A CRITICAL REVIEW OF THE LIFE SPAN OF TPO, PVC AND OTHER SINGLE PLY ROOF MEMBRANES

by

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INTRODUCTION

The objective of the paper is to present an engineering, professional view of the Life Span performance of existing PVC, TPO and other single ply roofing systems now on the market, and describesome problems that recently appeared in TPO, as well as some potential issues with PVC. A case study of a then 18 year old PVC roof and a then 7 year old TPO roof, are presented.

About ten years ago the author along with a team of other roofing professionals, visited single ply roofs in the Southwest. The author has now visited various other older PVC and TPO roofs in other parts of the country to compare life expectancy and performance. He also reviewed premature failures of TPO roofs, possibly due to high UV exposure and failures associated with them. The author has compiled information from his two studies and will present it in this paper and at the January 20-21 presentation.

Some of the problem areas to be discussed include failings of the membrane above the scrim, the scrim itself, the impact of condensate draining across the roofs, the ability of the membranes to be heat welded after being on the roof for many years, condition of manual fasteners, possible manufacturing issues, the impact of roof storage, and related issues. In addition to visual observations, test cuts, seam pull tests and other tests have been made.

The paper will also include examples of design issues faced by the roof consulting professional.

OVERVIEW

Roofing consultants must keep pace with changing design implications and become current with their understanding of rapidly evolving technology in single ply materials, components, systems and assemblies. Every one of the systems has unique installation issues relating to the manufacturing and installation processes, roof design, water tightness, and roof longevity.

The last 30 years have seen a rapid growth in roofing technology. This growth in roofing technology has been driven by building designers and owners demanding roofing systems with excellent longevity at a fair price.

The criteria of long term performance and affordable pricing are difficult to reconcile. Roofing materials must perform in a severe environment. Large thermal stresses, ozone attack, ultraviolet (UV) exposure, and mechanical stresses must be accommodated in order for a roofing material to be successful. Each roof system is assembled in place from many discrete components. Excellent workmanship is required by the roofing contractor who must pay a premium for qualified craftsmen.

Roofing contractor organizations such as the National Roofing Contractors Association (NRCA), and the Western States Roofing Contractors Association (WSRCA) have developed standard recommendation sets and details to assist contractors. Roofing manufacturers have organized groups such as the Single Ply Research Institute (SPRI) and the Built Up Roofing Systems Institute (BURSI) in order to advance manufacturers roofing positions. Roof design professionals have formed working groups such as the Roofing Industry Educational Institute (RIEI) and the American Standard for Testing and Materials (ASTM) that address roofing education and research. Roofing consultants are active members of the Roof Consultants Institute (RCI). Unfortunately, each of these organizations has an underlying interest which they seek to foster. Roofing contractors seek to advance positions that allow for greater industry profits. Roofing membrane manufacturers seek to advance their membranes' share of the roofing market. Roofing design professionals seek to advance conservative uses of methods and materials so as to reduce client roofing dissatisfaction. Lastly, the consultants' groups seek to work with and address the concerns of all of the above noted parties, especially the building owners.

In view of the above observations, it is not always easy to acquire objective, consistent and reliable information on any roofing material. Proven in-place performance is the most reliable indicator of future roofing material performance, and there are four major factors in play: manufacture, design, workmanship and routine maintenance. This information and the survey of single ply roofing membranes has been assembled from industry experts, along with information and definitions generally accepted throughout the roofing industry.

The industry has seen a wide range of life expectancy from identical types of roof systems. Similar roof systems may vary in life expectancy from four to 40 years. Variables that change the life expectancy of a roof are:

1. **Manufacturing**
2. **Good/Poor Design**
3. **Good/Poor Workmanship and Installation**
4. **Maintenance**

Most roof systems are installed using material manufacturer's printed instructions and guide lines, which are usually general in nature and do not deal with every condition on the roof. Therefore, different parts of the roof system may have different life spans: a pipe flashing may last 10 years, the wall membrane may last 15 years, and the roof membrane may last 20 years. The maximum life expectancy of a roof system is thus limited to the lowest life expectancy of the component parts, provided they are properly constructed.

One significant factor in the long term performance of the roof system is workmanship during installation. Regardless of how well a roof is designed, workmanship plays a key role in the performance of any roof system. Poor workmanship may have an adverse effect on the roof membrane, the flashings, or both.

Lack of routine maintenance and inspection may result in avoidable leaks such as drains clogging up or failing sealants at counter flashing. Leaks in insulated roofs will usually cause the insulation to get wet which will significantly lessen the life expectancy of the roof system. Insulation is a double edged sword, installed properly and "dry," it creates a buffer between the substrate and roofing membrane, and can prevent premature failure in the roofing system by protecting the membrane from nails backing out and movement in joints.

ROOFING TYPES

The major roofing types can be defined in four broad categories. These categories are: Single Ply, Built Up, Modified Bitumen, and Spray Applied Polyurethane Foam.

1. **Single Ply**
   a. Poly Vinyl Chloride: PVC
   b. Thermo Plastic Olefin: TPO
   c. Ethylene Propylene Dien Monomer: EPDM
   d. Clorosulfanated Poly Ethylene: CSPE/Hypalon
   e. Poly Iso Butlyene: PIB
2. **Built Up**
   a. Asphalt
   b. Coal Tar Pitch
   c. Modified Asphalt
   d. Cold Process
3. **Modified Bitumen**
   a. Styrene Butyl Styrene: SBS
   b. Acrictec Poly Propylene: APP
4. **Spray Applied Poly Urethane Foam (SPF) with one of these coatings:**
   a. Urethane Coating
   b. Silicone Coating
   c. Acrylic Coating

This paper will address two single ply membranes – PVC and TPO. The others will be left for future presentations and reviews.

DISCUSSION

1. **Single Ply Membranes.**
   a. Summary. Single ply roof membranes are sheets of elastomeric material that are applied over a roof and joined into a single layer of waterproof covering. These sheets vary greatly in chemical constituents, manufacturing process, thickness and physical properties. Single ply sheets are typically from 40 to 75 mils (thousandths of an inch) in thickness. The sheets can be fabricated from a single layer of material or may be a composite of several materials that are laminated together.

      Single ply PVC and TPO membranes reviewed in this paper generally consist of a top layer, a fiberglass or other material middle layer – the "scrim" – and a bottom layer of material, all laminated or otherwise manufactured together.

Single ply roof membranes have been in use for more than thirty years although several of the membrane materials have vanished from the market due to poor performance. Today there appear to be five major generic membranes generally available. These membranes are PVC, TPO, EPDM, CSPE, and PIB.

b. Problem areas. One of the problem areas associated with single ply roof membranes installation is the joining of adjacent sheets. This process, known as seaming, depends on the type of material being joined. The most prevalent types of joint sealing are hot air welding and sealants. Chemical welding, adhesives and joining tape systems are used for certain types of the single ply market.

   A second problem encountered with single ply roof systems is one of securement or fastening of the assemblies to the roof structure. Several spectacular failures of single ply assemblies have encouraged the insurance industry to establish specific requirements for single ply securement. These requirements are based on building location, height, proximity to open water, and roof deck structure.

   The major single ply roof securement methods are fully adhered, mechanically attached, and ballasted. Fully adhered roof systems are secured to a rigid substrate utilizing adhesives ranging from asphalt to contact cements. Full adhesion has been proven to be the surest form of membrane securement.

   Mechanical attachment of single ply membranes is another prevalent form of membrane securement. It is the least expensive and most common method. In this configuration the membrane is secured at isolated locations with various forms of fasteners, securement bars and securement plates. These systems tend to concentrate stress in the area around the fastenings and often do not offer the performance of fully adhered systems.

   The final mode of membrane securement is ballast. A ballasted roof assembly is typically secured only at building perimeters and penetrations. The remainder of the roof is held in place utilizing either large washed river rock or concrete pavers. Due to the heavy dead loads added to a roof structure by the ballast, careful calculation of the roof deck structural capacity must be conducted prior to installing this type of single ply assembly.

c. Cost of installation. Installation costs for installing any single type of membrane are typically greatest for fully adhered systems and lowest for ballasted assemblies. A secondary factor affecting the installation cost for a single ply roof system is material price. The economic reason for this is simply that because of the cost of entry – machinery, distribution, engineering and sales – the major manufacturers of single ply systems have achieved an economy of scale that cannot be matched by those that are not widely utilized.

2. **Traits of good single ply roofs.** The traits and features that make for a long lasting single ply roof are similar to what makes for any good, long lasting roof:

   a. Good manufacturing processes.

   b. Consistent material selection and mix, as needed for the application.

   c. Good UV protection.

d. Proper ballasted surfacing for ballasted single ply roofs..

e. Good roof and substrate design, where the roof is properly designed, and details such as drains, sleepers, base flashings, all designed to last concurrently with the membrane.

f. Proper slope to drain.

g. Proper securement of roof and insulation.

h. Stable substrate such as concrete, light weight Insulating Concrete, or insulation over plywood or metal.

i. Protection from physical damage caused by maintenance crews, storage, other excessive traffic, hail, other weather.

j. Early attention to problem areas.

Because of constraints on the length of this paper, not all of these factors will be addressed, and many have been reviewed by other consultants in other forums.

3. Manufacturing Process.

a. PVC

PVC is an acronym for the polymer (a large molecule with linked, repeating chemical units) known as Poly Vinyl Chloride. When formed and cooled in its final use PVC is a rigid plastic material that is modified with various "plasticizers", coloring materials, fire retardants and other additives, depending on the requirements and the manufacturers. The color of PVC can vary, is integral and is provided early in the batching process at the factory.

Plasticizers are specially formulated oils or other materials that lubricate the cross link junctions of the material and make PVC roof membranes flexible. Fire retardants are exactly what the name implies – additives used to reduce the spread or rate of fire. Other additives could include chemicals to reduce Ultraviolent (UV) damage.

The membrane sheets are laid up in a composite through either a calendaring (heat and pressure are applied to roll sheets, to form a membrane), extrusion of liquid materials, or other laminating methods. All modern PVC sheets are reinforced with either polyester or fiberglass scrims. The quality of a PVC sheet membrane is directly related to the quality of plasticizers, fire retardants, UV protectants and other additives that are used in fabrication. This paper is limited in scope and does not review the actual interrelatedness of the various chemicals and compounds used in manufacturing. However, the types of products used in manufacturing and the relative percentage of each, and the way each constituent chemical reacts to others in the mix, will have a direct impact on quality and longevity, an impact that could be felt many years after manufacture and installation.

Early PVC sheets were prone to failure due to a process known as plasticizer migration that manifested itself in two forms. These early PVC sheet problems caused the sheets to lose market share and subsequently many manufacturers took their product off the market. However, not all PVC sheet manufacturers experienced migration problems. This was and is due to their strict use of only the best plasticizers available. PVC roof membranes from more than one manufacturer have been noted to be performing well in very severe service.

PVC sheets are spliced together through hot air welding. Hot air welding of the sheet is easily accomplished with automatic and hand welding equipment. The welding process involves hot tacking the weld in position by hand then welding the joint with either hand or automatic welding equipment. The quality of the weld can be easily checked by the presence of "bleed out" of material at the weld edge. The strength of the weld junction is typically much stronger than the adjacent membrane sheet.

LIFE EXPECTANCY OF PVC: It is somewhat difficult to ascertain maximum life expectancy; however, the best quality reinforced PVC membrane is believed to last about 25 years.

b. TPO

TPO is the acronym for Thermo Plastic Olefin, a blend of polypropylene and ethylene-propylene polymers. As with other types of roofing materials listed here, it contains performance enhancing products including flame retardants, UV absorbers and others, to obtain the desired membrane properties. The manufacturing process is also somewhat similar to PVC.

Some industry experts indicate that TPO can demonstrate near EPDM-like resistance to weathering change if appropriately formulated and manufactured. As with many other single ply products, mix design at some manufacturers has been known to vary, primarily due to cost cutting at the factory. The physical properties of TPO membranes can thereby vary significantly with the type and amount of filler, fire retardants and UV stabilizers. ASTM standards are being developed for TPO roof membranes, due in part to the varied formulations that are possible.

In Europe, TPO membranes have been used successfully below grade for more than 20 years. Early formulations also were used on several test roofs. Lap seaming of TPO sheets was not fully understood in the late 1970's and could not keep early TPO roofs watertight, but the product weathered very well. The early membranes were formulated with carbon black and tended to get quite hot. Newer membranes have titanium dioxide added to achieve a white reflective membrane surface.

LIFE EXPECTANCY: TPO has been known to vary greatly in life expectancy. A well manufactured product, properly installed, may last 12 to 18 years or more.

c. EPDM. For purposes of comparison only, the following describes EPDM manufacturing:

EPDM is the industry name for the synthetic rubber elastomer known as Ethylene Polypropylene Diene Monomer. EPDM is a cross linked vulcanized material that is extremely resistant to UV and ozone attack. The membrane fabricated from this rubber is typically black in color.

The sheets are manufactured in thickness ranging from 45 to 60 mills. The sheets can be factory assembled into large sheets as big as 50' x 200', and are available reinforced with polyester scrims and un-reinforced. Reinforced sheets have greater tear resistance than un-reinforced sheets. The reinforced sheets are normally associated with mechanically attached roof systems because of the higher point stresses that these systems generate at the membrane securement point.

EPDM roof membranes have been documented to have good performance. However, the best performing systems that have been documented were well designed and closely monitored during construction. EPDM seaming is extremely workmanship dependent. The complicated seaming process is a result of manufacturers addressing the single biggest recognized problem with EPDM, seam failure.

Chemical compatibility is another design consideration when reviewing EPDM. EPDM will swell when placed in contact with petroleum, vegetable oil, and animal fats. Other membranes should be considered when these materials may be present on the roof.

Flashing of EPDM roof systems is accomplished with uncured EPDM material. The uncured sheets will slowly cure when exposed to the environment. These sheets are easily damaged by over tooling during installation. Once again, carefully attention must be paid to design and workmanship of all EPDM flashing and membrane splice conditions.

EPDM's major problems with sheet splicing can be addressed when the system is correctly designed. By utilizing the largest sheets and carefully detailing flashing conditions EPDM roofs can be designed with fewer seams. Designing the roof system in this manner reduces the installed cost of the system by reducing the amount of labor required to perform complicated seaming. Additionally, because fewer seams are utilized, the roof system will have a much smaller potential for seaming problems.

Repairs to an EPDM roof membrane are accomplished in a similar manner to the splice procedure. First the problem area is thoroughly cleaned and then a patch is fabricated from an EPDM sheet. The patch is applied to the defect site using the same process as splice fabrication. Repairs can be applied to the roof system successfully throughout its anticipated performance life.

LIFE EXPECTANCY: Based on how the EPDM material appears to age, its estimated life expectancy is between 20 and 25 years.

4. PVC Case Study.

Two case studies are presented in this paper – an onsite review of a PVC roof and an onsite review of a TPO roof.

a. PVC Case Study Overview. Our firm performed a case study of a then 18 year old PVC roof of a department store located in Northern California. No leaks and no repairs had been reported at that time. The purpose of the study was to determine the longevity of a single ply membrane after 18 years of use. Admittedly, the team of roofing consultants was skeptical of the condition of the roof.

We performed a visual inspection of the roof to observe the performance of the system against sustainability criteria. We performed limited destructive testing and performed laboratory testing of samples to compare original and aged membrane thickness.

b. Our PVC sustainability checklist included:

  i. What is the roof system's ability to handle foot traffic and impact damage?
  ii. What is the membrane's ability to handle ponding water and condensate and rain water draining across the roof?
  iii. What is the membrane's ability to be patched and repaired?
  iv. Could we determine the membrane's physical properties, tensile strength, thickness, bend test, etc.?
  v. Was original design of the roof system adequate for its intended use, a department store?
  vi. Was original application (construction) installed per manufacturer's requirements?
  vii. Could repairs be made to an eighteen year old roof?

c. Our PVC sustainability findings were:

  i. 95%+ samples met original membrane test results.
  ii. Membrane material.
    1) Field areas of membrane performance appeared to be good/excellent.
    2) The membrane was easy to patch as we learned after making and repairing test cuts.
  iii. Traffic and impact damage.
    1) This roof and most likely other PVC roofs, are susceptible to impact damage from dropped tools, screws, stored equipment, excessive foot traffic, etc.
    2) Damage appeared to be easy to identify and repair.
  iv. Design issues.
    1) Original poor design of pipe supports caused damage to the roof membrane.
    2) Poor design of roof drainage caused ponding water and damage to the membrane top layer, exposing the scrim in some areas.
    3) Poor design of condensation control mechanism also caused visible damage.

v. Maintenance.

1) There appeared to be a lack of frequent and seasonal inspections.

2) There appeared to be a lack of proper roof protection during remodeling construction.

3) The lack of proper maintenance of HVAC equipment damaged the roof –dropped tools, screws, HVAC doors, etc.

4) New pipe penetrations were not properly flashed with compatible materials (use of asphalt mastic).

vi. Lessons Learned

1) Actual long term sustainability depends on many factors.

2) This PVC membrane's ability to handle normal exposure to sun, rain and elements is very good.

3) In 20+ years, expect the roof to go through many different challenges.

4) When designing a roof, consider that the building may undergo remodeling, HVAC replacement, new electrical addition, etc.

5) Be mindful of the impact of original design defects.

6) Owner's lack of frequent inspections, timely repairs, and use of proper patching techniques needs to be addressed.

5. **WSRCA TPO Study.** The Western States Roofing Contractors Association (WSRCA) in 2007conducted what they called an "in situ" test of the weathering characteristics of TPO roof membranes, beginning the test of four roofs in approximately 2000 and continuing to follow the roofs, most recently through 2009. The study was known as the TPO Weathering Farm Project, a study of the same four manufacturers' products on four test buildings.

a. Participating companies that provided test membranes were:

i. Carlisle

ii. Firestone

iii. Dow (formerly Stevens)

iv. GenFlex (withdrew in 2007)

b. Test Locations. Test Roof Locations are in:

i. Anchorage, Alaska

ii. Seattle, Washington

iii. Las Vegas, Nevada

iv. San Antonio, Texas

c. Initial summary report. In a summary report issued in 2007, WSRCA found, based on field inspections, no significant issues.

d. Updated report. In a summary report issued in May/June, 2010, based on the 2009 inspections, the following findings were made:

   i. Seam integrity after seven years considered "normal"

   ii. "Some tightening of the sheets"

   iii. Some roof pads "have degraded significantly"

   iv. Hard creases created during installation had cracked in the "top coating"

   v. Chalking test showed "minimal chalking or pickup"

   vi. "Sealant applied at cut edges of some patches and flashings appears to be reaching the end of its useful service life and in a few locations it has separated and failed"

   vii. Difference in color between sheets continues as does dirt accumulation, heavier on some sheets

   viii. "All roofs are presently leak-free and these 60-mil white TPO membranes are so far showing good in-service performance."

6. TPO Case Study.

a. TPO Case Study Overview. In the summer of 2010, we performed an on-site review of a large roof of a warehouse in Las Vegas. That roof covers a very large central beer distribution facility. The TPO roof is reportedly seven years old. No leaks or problems were reported to us. Our purpose was similar to that of the PVC case study, to determine longevity of TPO single ply after a long period of use. Again, we were with a team of other skeptical consultants. We performed a visual inspection of the roof to observe the performance of the system against sustainability criteria.

b. Sustainability Check List. Our TPO sustainability checklist included:

   i. Roof system's ability to handle foot traffic and impact damage.

   ii. Membrane's ability to handle ponding water and condensate.

   iii. Membrane's ability to be patched and repaired.

   iv. Is the roof system sustainable for type of use (warehouse)?

   v. Was original design of the roof system adequate for its intended use?

   vi. Was original application installed per manufacturer's requirements?

   vii. Could repairs be made to a seven year old roof?

   viii. To what extent could the WSRCA issues be viewed?

c. Sustainability findings:

   i. Regarding the membrane material:

1) Discoloration was observed.
2) Dirt is accumulating.
3) There are significant base flashing issues.
4) Top membrane missing or severely deteriorated, possibly leading to leaks.
5) At the walkpads, significant delamination was observed.
6) Significant chalking was observed.
7) Scrim is showing in many places
8) Scrim material is frayed
9) Lower part of laminated ply is missing in some areas, possibly leading to leaks.

ii. Regarding traffic and impact damage:

1) Susceptibility from impact damage undetermined, minimal traffic on this roof, although there was some evidence of damage. TPO is likely susceptible to impact damage in heavy use conditions.
2) Walk pads are in very poor condition.
3) Damage easy to identify
4) Ease of repair may be problematical, based on the extent of scrim damage.

iii. Regarding design:

1) Base flashing may have been under designed.
2) Condensate line mountings and other equipment mounts may have been under designed.

iv. Regarding maintenance:

1) Frequent future, detailed, inspections are necessary.
2) Roof pads will likely need replacement soon, possibly including the underlying membrane.
3) Many areas of base flashing will likely need replacement soon.
4) Equipment mounting needs to be addressed in some areas.

d. Lessons Learned:

i. Sustainability depends on many factors, some of which could have been due to the manufacturing process, although that determination was beyond the scope of this case study.

ii. Alternately, the membrane's ability to handle normal exposure to sun, especially reflected light, could be an issue.

iii. Repairs may be necessary immediately.

iv. In 20+ years, expect the roof to go through many different challenges.

v. Owners will need frequent inspections, timely repairs, and use of proper patching techniques.

CONCLUSION

Understanding the issues addressed in this paper will assist the roofing consultant in keeping pace with the possible problems and likely benefits of the use of single ply roofing membranes. Single ply PVC and TPO roofs, when properly designed, manufactured, installed and maintained, can be appropriate solutions to the needs of building owners across the United States, in various geographical areas and different weather conditions. We know of examples of single ply roofs, that having had these issues addressed, could last up to 20 years or more. The roof consultant should understand these issues, perform their own case studies, and be prepared to present the issues to their clients.