DIMENSIONAL STABILITY AND REFLECTIVITY OF FIELD EXPOSED THERMOPLASTIC POLYOLEFIN (TPO) ROOF MEMBRANES

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WSRCA’s TPO Task Group

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- KC Barnhardt, WSRCA Former President, Task Group Co-Chairman
- Arlene Lawson, WSRCA Executive Director
- Randy Ober, Carlisle SynTec
- Dwayne Wacenske, Firestone Building Products
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- Tim Gardner, Snyder Roofing, Seattle, Washington
- Misty Stoddard & Curt Miller, Rainproof Roofing, Anchorage, Alaska
- Mark Sansing, American Roofing & Metal Co., San Antonio, Texas
- Dennis Conway & Ray Snow, Commercial Roofers, Inc., Las Vegas, NV
- Tim Gardner & Kyle King, Snyder Roofing, Seattle, Washington
- Ana H. Delgado, Ralph M. Paroli, National Research Council of Canada
- Stephen Elliot, Michael Ludwig, Bill Collins, Darrell Hunt, Ernie Rosenow, Andy Leonard, and Jim Carlson of BET&R
Issues Reported by Contractors
Montana TPO Roof

Cracking Along the Interior Seam Line
Montana TPO Roof

Surface Crazing or Micro-cracking and delamination of top coating.
Early Generation TPO Roof in Oregon
Same Early Generation TPO Roof in Oregon

Section of Roof Adjacent the Windows
There can be no progress if people have no faith in tomorrow

President John F. Kennedy
Program Goal

To provide pertinent technical and performance information to the North American roofing industry at large, regarding 60-mil (1.5 mm) TPO roof membrane (over polyiso) attributes, their performance properties and resistance to degradation due to the effects of weathering.

Inception: 2000
The Roofs Are Divided Into Four (4) Individual Areas. Each Test Roof Area Is Separated by a Roof Area Divider and Must Drain Individually.
Overview of Properties tested

Mechanical Properties
• Thickness, Sheet Overall
• Thickness of Coating Over Scrim
• Linear Dimensional Change
• Water Absorption
• Tensile Properties
• Seam Strength
• Surface Characteristics (Thickness, Reflectivity)

Chemical Properties
• Dynamic mechanical analysis (DMA)
• Thermogravimetry (TG/DTG)
• Fourier transform infrared spectroscopy (FTIR)
Anchorage, Alaska
Cold and Damp
Seattle, Washington
Moderate and Wet/Dry
San Antonio, Texas
Hot and Humid
A slight increase in tightening was observed at year ten in multiple locations.
Anchorage – Roof Area 4
Weldability

Test patches were welded on the existing membrane, then field peel tests were performed.
A photo from original installation of the TPO membrane in 2000. Note how the bucket and roofer’s foot are hard-creasing the membrane.
A side lap seam where creasing during installation and sun/heat load have led to cracking of the creases (2011)
Las Vegas – Roof Area 2
Effect of Hard Creases

A close-up view of an isolated “crease crack”
Dimensional Stability

- Change in length or width of membrane due to exposure to elevated temperatures or membrane relaxation
  - Can affect waterproofing integrity
  - Expansion can cause wrinkling
  - Shrinkage can lead to tearing or cracking
Linear Dimensional Change

- Measured based on ASTM D1204-02
- Samples were removed from the oven and reconditioned in the laboratory at 23 ± 2°C (73 ± 4°F) and 50 ± 5% RH for at least 1 h.
- The linear dimensional change is the change in dimension as a percent of the original dimension.

\[
\text{Dimensional Change} = \frac{(D_f - D_o)}{D_o} \times 100\%
\]

A positive linear dimensional change indicates expansion while a negative value denotes shrinkage.
Linear Dimensional Change (MD)

![Graph showing linear dimensional change across different areas and locations.](image-url)

- **Area1**: Changes across different locations (AK, LV, SEA, TX) with different colors representing each area.
- **ASTM Spec. = ± 1%**: Indicates the acceptable range for dimensional change according to the ASTM standard.

The graph visually represents the percent change in dimensions for various locations and areas, highlighting the deviation from the ASTM specified limit.
Why is Reflectivity important?

• Solar reflectance is a key characteristic of a roof membrane in terms of mitigating the urban heat island effect and helping reduce energy demands during warmer months.

• New, white TPO membranes usually have a reflective value greater than 80%, which exceeds the U.S. Environmental Protection Agency’s ENERGY STAR performance levels set at 65% when new and 50% after three years exposure.
Reflectivity Testing in the Field
Reflectivity Testing
Reflectivity Testing
Reflectivity Testing
Reflectivity Testing
Reflectivity Test
Reading
Pressure Washing
Scrubbing to Clean Surface
Scrubbing to Clean
Reflectivity Testing
Cleaned Areas
### WSRCA TPO WEATHERING FARM

#### TEST COMPARISONS FROM REGIONAL LOCATIONS

<table>
<thead>
<tr>
<th>AGE OF ROOF</th>
<th>ROOF AREA</th>
<th>ROOF AREA</th>
<th>ROOF AREA</th>
<th>ROOF AREA</th>
<th>AVERAGE</th>
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<tr>
<td>New</td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
<td><strong>0.826</strong></td>
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<tr>
<td>7-Month</td>
<td>- - - -</td>
<td>- - - -</td>
<td>- - - -</td>
<td>- - - -</td>
<td>0.670 0.657 0.676 0.668</td>
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<tr>
<td>3-4 Year</td>
<td>0.720 0.595 0.603 0.626</td>
<td>0.693 0.721 0.654 0.701</td>
<td>0.000 0.000 0.000 0.000</td>
<td>0.683 0.605 0.618 0.656</td>
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<tr>
<td>Elapsed Change</td>
<td>- 0.190</td>
<td>- 0.125</td>
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<td>- 0.186</td>
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<table>
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<th>AGE OF ROOF</th>
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<th>ROOF AREA</th>
<th>ROOF AREA</th>
<th>AVERAGE</th>
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<td>New</td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
<td>1 2 3 4</td>
<td><strong>0.826</strong></td>
</tr>
<tr>
<td>3-4 Year</td>
<td>0.774 0.680 0.681 0.723</td>
<td>0.746 0.761 0.742 0.783</td>
<td>0.000 0.000 0.000 0.000</td>
<td>0.713 0.628 0.669 0.732</td>
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<tr>
<td>Elapsed Change</td>
<td>- 0.112</td>
<td>- 0.068</td>
<td>-</td>
<td>- 0.141</td>
<td><strong>0.107</strong></td>
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</table>
### Reflectivity Testing

**PROJECT:** LAS VEGAS, NEVADA  
**DATE:** 6/3/2004  
**SURFACE TYPE:** WHITE TPO  
**ROOF AREA:** 4  
**AGE OF SURFACE:** Approx. 48 MONTHS  
**PURPOSE:** REFLECTIVITY / REFLECTANCE TESTING  
**METER READER AND INSTRUMENT:** D & S Model SSR-ER (Version 5.0)  
**DATA ASSEMBLY:** Ernie Rosenow  
**TEMPERATURE & HUMIDITY:** 129 F at 3%  

#### Reflectivity Tests on Existing/Uncleaned TPO Roof Membranes

<table>
<thead>
<tr>
<th>TEST ZONE</th>
<th>EXISTING/EXPOSED ROOF AREA TEST LOCATIONS</th>
<th>AVERAGE</th>
<th>ROOF AREA</th>
<th>COMPARISON OF ENTIRE ROOF AREA AVERAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.707 0.712 0.711 0.705 0.671</td>
<td>0.701</td>
<td>1</td>
<td>0.693</td>
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<tr>
<td>2</td>
<td>0.680 0.669 0.672 0.689 0.696</td>
<td>0.681</td>
<td>2</td>
<td>0.721</td>
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<tr>
<td>3</td>
<td>0.714 0.709 0.699 0.713 0.707</td>
<td>0.708</td>
<td>3</td>
<td>0.654</td>
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<td>4</td>
<td>0.704 0.696 0.703 0.688 0.678</td>
<td>0.694</td>
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<td>5</td>
<td>0.692 0.700 0.679 0.686 0.699</td>
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<td>6</td>
<td>0.705 0.702 0.707 0.700 0.714</td>
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<td>7</td>
<td>0.694 0.724 0.710 0.709 0.708</td>
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<tr>
<td>8</td>
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<td>9</td>
<td>0.716 0.713 0.709 0.707 0.712</td>
<td>0.711</td>
<td></td>
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</tr>
<tr>
<td>10</td>
<td>0.689 0.697 0.701 0.688 0.680</td>
<td>0.691</td>
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</table>

**TOTAL ROOF AREA 4 AVERAGE:** 0.701

#### Reflectivity Tests on Cleaned TPO Roof Membranes

<table>
<thead>
<tr>
<th>TEST ZONE</th>
<th>CLEANED TEST LOCATIONS</th>
<th>AVERAGE</th>
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</thead>
<tbody>
<tr>
<td>4A(^a)</td>
<td>0.768 0.774 0.765 0.761 0.755</td>
<td>0.765</td>
</tr>
<tr>
<td>4B(^a)</td>
<td>0.804 0.795 0.808 0.800 0.804</td>
<td>0.802</td>
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</table>

**AVERAGE:** 0.783

\(^a\) Test Zone Pressure Washed And Dried Prior To Testing

\(^\rangle\) Test Zone Rinsed/Wetted, Scrubbed With Stiff-Bristle Push Broom, And Dried Prior To Testing
Reflectivity Laboratory Measurements

**Experimental procedure**

- Unexposed, three, seven and ten years samples from the WSRCA research project were selected for reflectivity measurements.

- Five specimens 3 cm x 4 cm (1.2 in x 1.6 in) in size were cut from each of the ‘as received’ (0-, 3- and 7-yrs) samples. Due to time limitation, only two specimens from each of the ten years samples were cut and tested.
Reflectivity
Laboratory Measurements

• A Cary 5E UV-VIS-NIR spectrophotometer equipped with a diffuse reflectance accessory and the Cary WinUV Scan software was used to measure the reflectivity of specimens.

• The top ply surface of the specimen before and after cleaning was measured in the 2500–300 nm range.

• The specimen surface was cleaned by wiping the surface with a damped kimwipes and allowed to dry for at least 20 minutes before re-scanning.
• The E903 Tool Simplified integrator, which is the newest version of the Spectral Integrator Workshop was used as calculating tool.

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a E903 Solar Reflectance, Coded by Ronnen Levinson, Lawrence Berkeley Laboratory. Revised 2008-03-02 to remove display of direct-normal (“collimated”) solar reflectance.

b Courtesy of Dr. Hashemn Akbari and Dr. Ronnen Levinson, Heat Island Group, Lawrence Berkeley National Laboratory, USA.
Typical Reflectance Graphs from Integrator

- **AK1e10 bot 1 dirty**
  - G:sol=0.86,uv=0.14,vis=0.92,nir=0.88

- **AK1e10 bot 1 clean**
  - G:sol=0.86,uv=0.14,vis=0.92,nir=0.88

- **AK1e10 bot 2 dirty**
  - G:sol=0.87,uv=0.15,vis=0.93,nir=0.88

- **AK1e10 bot 2 clean**
  - G:sol=0.87,uv=0.15,vis=0.93,nir=0.88

- **AK1e10 bot 3 dirty**
  - G:sol=0.86,uv=0.14,vis=0.92,nir=0.88

- **AK1e10 bot 3 clean**
  - G:sol=0.87,uv=0.14,vis=0.92,nir=0.88

- **400 nm line**
- **700 nm line**

**Typical Reflectance Graphs**

- **Wavelength (nm)**
  - sol=300-2500 nm; uv=300-400 nm; vis=400-700nm; nir=700-2500 nm

- **Irradiance (W m\(^{-2}\) nm\(^{-1}\))**
Laboratory Reflectivity

\( b = \) before cleaning \( c = \) clean

Minimum requirement for new:

<table>
<thead>
<tr>
<th>Reflectivity</th>
<th>Unexp.</th>
<th>3-Yrs.</th>
<th>7-Yrs.</th>
<th>10-Yrs</th>
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<td>AK1bc</td>
<td>0.8</td>
<td>0.6</td>
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<tr>
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<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
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<th>3-yrs.</th>
<th>7-yrs.</th>
<th>10-yrs.</th>
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<td>0.6</td>
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<td>0.2</td>
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<td>LV1c</td>
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<td>0.6</td>
<td>0.4</td>
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<tr>
<td>LV2b</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
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<td>0.4</td>
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<td>0.8</td>
<td>0.6</td>
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<td>0.2</td>
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<td>0.8</td>
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<td>0.8</td>
<td>0.6</td>
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</table>
Conclusions

- The linear dimensional change of all seven years samples was within the maximum allowable limit of ±1% as specified in ASTM D6878 for new membranes.
- After the small changes observed in the first year of exposure, the linear dimensional stability in MD and XD remained almost unchanged up to seven years of service in the field.
- In general, the reflectivity of the roof membranes increased by less than 10% after cleaning, regardless of the cleaning method with the exception of the Texas field values, which show an increase up to 16% after cleaning.
• Reflectivity values for the new samples measured in the laboratory are, in general, similar to those measured in the field.

• Values for exposed samples show larger differences.
  • Alaska and Las Vegas, the difference between lab and field values range from 0 to 8% and increases to 15% for the Texas samples

• The reflectivity values for the 3- and 7-year samples before cleaning (2nd time) range from 61% to 87% and from 69% to 88% after cleaning with a damped cloth.

• Higher reflectivity values after cleaning. Values after cleaning are above the 50% ENERGY STAR™ specified limit for exposed membranes
General Conclusions

- Climate plays a large role in the service life of all roof systems, including TPO materials.

- In general, all four test areas in all four climatic regions are doing well, with the exception of one area at the Las Vegas site.
  - Alaska: cold, harsh climate, roof covered with snow for weeks.
  - Las Vegas: hot, dry, and extremely sunny climate.
  - San Antonio: hot, humid, and sunny climate with hail.
  - Seattle: cool and rainy, predominantly cloudy climate.
Las Vegas – Roof Area 2

Overview Close-Up View
Conclusions (continued)

• The widespread rumored TPO craze-cracking, reported by some to be happening on many aging TPO roofs was not experienced with these 60-mil, white TPO roof research and testing project.

• Crease-cracking was experienced on one roof area in one isolated location in San Antonio at year 7, and in numerous locations on one roof area in Las Vegas at year 10.
  – Those cracks were initiated by creasing of the roof membrane during installation – a practice that was discouraged by the Task Group 5 years ago.
Conclusions (continued)

• Micro-cracking adjacent to the outer seam edge was observed at year ten on the Las Vegas roof area that also experienced crease-cracking.

• Some hand-welded T-joint covers, corner boots, and other hand-welded seam edges experienced some disbonding. But, no robotic-welded seams disbonded during this 10+ year study.

• The disbonded hand welds and the crazed or cracked membranes were all repairable, and all membranes are serviceable today.

• No widespread-catastrophic problems were observed. In general, these “3rd generation” white 60-mil TPO membranes are performing successfully.
Recommendations

- When specifying TPO roof membranes, consider using white, 60 mil (minimum). In hot, sunny, or high-altitude sunny regions, WSRCA also strongly suggests thicker membranes be considered.

- WSRCA strongly urges ASTM and other standards-setting organizations to develop rating classifications, which could include Types (e.g., Type I, Type II, etc.) and/or grades (e.g., 1, 2, 3, or Commodity-Grade, Commercial-Grade, Premium-Grade, etc.) for all roof system categories, including all single-ply membranes.
• As with all roof systems, WSRCA recommends inspecting TPO roofs on a yearly (minimum) basis.

• Just like regular service extends the life of your car – regular roof inspections, maintenance, and repairs – extend the life of all roof systems.

• Regular roof inspection, maintenance, and repair is essential for the longevity of the roof system.

• Every roof system is different, thus different repair techniques may be required. To thoroughly address TPO repair techniques, WSRCA developed the *TPO Maintenance and Repair Guidelines*. 
TPO ROOF MEMBRANE
REPAIR AND MAINTENANCE GUIDELINES

First Edition -- 2011
Supplement to the 2011 WSRCA TPO Roofing Research and Testing Program 10th-Year Report
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- M-IV Proper Hot-Air Welding
- M-V Protective TPO Roof Coatings
- M-VI Tools and Materials

REPAIR TYPES

<table>
<thead>
<tr>
<th>I-A</th>
<th>Repair of Breaches in Membrane</th>
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<tr>
<td>I-B</td>
<td>Repair of Failed Membrane Patches</td>
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<td>I-D</td>
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<td>I-E</td>
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<td>III-A</td>
<td>Insufficient Fasteners</td>
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<td>Louver Vent Flashing Repair</td>
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GLOSSARY OF TERMS

REFERENCES
In Memory of Terry Simmons
Thank you!