SINGLE-PLY ROOFING – 50 YEARS

HALF A CENTURY OF EXPERIENCE, BUT WHAT HAVE WE LEARNED?

By Dick Fricklas

A somewhat altered version of this article was first presented at the 25th Annual Convention of SPRI (representing the Single Ply Roofing Industry) in Rancho Bernardo, California, on January 13, 2007. Reprinted with permission.

Single-ply and modified bitumen roofing currently hold a two-thirds share of the U.S. commercial roofing market. This reflects remarkable growth, considering that these systems began just 50 years ago with a zero market share (see *Figure 1*).

What might the goals be for the next few years?

- Reduce liability.
  - Develop better products.
  - Enhance contractor quality control and product education.
- Increase productivity.
  - Simplify installation.
  - Offer systems that are more forgiving of weather conditions during application.
  - Prefabricate roofing panels with factory-installed nailing tabs so that fewer seams must be made in the field (*Figure 2*).
- Increase profitability through productivity gains.
- Help meet the country's energy and environmental needs.
  - Use less energy to produce product.
  - Develop more energy-efficient roof systems.
- Improve sustainability.
  - Offer systems that are easily repaired and more durable.
  - Offer systems that are recyclable.
  - Offer systems that are easier to inspect.

Right: Figure 1: Single-ply roofing systems offer proven durability and versatility.

BUILT-UP ROOFING (BUR) – WHAT IS ITS FUTURE?

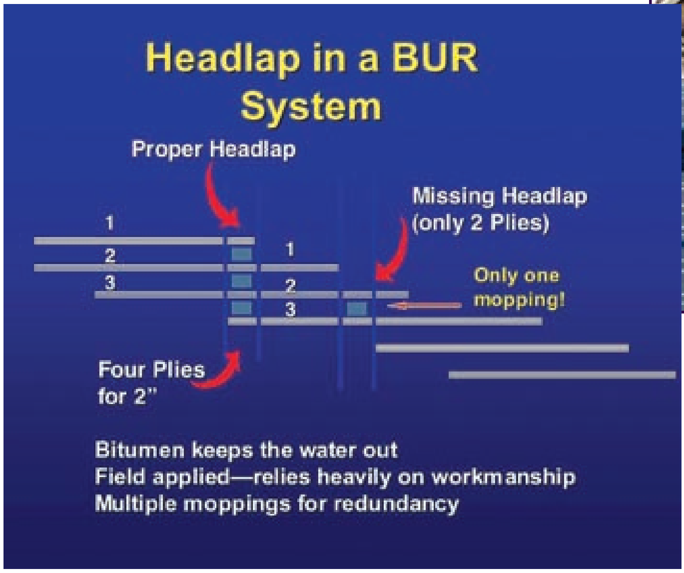
BUR today encompasses:

- Hot-applied,
- Cold process, and
- Self-adhered roofing.

BUR systems rely heavily upon field workmanship. Even a two-inch error in application markedly reduces membrane integrity (*Figure 3*). BUR requires intensive field labor due to the use of multiple layers during application. The field-spread bitumen provides the waterproofing, so skips and voids cannot be tolerated (*Figure 4*). Bituminous BUR is heavily dependent upon the availability of petroleum for producing asphalt, and the price trend has been upward. Cold-process and self-adhering systems are likely to continue to be specialty systems where fumes from the kettle or mop, difficult access, or odd roof shapes not con-

Figure 2: Factory-installed nailing tabs mean fewer seams to seal in the field..

Figure 3: With just a 2-inch head lap, good workmanship is essential to performance of the roofing plies.



Headlap in a BUR System

Bitumen keeps the water out
Field applied—relies heavily on workmanship
Multiple moppings for redundancy

Figure 4: The field-applied bitumen serves both as adhesive and waterproofing agent.

ducive to conventional hot application are issues.

MODIFIED BITUMINOUS ROOFING (MB)

Polymer-modified bituminous roofing (MB) takes advantage of the industry's experience with built-up roofing. Use of selected reinforcements and polymer additions yields higher performance membranes, even though fewer layers are used. MB sheets are coated under factory quality control, whereas BUR systems require field application of bitumen for water resistance. Most MB systems use just two or three layers, compared to the three to five layers needed in a conventional BUR. As a result, both labor and materials are reduced when MB is used.

Generally, MB systems use factory-applied granules or metal foil surfacing for appearance and UV protection, rather than the field-applied flood coat of bitumen and gravel of BUR systems. Ironically, the superior toughness and conformability of MB materials have extended the life of built-up roofing systems by providing superior flashing performance.

Potential problems of MB systems:

- Slippage when installed in hot asphalt.
- Blisters from voids or entrapped moisture.
- Torch application of MB systems is very effective but raises fire concerns (*Figure 5*).
  - Insurance may be a problem for contractors who do torch applications.
  - Some MB manufacturers are providing the requisite insurance as a service for their contractors.
  - A certified torch-applicator program should be in place, and only CERTA-trained applicators should be permitted on torch-down projects.

Current Issues with Modified Bitumens

- Better definitions are needed of the pros and cons of APP vs. SBS-polymer modifiers.
- Identification of which reinforcements are best for which applications – e.g., glass fiber mat, polyester/glass scrim, or fabric hybrids is needed.
- The difference between a "hybrid-BUR-MB" – where multiple BUR layers are installed in hot asphalt, followed by a MB cap-sheet – and a system in which MB sheets are used for all layers should be identified.

Figure 6: One layer of polyester mat laid in hot asphalt is a non-conventional single-ply roof membrane.

Figure 5: Multiple torch-heads allow rapid application of MB systems.

- Identify whether or not a heavy, one-ply polyester membrane laid in hot asphalt is actually a single-ply system (*Figure 6*).

Major milestones in MB and single-ply have already been reached, such as:

- *Interim Criteria for Polymer-Modified Bituminous Roofing Membrane Materials*, published by the National Institute of Science and Technology (NIST), February 1989.
  - There has been a lack of acceptance on the proposed minimum strain energy of 3.5 pound-inches per inch for MB.
- Many ASTM and ANSI standards have been issued and most have been accepted by building code officials.

WHAT CAN WE LEARN FROM HISTORY?

The first generation of single-ply polymeric materials appeared in the 1950s, primarily from Europe. Perhaps the higher costs of energy in Europe at that time, particularly in petroleum products, triggered earlier experimentation with polymeric-based systems.

Polyisobutylene (PIB)

One of the first new products was based upon polyisobutylene (PIB). PIB is very similar to butyl rubber (which is a co-polymer of isobutylene, but with small amounts of isoprene), except it lacks conjugated double bonds needed for vulcanization. (This is similar to EPDM, where the "D" represents a diene, a monomer with at least two double bonds). Since PIB has no UV-vulnerable double bonds, it possesses an extraordinarily high degree of ultraviolet resistance. PIB sheets in Germany were first used as UV screens for asphaltic roofs. Low-molecular-weight PIB products were also used in adhesives and even introduced as additives to improve the low-temperature flexibility for other polymers.

Figure 7: Polyester fleece replaced neoprene-bonded asbestos backer materials.

The first PIB products introduced into the U.S. market were only 45 mils thick (1.1mm), as compared to the previously successful European product at a thickness of 250 mils (plus a membrane beneath). This pattern of taking successful European products and modifying them to make them more competitive for the U.S. market continues today.

The PIB products incorporated the use of factory-bonded backer materials, both as fire barriers and to separate the polymer from the substrate. Solvent-based cold adhesives were used as lap sealant, flashing adhesive, and deck adhesive. Since Volatile Organic Compound (VOC) regulations did not yet exist, there was no problem with the use of volatile hydrocarbon solvents. Versions of the PIB membrane included asbestos-paper-backed product for membrane, a scrim-backed material for flashings and expansion joint covers, and a nonreinforced film for forming pipe flashings, inside and outside corners, and the like. This practice of multiple versions is still used today with EPDM products.

The backing for PIB membranes ultimately shifted from latex-bonded asbestos paper backer to polyester fleece (*Figure 7*) in order to achieve greater toughness and to improve isolation for the substrate. The early PIB materials tended to creep (cold flow), resulting in thinning and, ultimately, cracking. Incorporating the flexible fleece helped. Blending PIB with ethylene-vinyl-acetate (EVA) assisted in both forming and reinforcing the PIB, and this PIB-EVA blend is the only one still manufactured today. While PIB was originally compounded as a black sheet, currently it is produced in white and does not require a field-applied color coating.

The PIB systems were the first to offer a selvedge of factory-applied splice tape. This has since been adopted for EPDM systems. Because of the potential for wicking of the fleece backing, "wet" sealants are required at "tee" joints and other points where the polymer selvedge is absent.

PIB is a difficult polymer to process. It is also relatively expensive compared to the polymers used in most other single-ply membranes. While some PIB remains in the U.S. market, other polymers, such as EPDM, TPO, and PVC, have generally displaced it.

Early Research on Single-ply Systems

Maxwell Baker of the National Research Council of Canada authored a *Canadian Building Digest* in 1964 entitled "New Roofing Systems." Baker pointed out the dangers of too much enthusiasm for "new" products "without regard for the fact that they are still vulnerable to building movement, trapped moisture, and workmanship errors. In addition, new factors are introduced such as a dependency upon thin layers of adhesive and narrow joints." (See *Figure 8*.)

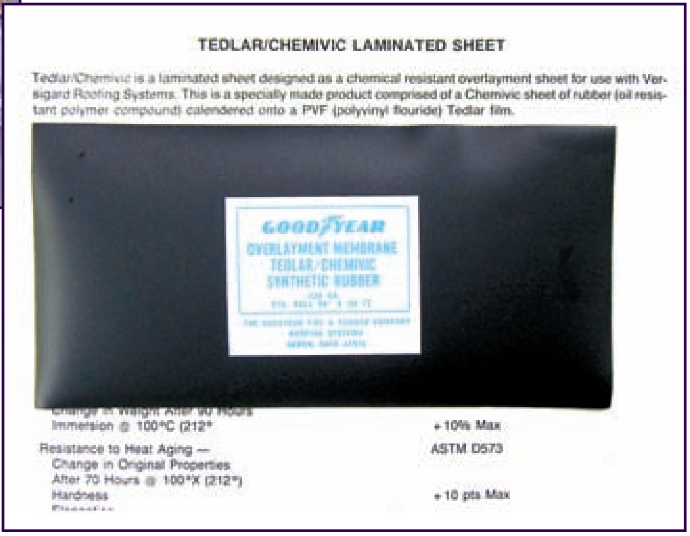
In 1966, Tom Boon and Bill Cullen of the National Bureau of Standards (NBS – now NIST) issued *Report #9381, Progress Report on Exposure of New Roofing Systems*. Their field exposures included butyl rubber, Tedlar®, Monoform® (asphalt emulsion with glass fiber reinforcing), PIB, and several liquid systems such as Neoprene-Hypalon®.

The Tedlar® roofing membrane (polyvinyl fluoride) tested was just two mils thick. It was factory laminated to a backing – generally, Neoprene-latex bonded asbestos paper (hence the designation "TNA 200®," for Tedlar-Neoprene-asbestos, 2 mils). The TNA-200® could be installed in the field using latex adhesive or applied in hot asphalt. The critical lap joints were sealed with a pressure-sensitive Tedlar® tape. Unfortunately, this tape tended to creep, resulting in a "zebra" effect. It was very difficult to get tape and patches to stick to Tedlar®, since it is very much like Teflon®.

Years later, a Tedlar® film laminated to a nitrile rubber sheet (*Figure 9*) was successfully introduced as an expansion joint cover. Since the nitrile-rubber base has excellent oil resistance, the cover could be embedded in asphaltic mastic. The Tedlar® provided UV protection for the nitrile rubber. Splices were tricky, with Neoprene splice covers embedded in a moisture-curing urethane adhesive. A weakness of the system was that if the Tedlar® film was nicked or scratched during or after installation, it could easily tear, exposing the Neoprene to UV attack.

Korad®, a thin acrylic film, was also introduced into the roofing market. The innovation in this case was to factory-bond the Korad® to plywood or OSB roof decking. In the field, the panels were nailed to

Figure 8: A major innovation in roofing was the offering of contractor applicator schools.



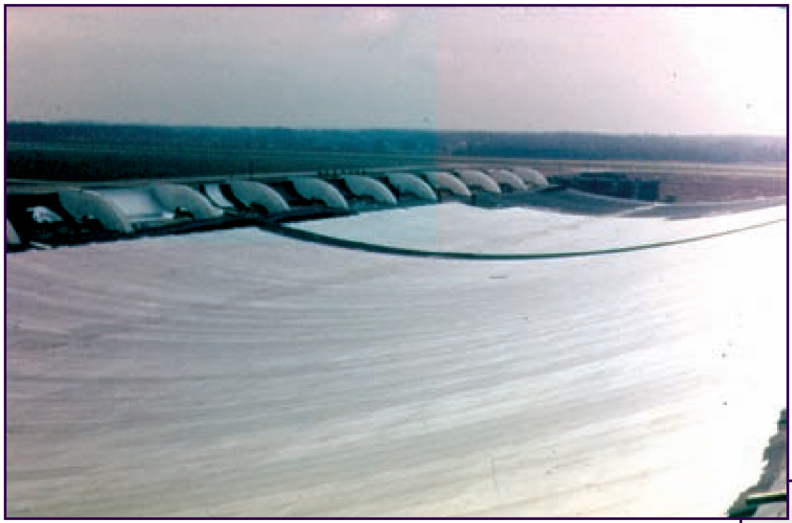
TEDLAR/CHEMIVIC LAMINATED SHEET

Tedlar/Chemivic is a laminated sheet designed as a chemical resistant overlayment sheet for use with Versigard Roofing Systems. This is a specially made product comprised of a Chemivic sheet of rubber (oil resistant polymer compound) calendered onto a PVF (polyvinyl flouride) Tedlar film.

Immersion @ 100°C (212° +10% Max

Resistance to Heat Aging — ASTM D573
Change in Original Properties
After 70 Hours @ 100°X (212°)
Hardness +10 pts Max

Figure 9: Tedlar® film provided weather protection for the acrylonitrile (rubber) membrane.



Figures 10A (left) and 10B (below): Dulles Airport required a flexible roof membrane to withstand expected structural movement.

rafters, with Korad® tape both covering the fasteners and sealing the panel joints. This art has reappeared in several versions, usually with insulated deck panels faced with polymer-coated metal.

Early Versions of Elastomeric Roof Systems

The first major U.S. application of an elastomeric, single-ply roof was at Dulles Airport (*Figure 10*). Due to the unusual building design, the roof membrane had to be extremely flexible. Sheet Neoprene was installed, followed by liquid Hypalon®. In the years that followed, many all-liquid Neoprene-Hypalon® systems were applied to continuous substrates such as thin-shell concrete, taped-plywood decks, and as a coating system for sprayed-in-place polyurethane foam (SPF).

Neoprene rubber could be produced and shipped as either a vulcanized roofing sheet or in a semi-cured state. Semicured was very handy for flashings where conformability was critical (*Figure 11*). Vulcanized rubber has a memory and does not permit stretching to conform to inside and outside roof corners or other odd shapes. This semi-cured Neoprene solved many problems – not only for Neoprene roofs, but for prototype EPDM and butyl roofs as well. Unfortunately, this Neoprene cross-linked to an elastomer upon aging, eventually over-curing and becoming especially brittle on south-facing exposures. Development of uncured EPDM or the use of factory-vulcanized EPDM membranes solved most of these problems. Factory premanufactured inside and outside corners and witches' hats have been highly successful in solving those conformability issues.

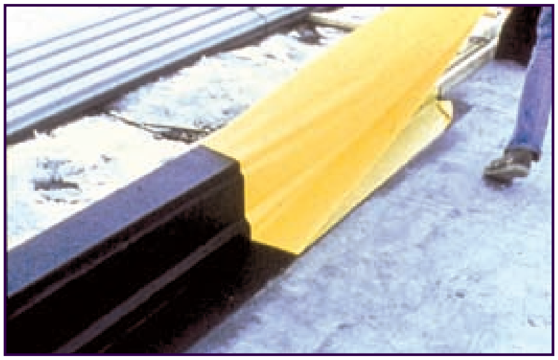


Figure 11: Uncured neoprene sheeting provided the conformability needed for flashings and penetrations.

Liquid Elastomers

Many other liquid-elastomeric roofing systems have been introduced over the years. Most required multiple coats to avoid pinholing and are only available at relatively low solids. Several had inadequate fire resistance for roofing applications. Since sprayed-in-place polyurethane foam always requires a protective coating, silicone, urethane elastomer, and acrylic coatings have filled this niche market very well. (On flat roof surfaces, aggregate has also been used as a UV screen.)

Thermoplastics

Interest in weldable thermoplastic systems surged in this country as the single-ply market developed. Most of the technology originated in Europe. Some thermoplastic systems were based upon nonreinforced PVC films. They were offered as very thin films – as thin as 32 mils (0.8 mm). Unfortunately, some of these early PVC systems were poorly compounded. Many suffered from severe shrinkage and embrittlement.

Curiously, it was observed that ballasted PVC roofs were failing faster than roofs that were exposed to the weather. One theory was that the sediment associated with the ballast was drawing out the plasticizer from the PVC compound. Thicker sheets should retain the plasticizer longer, since the loss is a surface-related phenomenon. Today, manufacturers offer few, if any, nonreinforced systems. Mechanically fastened systems represent the largest market segment.

Compatibility between PVC compounds and substrates is very important. Direct contact with expanded styrene foam insulation could lead to plasticizer extraction. Volatiles from an underlying coal-tar pitch roof could migrate into the PVC. Foil air barriers evolved as a necessary component of the assembly as a means to isolate the system components. Various "slip-sheets" are still used today to isolate the new PVC membrane from contacting soft bitumen or

Figure 12: Various slip sheets have been used with plasticized PVC membranes.

recently applied asphaltic patches (*Figure 12*).

One notable innovation of these early PVC systems was to incorporate polymer-coated metal for edging and flashing. This turned flashing details around, with the metal flashings installed first and the membrane bonded to the preformed metal edging, coping, or flashing (*Figure 13*).

Figure 13: Polymer-coated metal flashings anchor this PVC roof membrane system.

In 1990, a bulletin was published jointly by NRCA and SPRI warning about premature embrittlement and the dangers of even walking on an older PVC membrane. The bulletin noted that the reinforced sheets were less vulnerable to the shattering phenomenon. Impact damage on brittle PVC roofs can be profound and has led to the use of thicker membranes and denser substrates in hail-prone regions.

Recent evidence has shown that some properly compounded PVC membranes are lasting well over 20 years. They are still weldable (repairable) after all that time and may be suitable for recycling at the end of their life. Most can meet EnergyStar® reflectivity requirements, opening up new opportunities on the West Coast where white mineral-surfaced cap sheets have traditionally dominated this wood deck market.

Chlorinated polyethylene (CPE) sheets were designed to use less plasticizer than PVC, but in many cases the CPE was found to be harder to weld, a poor trade-off (*Figure 14*). Currently, there are a number of successful PVC systems that either use superior plasticizer systems or which are compounded with other polymers such as ethylene-vinyl acetate (EVA) or ketone ethylene ester (KEE) to achieve the needed flexibility and durability, while pure CPE sheets essentially have vanished. Chem-ply® was an early CPE system that used flexible open-cell foam as a backing. The idea was that the foam could vent pressure laterally to avoid blistering, as well as serve as a separation barrier. Unfortunately, the foam disintegrated with age, and the Chem-ply® exhibited less-than-favorable weathering performance.

SYSTEM TESTING OF SINGLE-PLY ROOFING SYSTEMS

Dr. Bas Baskaran of the National Research Council of Canada has documented the "weakest-link" approach to mechanically fastened roof systems. Double welds distribute stress under wind loading, achieving higher wind ratings. Seam failures should be dramatically reduced when the wider double weld is incorporated. Properly selected fasteners, stress plates, and air barriers also resolve weak link issues.

With reinforced sheets, there is always a concern that water will wick into exposed edge fibers, causing film delamination. Some sheets use a selvedge of nonreinforced polymer, while others require a wet sealant at all cut edges (*Figure 15*).

By 1978, single-ply systems had made enough penetration into the commercial roofing market for the National Bureau of Standards to publish "Elastomeric Roofing: A Survey." This document suggested tests and standards that ought to be employed in evaluating the new roof systems. One item mentioned was the high degree of chalking (surface erosion) of some liquid-applied and Hypalon® systems. Algae attack was also reported in semitropical climates.

USING FOAMED PLASTIC INSULATIONS WITH SINGLE-PLY SYSTEMS

Polystyrene foam (EPS) has proven to be a very economical insulation for nonbitumi-

Figure 14: Lead weights have been stacked on this seam welder to improve CPE seam fusion.

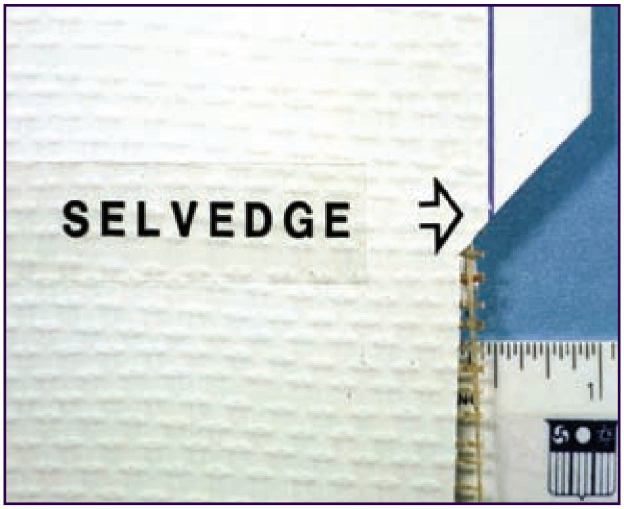


Figure 15: Selvedge region with no scrim to avoid wicking of water.

nous roofing systems. However, because styrene dissolves in aromatic and aliphatic solvents, vapors from solvent-welded membrane laps, solvent-based flashing cements, and cold-applied membranes can collapse the cells of the foam (*Figure 16*). On a sunny day, EPDM can absorb enough heat to cause cell deformation if the black rubber is not promptly covered with ballast.

Low-density polystyrene boards are also subject to stress relaxation in mechanically attached systems. Most membrane manufacturers require the use of higher density foam (>1 pcf) to minimize this phenomenon. A research paper by Dr. René Dupuis for SPI recommended that EPS boards be heat-treated prior to shipping to a job, as the installed boards could otherwise shrink the first time the roof heats up.

Figure 16: Cells of polystyrene foam have collapsed from solvent vapor attack.

Recent Developments in Attachment and Joining of Single-Ply Systems

Attachment methods vary widely with single-ply systems. Hot asphalt, applied in a serpentine pattern, provided about 50 percent adhesion; controlled spot attachment or sprinkle mopping, likewise (*Figure 17*). Parallel ribbons of adhesive date back to the 1960s, but at the end of a run where the applicator made U-turns, these areas were often deficient in adhesive.

Fleece-backed sheets facilitate adhesion with asphalt, low-rise foam, and solvent adhesives. A new generation of self-adhering sheets has been introduced just recently. Problems this author anticipates with the self-adhering sheets include limited shelf life, disposal of the release film, and special treatment at penetrations, tee joints,

Figure 17: Attachment methods for single-ply systems have included adhesive ribbons, serpentine application of hot asphalt, and self-adhesive systems.

Figure 18: Examples of some of the nonpenetrating mechanical fastener systems that have been tried.

Figure 19: Edge restraint strips have reduced the tendency towards shrinkage and tenting of single-ply membranes.

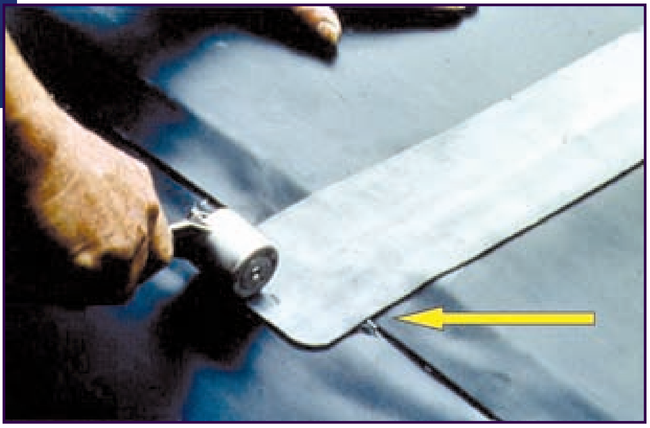


Figure 20: Illustration of the use of wet sealant on both sides of the batten.

and intersections. Substrates need to be smoother, drier, and cleaner than with any other roof system.

Consultants may remember attempts with "nonpenetrating" fastener systems. The idea was that every hole in a membrane is a potential leak, so these buttons and tracks would provide "hold down," while leaving the membrane intact (*Figure 18*).

For various reasons, most are gone, but the in-the-seam methods and batten seams appear to work just fine. Perhaps the double welds and edge-restraint systems now used reduce the shrinkage and tugging at the fastener stems (*Figure 19*).

The use of primers and splice washes is still a good idea. Talc-free elastomers help, but we are still totally reliant upon our ability to successfully seal narrow joints for watertightness. While solvent-based seam adhesives are still used, the butyl-tape systems have been widely adopted and apparently are very successful.

Figure 21: In retrofitting older EPDM roofs, all flashings are generally replaced and target pieces are added at all critical joints.

Tee joints are always critical. In some systems, butt endlaps are used, followed by a batten cover that extends beyond the side lap (*Figure 20*). Other manufacturers are going to "target patches" at the tee joints as an extra line of defense (*Figure 21*).

Consultants may also recall that the implementation of in-seam sealant application (*Figure 22*) gave extra protection against moisture migrating either from below the membrane or from a poorly sealed side lap.

50 YEARS - WHAT HAVE WE LEARNED?

We have learned a great deal. We can offer durable sheets with adequate mil thickness, which are well-positioned in terms of energy conservation, sustainability, and economy.

With the help of SPRI, ANSI, and ASTM, product and test standards have been developed. Single-ply systems are mainstream in both designers' and building owners' eyes. Accessories such as walkways and premolded pipe fittings have solved many of the problems of the bituminous world and

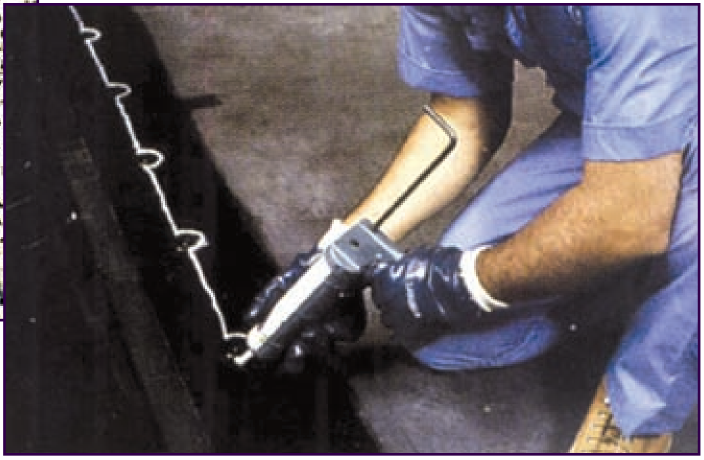


Figure 22: Use of in-seam sealant as extra measure against water penetration.

Figure 23: Polyepichlorohydrin rubber was used in this roof bay in order to resist oil contamination.

Figure 24: King-sized ballast on this roof!

continued evolution of these systems can be expected.

Specialized sheets for chemical and oil resistance are available (*Figure 23*). New versions of single-ply roofing suitable for vegetated roofs are certain to appear.

Perhaps the reader has never seen a ballasted roof like that shown in *Figure 24*, but who knows what form our next generation of single-ply systems will take?

WHAT DO WE STILL NEED TO ACCOMPLISH?

In the presence of product and systems evolution, the key parameter of performance is perhaps the most readily discernable benchmark by which all roof assemblies are measured. Manufacturers promoting new and improved roof components and accessories should strive to provide the end user with comparative performance criteria based upon level of performance.

Some years ago, our European colleagues published articles on the FIT system. This system is an entirely different approach from that in the U.S. The first step in this performance approach is to describe the structure and how the roof is to be used. Industry experts have quantified what levels of fatigue, heat, or impact resistance are needed for a roof system intended to serve in an exposed position, such as a protected roof or a vegetated roof. A roof with a lot of roof traffic, for example, might require a Level Four impact and puncture resistance, while a protected membrane roof might get by with just a Level Two.

Once performance levels are established and the roof described, one need only to search for those systems that meet these levels of performance. Perhaps a 90-mil EPDM would work, but so might a polyester-reinforced MB, a 60-mil reinforced PVC, etc.

Much of this work has already been done and published by the RILEM 74-SLR/CIB W.83 Joint Committee on Elastomeric, Thermoplastic, and Modified Bitumen Roofing in its report, “Performance Testing of Roof Membranes.” ASTM has already implemented some of these new tests. Wouldn’t it be great if in this decade SPRI joined forces with RCI, ARMA, and NRCA to actually implement this performance concept?

Life-cycle Costing

In closing, there is still another area in which we need to do a better job: the validation of roof life, life-cycle costing (LCC), and sustainability. In just the past couple of months, articles have appeared “proving” that a metal roof – or polyurethane foam – or PVC – has the lowest life-cycle cost. Who is right, and based upon what?

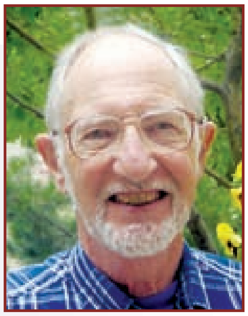
Unfortunately, there are many variables that must to be estimated in LCC analysis. In addition to strictly financial considerations, we must now consider “carbon-footprints,” total energy consumption from birth to death, recycling, urban heat islands, toxicity, VOCs, ozone holes, and the energy/petroleum status.

Are We There Yet?

Hopefully, we soon will be able to chart these turbulent waters so that the specifier, consultant, building owner, or government agency can make more rational decisions. There is no single roof system that can do it all. Defining the performance requirements for each roof and building is possible and needs to be further explored. We have the experience and resources to define the minimum requirements for every roof – we just need to do it!

In this past half-century, we have learned a great deal. Our actions over the next few years could enable us to apply this knowledge to determine the most appropriate systems for any given set of conditions.

Dick Fricklas



Dick Fricklas is an author, journalist, and educator. He served as technical director of the Roofing Industry Educational Institute (RIEI) from 1979 until his retirement in 1996. With his coauthor, Bill Griffin, Dick last year completed the fourth edition of the *Manual of Low-Slope Roof Systems* for McGraw-Hill. He is a contributing editor for *RSI* magazine, a web columnist for *Buildings.com* Web magazine, and a contributor to *Interface* journal. Dick holds a B.A. from Hofstra University and a master’s in physical chemistry from Rutgers University. His honors include the William C. Cullen and Walter C. Voss awards from ASTM, the J.A. Piper Award from NRCA, the James Q. McCawley Award from the MRCA, and Lifetime Achievement Awards from the Educational Foundation of the Institute of Roofing and Waterproofing Consultants and the Colorado Roofing Contractors Association. He is an honorary member of RCI. Dick and his wife of 49 years, Anita, reside in Centennial, Colorado.