TPO MEMBRANES — WHY PERFORMANCE MATTERS

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GAF

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New Orleans, LA
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Roadmap...Where We’re Going

► TPO Membranes in the Marketplace
► ASTM, TPO Membranes & 10 Years of Testing
► Sampling & Testing – a Comprehensive Approach
► Results
► Recommendations
Let’s Step Back …
and Check Where We’ve Been

- **1980’s**: TPO Introduced
- **1990’s**: Reinforced Sheets
- **2001**: SPRI Separates TPO Out
- **2008**: TPO Sales 1B Sq.Ft.
- **2015**: TPO > 50% of SP Mkt
History of Use in the Market Place…2001-2014
1 Billion sq.ft installed every year.
~25,000 miles of welds – that’s once around the Earth!!
TPO in 2015…

- TPO Growing
- Industry Is Investing
- Education and Service
- Significant Product Testing
What Does ASTM Tell Us… About TPO Membranes?

- Thickness
- Brittleness Point
- Dimensional Stability
- Seam Strength
- Breaking Strength * Elongation * Tearing Strength
- Retention after Heat Aging
- Accelerated Aging
And Like the Product...
D6878 Has Been Evolving

- UV Testing Doubled
- Heat Aging X8
- Thickness Over Scrim ↑
- Thickness Over Scrim Thicker Products

2003..2006......2011......2013
Perceptions of ASTM...
Over the Past 10+ Years…

We’ve Really Tried to Put Product Through Some Paces

And Bought A Lot of Ovens…
We’ve Listened to Concerns…

For Self Adhering Seams…
does the cleaner/primer make a difference?

7 Day Aged Commercial Cleaner Study
(Not Rolled vs. Rolled @ Room Temp)
And We’ve Welded a Lot of Seams…

And Pulled Apart Just as Many…
We’ve Examined Temperature Concerns…
We’ve Tested In Situ Temperatures

Just because it’s white doesn’t mean that it is ALWAYS cool…
In Fact, Over the Past 8 Years…

> 20 Presentations & Papers/Articles About TPO Membranes
Many, You Might Recall…

Linlin Xing¹ and Thomas J. Taylor²

Correlating Accelerated Laboratory, Field, and Thermal Aging TPO Membranes

ABSTRACT: Thermoplastic polyolefin (TPO) roofing membranes have been used in the US low-slope roofing industry as single-ply membranes for over 15 years, and have seen widespread acceptance. TPO mem-
Something All of These Papers/Articles Have in Common…

**Significant amount** of product testing…

Much done to **show performance**…
Heat Aging

Used in evaluating product formulation

The higher the temperature, the faster you get an answer (weeks not months!)

ASTM calls out for testing at 240F

8-10 years ago, mfrs started testing at higher temperatures
Even Drawing Conclusions About Longevity Based on Oven Aging…

<table>
<thead>
<tr>
<th>Product (and thickness)</th>
<th>280°F</th>
<th>240°F</th>
<th>200°F</th>
<th>200°F Field Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. 45 mil</td>
<td>20</td>
<td>941</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. 45 mil</td>
<td>28</td>
<td>1017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C. 60 mil</td>
<td>31</td>
<td>941</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>D. 80 mil</td>
<td>34</td>
<td>255</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>E. 60 mil</td>
<td>37</td>
<td>268</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>F. 80 mil</td>
<td>40</td>
<td>1314</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>G. 80 mil</td>
<td>48</td>
<td>315</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>H. 80 mil</td>
<td>68</td>
<td>400</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>I. 60 mil</td>
<td>76</td>
<td>434</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>J. 80 mil</td>
<td>80</td>
<td>452</td>
<td>23</td>
<td></td>
</tr>
</tbody>
</table>

**Predicted Years**
(assuming 6 hrs/day @ 200°F)
Confused About WHAT Temperature?

Is there a difference in results between testing at 240F or 275F?

2014 ASTM Inter-Laboratory Study to evaluate *IF* there is a difference…

“It appears that the use of 275F as a new nominal temperature is very appropriate”
ASTM ILS…What does it mean?

In other words…relative performance between products/formulations tested at 240F or 275F is the same…

It’s just that testing at 240F will take longer

(6 months at 275F…>30 months at 240F!)
Yet... Maybe You’ve Been Right

- Internal testing/ Single attribute testing
- Used old competitive material
- Data presented out of context
- Didn’t always show all samples
- Cherry picked your own material
- Not using the right measurement
Yet... Maybe You’ve Been Right

Internal testing/
Single attribute
testing

Used old
competi-
tion
material

Not using the
right
measurement

There’s Been NO Independent
3rd Party Testing With Rigorous
Sampling!
In 2013, GAF retained SRI to independently obtain material. SRI targeted testing beyond D6878. Therby meet the production dates.
THE PROGRAM . . .
SAMPLING, TESTING, & RESULTS
TPO Study Sampling Plan

- Obtain rolls with different 2013 manufacturing dates for each
- Obtain 5 rolls per plant if possible for each manufacturer
- Purchase full roll 10’ x 100’, ship 10’ length to SRI with original roll wrapper and tag
- Obtain rolls directly from the market or distribution
TPO Manufacturers/Products Sampled - White 60 mil except as noted

- Carlisle
- Firestone
- GAF
- GAF Extreme – 50 mil
- GAF Extreme
- JM
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

JM
- Plant 1
  - Roll 1
  - Roll 2
  - Roll 3
  - Roll 4
  - Roll 5
TPO Sampling Data

- Carlisle – 10 Rolls dated from Jan – Dec 2013
- Firestone – 10 Rolls dated from May – Nov 2013
  - GAF – 8 Rolls dated from May – Dec 2013; 2 Rolls Jan 2014
  - GAF 050 Extreme – 5 Rolls dated from Jan – Dec 2013
  - GAF 060 Extreme – 5 Rolls dated from Jan – Dec 2013
- JM – 5 Rolls dated from Jan – Nov 2013
Where We Ended Up... 45 Rolls!
45 Rolls… Manufactured over 13 Months

Month TPO Roll Manufactured
Jan 2013 to Jan 2014

Number of Rolls

Month

1 2 3 4 5 6 7 8 9 10 11 12 13
0 1 2 3 4 5 6 7 8 9 10 11
Test Methods
Thickness

- Overall Sheet: ASTM D751
- Thickness of Coating Over Scrim: ASTM D7635
Lamination Strength

- ASTM D1876 Standard Test Method for Peel Resistance of Adhesives (T-Peel Test)
Heat Aging

► ASTM D573

► 275F (135C)

► Measured weight change to 0.001 gram accuracy during heat aging of 2”x6” samples

► Cracks were checked by mandrel bend over a 3” diameter solid round section @ 7x magnification

► Days to cracking were monitored concurrent with weight change

Of note: samples underwent bending from 5 – 40 times!
Accelerated Weathering

- ASTM G154
  - QUV with UVA 340 lamps
  - 700 minute light cycle followed by 20 minutes of water spray (12 hour total cycle)
  - Exposure was 30,240 kJ/(m²·nm)

226 Days… 3X Current ASTM Requirements
BUT WAIT!
WE WEREN’T DONE YET…
One Final Test...

Accelerated Weathering
- ASTM G154
  - QUV with UVA 340 lamps
  - 700 minute light cycle followed by 20 minutes of water spray (12 hour total cycle)
  - Exposure was 30,240 kJ/(m²·nm)

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  - Days to cracking were monitored concurrent with weight change

226 Days... 3X Current ASTM Requirements
Results
Overall Sheet Thickness — Location Key  
(where we measured 6 times across the width of the sheet)

<table>
<thead>
<tr>
<th>Reading locations, in inches, measured</th>
<th>Width, ft</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>from exposed edge</td>
<td>5</td>
<td>1</td>
<td>13</td>
<td>25</td>
<td>37</td>
<td>49</td>
<td>59</td>
</tr>
<tr>
<td>(A &amp; F locations both 1-inch from edge)</td>
<td>6</td>
<td>1</td>
<td>15½</td>
<td>30</td>
<td>44½</td>
<td>59</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>1</td>
<td>20</td>
<td>39</td>
<td>58</td>
<td>77</td>
<td>95</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1</td>
<td>24</td>
<td>48</td>
<td>72</td>
<td>96</td>
<td>119</td>
</tr>
</tbody>
</table>

*This same location key was used for thickness over scrim.*
Overall Sheet Thickness

- 060 TPO the average thickness of each product was 55-57 mils
- The greatest difference between the average thickness of rolls from the same manufacturer was 3 mils
- In addition, approximately 12,000 total individual measurements taken across the width of the 45 sample rolls to create a thickness profile of each roll
Overall Sheet Thickness Profile

TPO Product #4

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average value, in</td>
<td>0.056</td>
</tr>
<tr>
<td>Minimum reading, in</td>
<td>0.050</td>
</tr>
<tr>
<td>Maximum reading, in</td>
<td>0.058</td>
</tr>
<tr>
<td>Number of Readings</td>
<td>319</td>
</tr>
<tr>
<td>Gauge deadweight, oz</td>
<td>6</td>
</tr>
<tr>
<td>Gauge pressure foot Ø, in</td>
<td>0.375</td>
</tr>
</tbody>
</table>

8 mil range
Overall Sheet Thickness Profile

TPO Product #6

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average value, in</td>
<td>0.056</td>
</tr>
<tr>
<td>Minimum reading, in</td>
<td>0.053</td>
</tr>
<tr>
<td>Maximum reading, in</td>
<td>0.058</td>
</tr>
<tr>
<td>Number of Readings</td>
<td>322</td>
</tr>
<tr>
<td>Gauge deadweight, oz</td>
<td>6</td>
</tr>
<tr>
<td>Gauge pressure foot Ø, in</td>
<td>0.375</td>
</tr>
</tbody>
</table>
Overall Sheet Thickness Profile

TPO Product #5

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average value, in</td>
<td>0.056</td>
</tr>
<tr>
<td>Minimum reading, in</td>
<td>0.053</td>
</tr>
<tr>
<td>Maximum reading, in</td>
<td>0.056</td>
</tr>
<tr>
<td>Number of Readings</td>
<td>321</td>
</tr>
<tr>
<td>Gauge deadweight, oz</td>
<td>6</td>
</tr>
<tr>
<td>Gauge pressure foot Ø, in</td>
<td>0.375</td>
</tr>
</tbody>
</table>
Thickness Over Scrim

![Chart showing thickness over scrim for various products.](chart.png)
Laminate Strength @ Exposed Edge

- 1 roll randomly selected from each plant, all measurements showed film-tearing bond

- Minimum of all T-Peels = 29.3 lbf/in

- Maximum of all T-Peels = 51.3 lbf/in

- Average of all 9 rolls = 40 lbf/in
Heat Aging

- 6 products spread over 45 rolls
- Current standard...< 1% mass loss
- Current lab practice is “failure” is defined as cracking at 7x magnification when bent

What this program shows...

- Variation in amount of weight loss between manufacturers
- Significant differences in total time to failure between manufacturers
- Stark differences between the “tightness of the data”
Why We Look At Cracking

Test Sample

Real World
Weight Loss vs. Cracking
As a Failure Mode

Product that cracked at less than 1.5% weight loss

Product with excessive weight loss
Results

Product #1

[Graph showing weight loss (%) against heat exposure (Day)]

1.5% Weight Loss

Heat Exposure (Day) vs. Weight Loss (%)
Results

Product #2

Weight Loss (%) vs. Heat Exposure (Day)

1.5% Weight Loss
Results

Product #3

Weight Loss (%) vs. Heat Exposure (Day)

1.5% Weight Loss
Results

Product #4

Weight Loss (%) vs Heat Exposure (Day)
Results

Product #5

Heat Exposure (Day)

Weight Loss (%)

1.5% Weight Loss
Results

Product #6

Weight Loss (%) vs. Heat Exposure (Day)

1.5% Weight Loss
Heat Aging Composite View

Product #1

Product #4

Product #2

Product #5

Product #3

Product #6
Heat Aging - Days to First Crack

Product Number

<table>
<thead>
<tr>
<th>Product Number</th>
<th>Heat Exposure (Day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
</tr>
<tr>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>5</td>
<td>110</td>
</tr>
<tr>
<td>6</td>
<td>80</td>
</tr>
</tbody>
</table>

Heat Exposure (Day) from 0 to 240.
Heat Aging - Days to Either First Crack or >1.5% Wt. Loss
Accelerated Weathering

- ASTM G154
  - QUV with UVA 340 lamps
  - 700 minute light cycle followed by 20 minutes of water spray (12 hour total cycle)
  - Exposure was 30,240 kJ/(m²·nm)

226 Days... 3X Current ASTM Requirements

No failures after 3x ASTM requirements for any product
**QUV + Heat Aging**

**QUV Exposure 30240 kJ/m² 226 Days - No Failures After QUV Exposure Only**

**Plus Heat Aging**

**Average Days to Crack (Percent Weight Loss)**

<table>
<thead>
<tr>
<th>Product No.</th>
<th>Days to Crack</th>
<th>Weight Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>(1.2%)</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>(1.3%)</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>(1.5%)</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>(0.9%)</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>(0.8%)</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>(5.3%)</td>
</tr>
</tbody>
</table>

**Heat Exposure @ 275°F (Day)**
Conclusions…
Pulling it All Together
Take Aways

- TPO as a Product Class
- Product Quality
- Product Durability
- Suggestions for Raising the Standard
TPO As a Product Class

- There has been significant and notable improvements in product formulations over the past 10 years

- These improvements have been made to raise the performance of these products in service, especially temperature loading
Product Quality

- This testing took *multiple measurements from multiple rolls*...and in general, the results show notable consistency, both within roll and between rolls

- *Even with manufacturing dates that generally spanned over a full year,* there were many products that showed consistency in results – which indicates process control in manufacturing and confidence in formulation
Product Durability

- Today’s TPO membranes have evolved
- QUV + Heat Aging – shows a level of product durability not seen 10 years ago (consider heat aging failures at 28 – 45 days without QUV 10 years ago)
- There are formulations available that approach 300 days of heat aging with minimal weight loss
- This body of work may contribute to the correlations between heat aging, UV resistance and predicted service life
Considering ASTM...
Suggestions for Raising the Standard

► At a minimum…2 Grades Based on Heat Aging – Failure Mode Cracking

<table>
<thead>
<tr>
<th>Grade</th>
<th>Heat Aging Days to Cracking, Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70</td>
</tr>
<tr>
<td>2</td>
<td>140</td>
</tr>
</tbody>
</table>
Suggestions for Raising the Standard

- The data suggests a strong relationship between cracking and 1.5% weight loss.

- Given this relationship, the case can be made for 3 Grades.

<table>
<thead>
<tr>
<th>Grade</th>
<th>Heat Aging Days to Cracking, Minimum With &lt;1.5% Weight Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
</tr>
<tr>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td>3</td>
<td>140</td>
</tr>
</tbody>
</table>
Thank You!