Progress in Bitumen Modification; Lessons From the Paving Industry

By Dr. Heshmat Laaly

THE PAVING INDUSTRY

Consider your drive to work each morning. Chances are, it was a bumpy one…literally. It's likely that you drove through a few ruts, cringed when you hit a pothole or two, and witnessed more than your fair share of cracks in the road.

The American Society of Civil Engineers (ASCE), which conducts a comprehensive report of the country's major infrastructure every four years, gave America's roadway system a D+ rating in 2013. The grades have been averaging D's for the last 15 years.[1] And while there is no overarching organization dedicated to conducting comprehensive inspections of our country's low-slope commercial roof systems, ASTM reports that the U.S. construction industry spends about $9 billion annually on construction defects due to water and moisture intrusion, leading to the conclusion that our commercial low-slope roof systems likely aren't faring much better than our roads.[2]

So, what do cracked and rutting roads have to do with failing roofs? An effort to find a solution to failing roads has led to an improvement in the modified-bitumen roofing industry.

The technology was actually first discovered by the European paving industry. Researchers there determined that modifying bitumen with polyurethane extended the life of the road while only increasing construction costs marginally.

If the technology of modifying bitumen with polyurethane (two products known for their resiliency) improved the performance of asphalt roads, applying the same methodology to roofing technology should provide similar results. Bitumen, which is a component of asphalt pavement, makes up about 5% of the composition of a road, while it makes up about 10 times that amount in roofs.

Additionally, polyurethanes are already used as high-performance roof restoration coatings where they impart UV resistance, waterproofing protection, and chemical resistance.

But before we explore the time-tested benefits of polyurethane, let's explore the reasons for bitumen modification and the most commonly used modifiers.

MODIFYING BITUMEN

Bituminous materials have long been known as a reliable and widely used waterproofing material in a variety of industries. In 2007, the latest year for which figures are available, about 1.6 trillion metric tons of bituminous materials were produced worldwide.[3] The largest percentage (about 85%) is used in asphalt pavements, with about 10% used in roofing. The remaining 5% is used in other ways.

Bitumen in itself is an excellent waterproofing material, but it lacks in performance when subjected to extreme temperature changes and has no elasticity or strength built into the system, meaning (in both roads and on roofs) that bitumen tends to crack as a result of the freeze/thaw cycle and from any shifting or movement. In an effort to increase the thermal window and improve strength and performance, various modifiers have been added to bitumen.

Extensive research has been conducted by the U.S. Department of Transportation (DOT) to study the mechanism of adhesion of aggregates with bituminous components. As we know, asphalt and coal tar pitch are complex mixtures of aliphatic, aromatic, heterocyclic compounds, along with complex molecules containing hydrocarbons, sulfur, phosphorus, iron, and more. However, the asphaltenes, asphaltic resins, and oily constituents are the main components of this thermoplastic binder. Over time, asphalt and coal tar pitch, which are widely used in road construction as asphalt pavement, will become hard and brittle. Engineers and chemists have used their knowledge to combat hardening and brittleness of bitumen at lower temperatures by modifying it.

By combining bitumen with a polymer, new and advantageous physical properties are obtained and are always different, depending on the bitumen, the modifier, and the proportions that are used. Some of these advantages include:

- Improved elasticity, making them capable of accommodating the repeated thermal movements of the roof

Figure 1 – Surface of polyurethane-modified bitumen that has been exposed to unfiltered ultraviolet radiation for 1,500 hours.

Figure 2 – Surface of SBS-modified bitumen that has been exposed to unfiltered ultraviolet radiation for 1,500 hours.

- Improved flexibility at low temperatures
- Improved strength, allowing for a reduction in the number of plies or felt
- Greater capacity to bridge movements of cracks or joints in the substrate
- Better fatigue resistance

Among the most widely used modifiers of bitumen are atactic polypropylene (APP) and styrene-butadiene-styrene (SBS). APP polymer is blended with bitumen and fillers and is generally resistant to high-temperature flow. The prefabricated sheet is typically reinforced with fiberglass, polyester, or a combination of both. A field-applied coating is often applied to APP membranes to prevent surface cracking from ultraviolet (UV) radiation.

Similarly, SBS polymer is blended with bitumen and fillers and then factory-fabricated into rolls with reinforcement and surfacing similar to APP sheets. SBS sheets have good low-temperature flexibility and weatherability, but are susceptible to premature deterioration when exposed to UV radiation. Therefore, SBS sheets are often mineral-surfaced or coated.[4]

Any commercial roofing membrane manufactured in the last 40 or so years has likely been modified with APP or SBS. There have been changes to the amount of modifiers added to the bitumen or the types of reinforcements used for strengthening, but overall, the chemistry has remained the same—until now.

Combining polyurethane and bitumen—two of the most effective waterproofing materials in the industry—is the most groundbreaking innovation the roofing industry has seen in the last 40 years. This technology has the potential to redefine an entire industry by vastly extending the life cycle of a low-slope commercial roof system.

BENEFITS OF POLYURETHANE

Polyurethanes have a long history of performance in a variety of industries, including the military, aeronautics, automotive, mining, transportation, electronics, and the marine industry, among other applications. So what are polyurethanes? They are polymers, which are best thought of as chains of three-dimensional structures made up of long, repeating smaller units called monomers. These monomers contain carbon, hydrogen, oxygen, and nitrogen. To form the chains, the smaller links are "polymerized" or hooked together.[5]

As this jumble of growing chains is expanded—often in the presence of moisture and heat—the film becomes tighter knit, like a chain-link fence, until there are no more units to link or the chains become so dense that they can no longer grow. Polyurethane's versatility comes from being able to alter the composition of the links themselves to change properties such as flexibility, hardness, impact resistance, etc. to fit the environment in which they will be incorporated.

An overview of its benefits is provided below.

Versatile

Polyurethanes can be tailored to suit the needs of the specific application (i.e., hard, flexible, bio-based, exterior/interior grade, etc.).

High Load-Bearing Capacity

Polyurethanes can be formulated to have a high load capacity in both tension and compression.

Flexibility

Polyurethanes perform very well when used in high flex-fatigue applications. Flexural properties can be isolated, allowing for very good elongation and recovery properties.

Tear Resistance

Polyurethanes possess high tear resistance, along with high tensile properties.

Resistance to Water, Oil, and Grease

Polyurethane's material properties will remain stable (with minimal swelling) in water, oil, and grease. Polyether compounds will last many years in subsea applications.

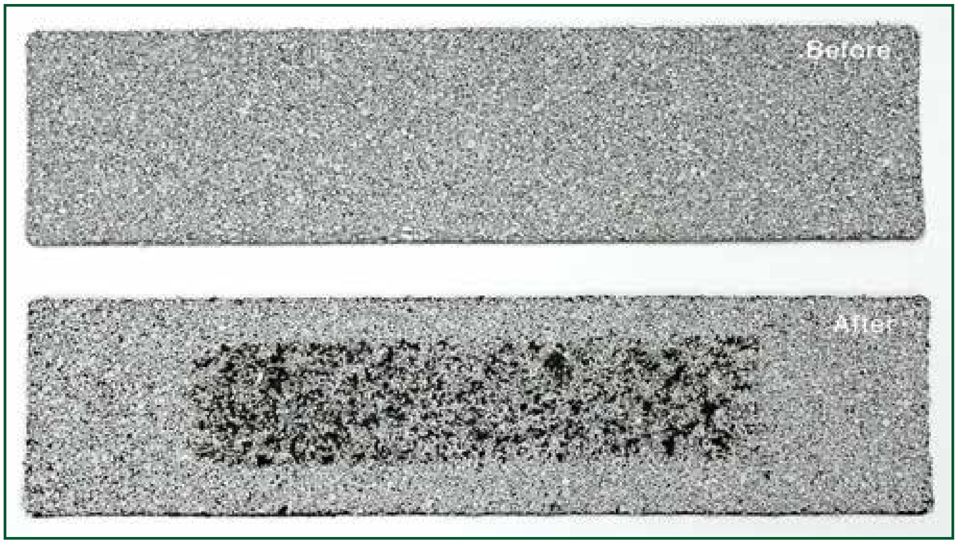


Figure 3 – ASTM D4977 scrub panel of a traditional SBS-modified bitumen membrane before and after aging in California for about six months.

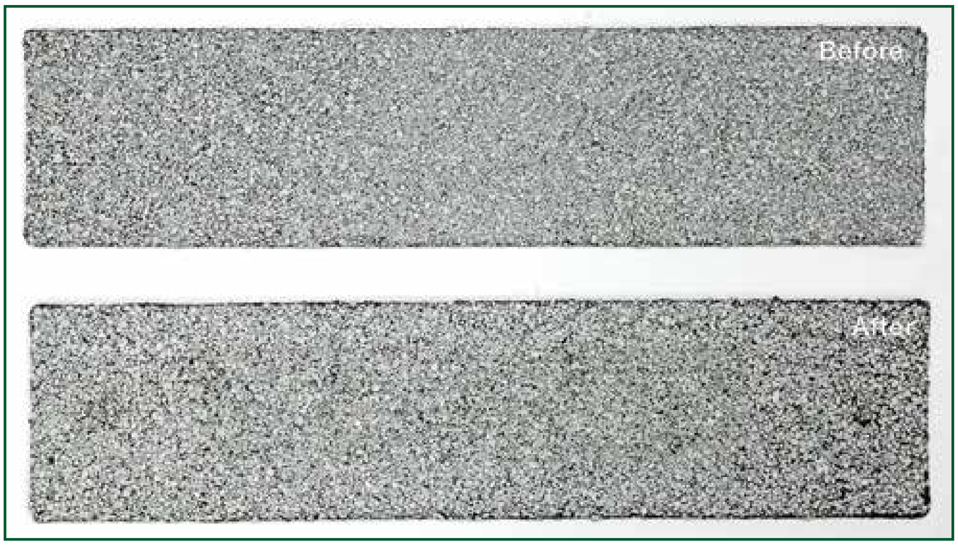


Figure 4 – ASTM D4977 scrub panel of a polyurethane-modified bitumen membrane before and after aging in California for about six months.

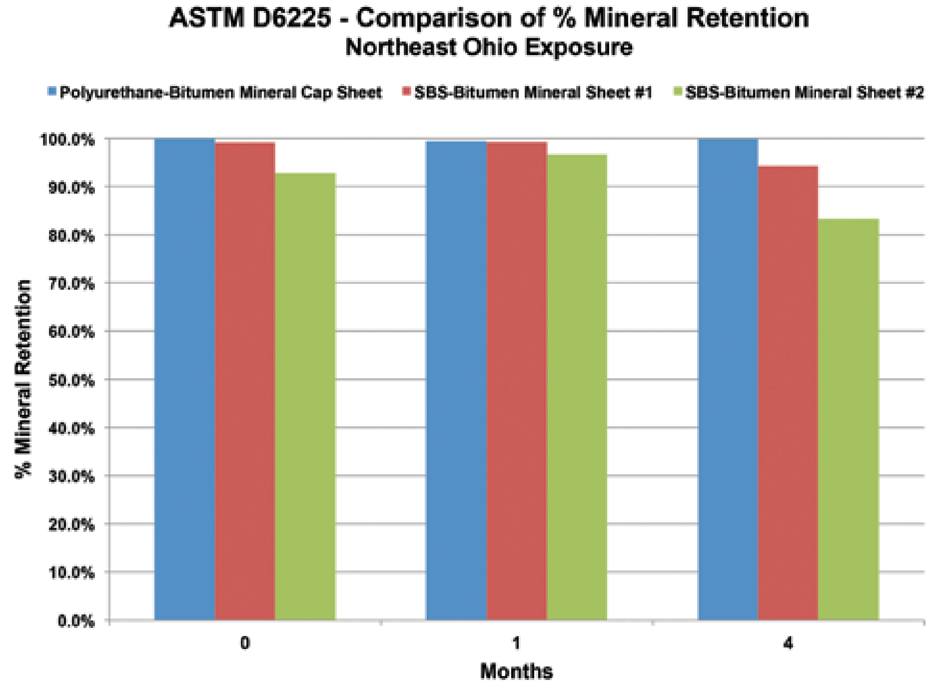


Figure 5 – ASTM D6225 comparison of percentage of mineral retention of a polyurethane-modified bitumen vs. various SBS-modified bitumen aging in Northeast Ohio for four months.

Wide Resiliency Range

Resilience is generally a function of hardness. Polyurethane's versatility enables formulators to dial in that hardness. For example, for shock-absorbing materials, softer polyurethane could be formulated. Likewise, harder polyurethane could be created for a product that would need high recovery. Typically, toughness is enhanced by high resilience. This property makes polyurethane an ideal material for wheels, rollers, and inserts.

Strong Bonding Properties

Polyurethane bonds to a wide range of materials during the manufacturing process. These materials include other plastics, metals, and wood and—in the case of roofing—the mineral surfacing.

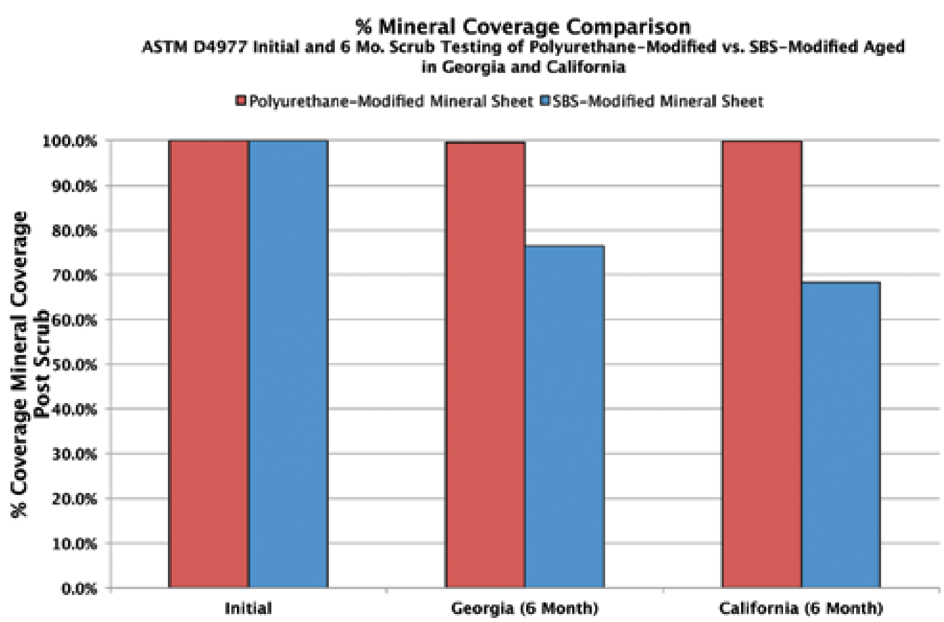


Figure 6 – ASTM D4977 comparison of percentage of mineral retention of a polyurethane-modified bitumen vs. an SBS-modified bitumen aging in Georgia and California for six months.

Performance in Harsh Environments

Polyurethane is very resistant to temperature extremes, meaning harsh environmental conditions and many chemicals will not cause material degradation.

URETHANE AS A BITUMEN MODIFIER

Unlike traditional SBS-modified bitumen, which is actually a blend of two incompatible materials, when polyurethane is used to modify bitumen, it creates a molecular bond that becomes more resilient with time as the polyurethane-bitumen network "cures." Specific chemical zones within the bitumen are targeted as linking sites for the polyurethane resin; and at the end of the process, a portion of the bitumen becomes part of the final polymer matrix, locking it within a more durable "chain-link" system. The resulting product has properties not found in traditional SBS systems.

In roofing, one of the key components to longevity is long-term mineral retention. The longer the minerals remain on the membrane, the longer the polymer-bitumen blend beneath is protected from ultraviolet radiation. In SBS-modified systems, UV radiation from daily sun exposure targets the areas of the rubber that give the product flexibility, which weakens the adhesion to the minerals. As more minerals fall off the membrane, more SBS polymer degradation occurs, and the cycle continues. Minerals used on roof membranes are attracted to polyurethane and adhere much longer, reducing what is already a much slower aging process.

Polyurethane-modified bitumen, when compared to traditional SBS-modified bitumen, is not as susceptible to the effects of exterior exposure and, as such, weathers more slowly than its SBS counterpart. "Alligatoring" is a term describing the defect in an applied coating or mastic when it cracks into large segments or shrinks due to photo oxidation. As shown in *Figures 1* and *2*, surface testing of the modified asphalt has shown that after nearly a year of exposure, there are far fewer surface cracks present in the urethane-modified bitumen compared to the SBS-modified bitumen. The urethane-modified bitumen also retained its tensile strength when exposed to UV radiation.

As stated in *The Science and Technology to Traditional and Modern Roofing Systems,*[6] dimensional changes resulting from heat aging or water absorption can be readily assessed with a traveling microscope.

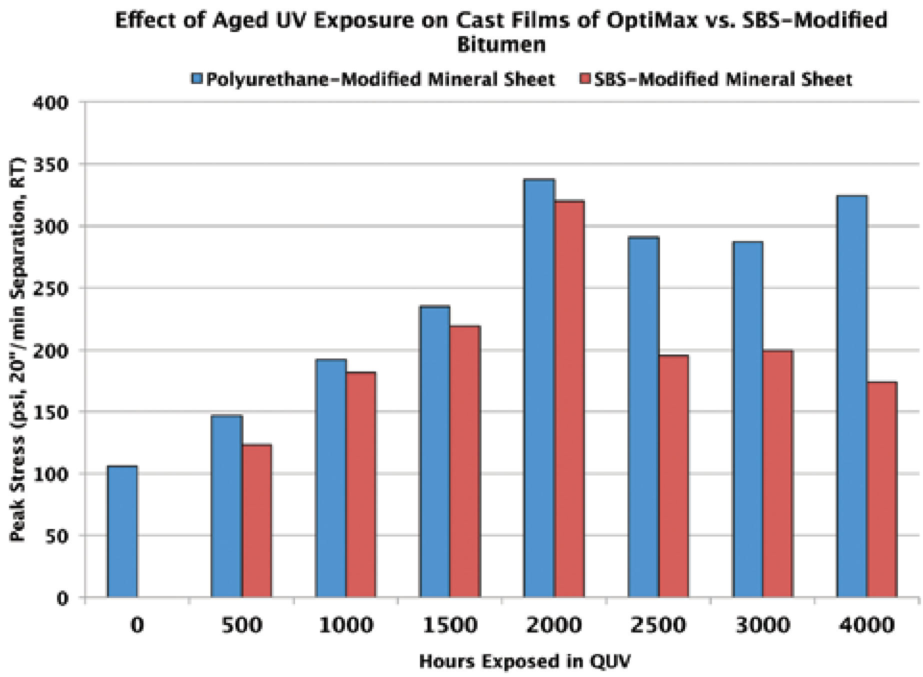


Figure 7 – ASTM D412 testing on UV-exposed cast films of polyurethane-modified bitumen vs. SBS-modified bitumen.

Most membranes are protected by mineral granules, which must be checked for their embedment. During a granule-embedment test, the urethane-modified membrane retained more than 99% of its minerals, as opposed to the less than 80% on similarly tested traditional SBS-modified mineral sheets. See *Figures 3* through *7*.

Additional benefits of modifying bitumen with polyurethane include opening new avenues of research into the use of alternative green reactive technologies such as soy to produce the polyurethane-modifying resin.

All of these improved performance characteristics will significantly slow the aging process of the membrane and ultimately lead to a longer-lasting roof system.

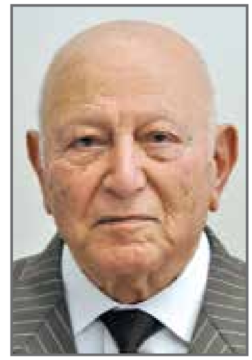
SUMMARY

Innovation is what drives any industry. And while SBS- and APP-modified roof systems have delivered proven performance over the last several decades, the emergence of polyurethane-modified bitumen roof systems serves as an alternative option for building owners seeking enhanced performance and increased service life.

And while the technology is new, it incorporates the tried and true bitumen waterproofing methodology that has been used for 200 years, with more than 80 years of proven urethane technology. It is not a start-from-scratch new technology, but rather the discovery of combining two highly effective waterproofing materials together to create a resilient, long-lasting roof membrane designed to outperform what is currently available in the industry.

FOOTNOTES

1. American Society of Civil Engineers, *2013 Report Card for America's Infrastructure*, March 2013, (www.infrastructurereportcard.org/wp-content/uploads/2013ReportCardforAmericasInfrastructure.pdf).
2. Steve Easley, "Better Design and Building Practices for Reducing Water and Moisture in Wood-Framed Commercial and Multifamily Buildings," *Interface*, March 2011.
3. Asphalt Paving Industry, *Production, Use, Properties, and Occupational Exposure Reduction Technologies and Trends*, February 2011 (http://www.eapa.org/userfiles/2/Publications/GL101-2nd-Edition.pdf).
4. Whole Building Design Guide, *Building Envelope Design Guide – Roofing Systems*, July 2014 (http://www.wbdg.org/design/env_roofing.php).
5. European Diisocyanate and Polyol Producers Association, "What Is Polyurethane?", June 2015, (http://www.polyurethanes.org/en/what-is-it).
6. Heshmat Laaly, *The Science and Technology of Traditional and Modern Roofing Systems*, 1992, (www.roofsandroofing.com).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