Chemistry Lessons to Help Your Roof Survive the Elements

By Jason Smith

Nature has been waging a war with roofs since humans stepped out of caves and began building stand-alone shelters. Since then, constant advances in science and manufacturing have brought many new innovations in roofing products. This article explores the ongoing struggle to beat the elements and withstand Mother Nature's wrath.

Nature has been waging a war with roofs since humans stepped out of caves and began building stand-alone shelters. Each construction technique was unique to the area, using any materials available for the conditions: sticks, leaves, straw, clay or mud, turf, animal skins, etc. Each technique had its benefits, but they still were subject to the effects of continuous weather exposure. Advances in science produced refined petroleum or heating coal that gave us asphalt and coal tar. We learned to improve the properties of these base materials through better processing and polymer modifiers to protect us from the elements. We learned that we could link polymers and extrude them in sheet form to form durable single-ply sheets. These innovations have all been made with an underlying goal in mind – to withstand Mother Nature for as long as possible.

This paper will take a close scientific look at this daily struggle with the elements to give the reader an appreciation for what it takes to make a good roofing product. Because this is an article on the science and effects of weathering, the roofing technologies mentioned herein are used merely as examples of how the roofing industry as a whole is fighting the same fight against the elements, and are not meant to single out any specific technology. Unfortunately, trade secrets being what they are, this article can only use a broad brush to explain how we are winning the weathering war. To start, it may help to revisit the construction of a modified roof membrane and a single-ply membrane in order examine what is in place to protect against the daily pounding a roof takes.

A typical modified bitumen roof membrane consists of a fabric scrim usually made up of fiberglass, polyester, or fiberglass/polyester blend that is sandwiched between a coating of polymer modified bitumen. The polymer modifier can be a myriad of styrenic block copolymers (SBS, SEBS, SIS) of varying molecular weight or construction (linear, radial) or other polymers such as atactic polypropylene (APP) or polyurethane. The scrim provides strength and acts as the reinforcement to the sheet. The primary function of the polymer modified bitumen is to protect the scrim reinforcement but also to impart flexibility, especially at low temperatures, and act as an adhesion medium for the aggregate or slag top as well as the glass or plastic burn backer or release liner on the back side.

Thermoset membranes are formed from rubber polymers, EPDM being the most common. They differ from thermoplastic membranes in that once created and allowed to cure over time, there is a chemical change that occurs to give the final product different and improved properties over its initial state. Additives are added to improve tear strength, UV resistance, flexibility, fire resistance and dimensional stability.

Thermoplastic membranes are based on polymers such as polyvinyl chloride (PVC) and thermoplastic polyolefin (TPO). TPO has gone through a few changes since its introduction in the late 1980s, each change meant to address different issues the environment threw at it. PVCs are more flexible than TPOs due to the use of plasticizers, similar to how butter is used in a bowl of noodles. Blends of ketone ethylene ester (KEE) and PVC form very robust single-ply systems that combat everyday environment exposure. Scrim reinforcement is usually sandwiched in between plies, similar to a modified bitumen membrane, to provide tensile and tear strength. Like thermoset membranes, additives can be added to impart improved physical properties.

Formulations vary depending on manufacturer, but for the most part, this simplistic construction shows that these 80- to 120-mil-thick membranes – more so if one includes the insulation – are all that stand between the elements and a wet ceiling or floor, so it must be constructed properly to withstand these destructive forces.

Hail

It is a good bet that at least one time during the life of a roof it will be subjected to a hail storm of varying intensity. The National Oceanographic

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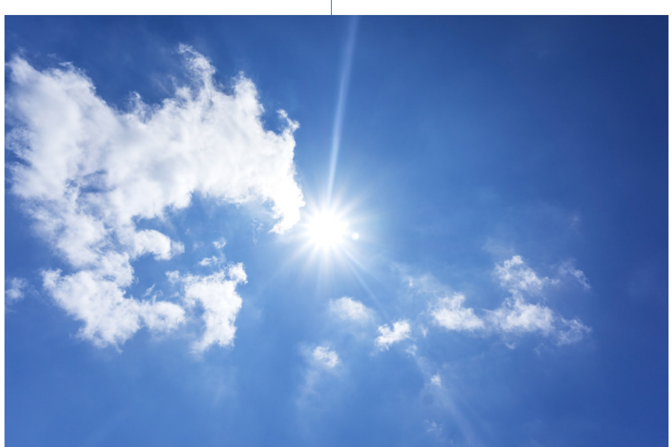
and Atmospheric Administration estimates an average 1 cm hailstone falls at a rate of 20 mph, which at that diameter would not be lethal. But on a roof, combined with driving wind, that continuous short pounding contains sufficient energy to knock minerals off a modified bitumen membrane surface. When this happens, UV radiation begins to break down the modifier in the membrane (see *UV Radiation*).

Single-ply thermoset or thermoplastic membranes are not safe from hail. Even a single hail storm can cause cracks and punctures that allow moisture to penetrate into the membrane below. Codes that contain provisions requiring roofing systems to meet minimum impact requirements include BOCA National Building Code, International Building Code (IBC), and the South Florida Building Code (SFBC). ASTM D3746 is the standard test method used to test impact resistance, other tests include FM 4470 or UL 2218.

To counter the damaging effects of hail on modified bitumen membranes, mineral retention is important. The more secure the mineral is to the sheet, the better resistance it has against being knocked off during a hail event. Innovations and improvements in the polymer modifiers that are blended with the bitumen, such as more specially designed weather-stable polyurethanes, tenaciously anchor the minerals to the sheet forming a protective shield over the more UV-unstable bitumen, leading to a longer service life. For single-ply roofs, harder cover boards can be installed to resist the impact force of hail. However, most of these polymeric materials still rely on plasticizers to improve flexibility. Initially, single-ply roofs such as TPO or PVC are resistant to hailstones as much as 1-3/4 inch in diameter. But as the plasticizers or flexibilizers leach out of the membrane during aging, it becomes more susceptible to hail damage. This is why, when considering a single-ply option, it is important to obtain more information on its aged hail resistance or test results from one of the tests mentioned earlier, especially if the building is prone to hail events.



Water: Rain, Snow & Ice

The size of a water molecule is approximately 2.8 angstroms. To put this size into perspective, imagine a single water molecule is placed on a golf ball and then both are proportionally expanded until the golf ball is the same dimension as the Earth – the water molecule would take up about 1 square inch. This tiny water molecule in the presence of about a *thousand trillion* more water molecules (that's 1 with 21 zeroes) comprise a single rain drop, and can cause surprising damage to roofs. At its freezing point, 32°F, water does something that most liquids *don't* do as it turns to ice: it expands. In fact, it expands by approximately 9 percent. Anyone who ever put a full water bottle in the freezer can confirm this fact. A 9 percent increase may not seem like a lot, but consider a roof that has a tiny tear in it, say a centimeter-long crack about 1 mm wide, perhaps formed from an earlier hail event. To a casual untrained observer, this flaw probably would be overlooked. But to water molecules, that crack might as well be the Grand Canyon. Suppose further that this rain event on our compromised roof occurs on an evening prior to a drastic drop in temperature, below freezing. Water fills the crack quite easily and then begins to expand as the temperature drops to below freezing, pushing the dimensions of the crack outward in proportion by about 9 percent. The temperature warms, the ice melts, and the water evaporates, but the crack is now larger. This cycle of freezing and thawing continues over and over for several years and one begins to see how a tiny crack could turn into a real problem.

Snow is another of Mother Nature's weapons. It's pretty, white, and fun to ski or sled in, but on a roof, it's still water and it's just plain heavy. Although snow comes in many forms and there are atmospheric and geographic variations that could affect snow density, it is generally accepted that snow weighs about 1.25 lbs/ft^2 per inch of snow depth. A 100,000-square-foot roof with only 1 inch of snow will have about 57 tons of water spread out across its surface. Ice complicates matters, adding about 5.2 lbs/ft^2 for each inch of depth. Now imagine this same building in Buffalo, where, in 2014, about 88 inches of snow fell in a single snow event over several days in November. That same roof now has to shoulder approximately 5,000 tons of water spread out over its surface, even more in areas where the snow blows and forms deeper drifts. If the roof is not designed properly, the building owner will have serious problems with a roof collapse. A stark reminder of this would be in the 2010 roof collapse of the old Metrodome in Minneapolis, and that was after only 17 inches of snowfall. Fortunately, there are specifications in the building code that address acceptable loads. These safeguards take into account the enormous loads a roof can absorb. Like ice formation, prolonged exposure to water, frozen or liquid, is an unavoidable problem on the roof. Regular maintenance, which may include a simple walk over to check for premature cracking, performed by roofing professionals can be the best defense against the damage caused by water.

Sunlight

The sun is an inescapable constant in roofing. The sun will shine, although not always in consecutive days in some climate zones. With the sun comes its two byproducts: UV radiation and heat. UV radiation penetrates into the polymer binder and bitumen, targeting specific molecular sites to chemically break down and stiffen the membrane. This leads to cracking that presents a problem during a freeze event like the one mentioned in the previous section. The mineral granules on modified bitumen membranes act in a similar fashion as sunscreen lotion on skin, protecting the polymer modified blend from the damages of UV radiation. As the minerals gradually fall off, the polymer and bitumen are at the mercy of UV degradation. Single-ply surfaces fare better because the chemistry itself is its best defense. TPOs are regarded as being highly UV resistant while PVCs and KEE-PVCs are more geared for high-temperature surfaces.

Heat exacerbates the UV degradation process and contributes to the formation of surface blistering. When moisture is inadvertently trapped in mopping voids or on the interply sheet during storage, evaporating water has no place to go as it tries to penetrate through an impermeable top sheet. Physics tells us that pressure and volume are directly related to the temperature and that if temperature increases, either the pressure or volume must increase proportionally. Water vapor trapped in a void (fixed volume and pressure) beneath a membrane on a cool morning (low temperature) must either gain pressure or increase its volume, or a blend of both, as the heat of the day increases. The heat from the sun softens the asphalt somewhat to allow the increased pressure to expand the void sideways or toward the top cap sheet. This cycle continues, sometimes gathering more trapped water as voids link with other voids until the blister is quite large. The result is a blister that can range from the size of a blueberry to a few feet in diameter. Further, when surface heating is followed by a rapid cooling process such as a sudden rain, there are dimensional changes that occur in the membrane that can cause stress cracking or other failure. Additionally, heat on a roof, especially a wet one, provides the perfect conditions for microbial growth. If there are not safeguards in the formulation to account for microbial growth, it will not take long for a continually wet roof to show signs of algal growth (reddening or blackening), or fungal attack. Advances in polymer modification have improved the longevity of membranes by retaining the minerals longer, purposely engineering the polymers with more heat resistant or UV stable components. Furthermore, the use of cool roof coatings such as white or aluminum acrylics, polyurethanes, or silicones can lower the surface temperature by as much as 50 to 60°F. Proper drainage at time of installation still remains the best way to remove standing water and the risk of microbial growth in those areas.

TPO single-ply surface are formulated for excellent resistance to heat and UV resistance because there is nothing in its formula that UV radiation can further break down. In spite of this superior weather resistance, TPO sheets have their drawbacks, including issues with weld popping, crazing, and cracking. They do wear eventually, and once the scrim reinforcement is exposed, the sheet is doomed. PVC single-ply roofs are more flexible than TPO roofs, but during continual heating the PVC plasticizers, are leached out. The use of KEE as a solid flexibilizer eliminates the need for a plasticizer and does not leach out upon heat exposure. Both are usually white, which cools down the surface and slows the degradation process.

Wind

Lastly, just as the sun is an unavoidable factor in roof science, so too is the direct and indirect effect of wind. So much so that a sizable fraction of the testing dollars that go into roof research goes into how much punishment a roof can undergo strictly because of wind. Building codes are in place that require systems to be tested and certified for use in wind conditions in order to be used. The roofing surface is present on the horizontal, or field, where the insulation is mechanically fastened or adhered and the membrane sheets adhered. This is continued up a wall edges, or flashing, where it is terminated and met with a metal flashing or fascia to protect the materials from wind and rain. Unfortunately, especially in more windy climates or hurricane zones, physics in the form of wind uplift is continually working against this assembly. This uplift is the net upward suction force resulting from two simultaneous sources: wind flowing across the building above the roof surface and increasing internal air pressure caused by cracks, openings, windows, etc. The uplift pressure is proportional to the density of the air and the square of its velocity. This squared value is significant because when the wind speed doubles, the pressure quadruples. Considering a typical building, as the wind meets that structure, the wind must alter its path and either flow up, down, or around the building. Altering the wind path accelerates the velocity at the roof top, which causes a suction force (uplift) to act against the roof membrane. Roof systems are tested to withstand the greatest wind speed while taking other variables into consideration: building height, type of roof deck, construction, and even building use. Based on this testing, the roof is given a wind uplift rating. When the suction force exceeds this rating, there is a high risk of roof destruction ranging from light damage in the form of bent or dislodged sections of flashing to severe damage where entire areas of the roof are blown free from the roof deck. There are a number of sources available that describe this force in greater detail; they are listed in the references section.

Most roofing adhesives are specifically designed to help keep the membranes (modified bitumen and single-ply) in place not only during peaceful wind-free days but also in the face of hurricane force wind. A myriad of mechanical fasteners are also available to prevent catastrophic failure due to wind. Details, right down to the fastener pattern, are spelled out in building specification that provides the best configuration for keeping the roof where it belongs, on the roof!

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Conclusion

In closing, while cost considerations are important for the building owner, it is vital to take into account the structure's weather conditions to help decide which roof will fit the needs of the building and the owner. Knowing that the owner's investment will be continually punished by the environment should make one take a closer look at not only the technology that is available, but also the testing that goes into it to fight against this continual attack. Roofing professionals can be of valuable service when choosing a roof system because they are educated on the products being applied to the roof, but also are keenly aware that the surface will be under continual attack by its environment long after the roof project is finished. Longevity of the roof will determine its true value long after the purchase order has been received and the check has been mailed.

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