195°F**
- 10
- 20
Prior study – many failures below 50 days at 138°C (280°F)

This included known problem membranes!

Today’s production – all exceed 50 days at 135°C (275°F)
All plants; all rolls tested!

TPO continues to improve!
Time Before Failure Begins (>1.5% wt. loss or cracking)

- **TPO A**
- **TPO B 50 mil**
- **TPO C**
- **TPO D**
- **TPO E**
- **TPO F**

**Utility Grade**

**Standard Grade**

**Premium Grade**

**Days to Failure at 275°F**

**Years, <160°F**

**Years, <195°F**
That was a lot of information

Let’s simplify and think in terms of specifying....
Categorizing & Specifying

<table>
<thead>
<tr>
<th>TPO Grade</th>
<th>Heat Aging, days to failure</th>
<th>Weather Resistance kJ/(m².nm) @ 340 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>240°F</td>
<td>275°F</td>
</tr>
<tr>
<td>1 – utility grade</td>
<td>224</td>
<td>27</td>
</tr>
<tr>
<td>2 – standard grade</td>
<td>490</td>
<td>90</td>
</tr>
<tr>
<td>3 – premium grade</td>
<td>750</td>
<td>150</td>
</tr>
</tbody>
</table>

Failure= cracking using 7x magnification or weight loss > 1.5%
Key Takeaways:

• **TPO has evolved** – the leading sheets are continuing to get better

• **TPO standards are improving** – TPO has the strongest ASTM single ply spec

• **TPO has reached a fairly uniform physical properties level** across all manufacturers

• **Weathering and consistency** of formulation are **key differentiators** between membranes

• There are **three classes** of membrane
  • Premium Grade
  • Standard Grade
  • Utility Grade
Future Work

• Evaluation of...
  • Sequential testing
    • UV followed by heat aging & vice versa
  • Higher temperature UV testing
    • A challenge to the equipment manufacturers!
• Reports of cracking adjacent to welds
  • Is the seam simply a stress concentrator, or is there another mechanism?
Thank You!

Questions?
High Weight Loss
Heat Aging – Days to First Crack

Days at 275°F

TPO A
TPO B 50 mil
TPO C
TPO D
TPO E
TPO F

ASTM D573

Minimum