Dow Construction Chemicals

TECHLINE 11
Cool Reflective Roof Coating

Elastomeric Reflective Maintenance Coatings Increase the Longevity and Energy Savings of Bitumen Roofing

Summary

Globally, bituminous roofing materials represent the largest roofing material segment on a square meter basis especially in the segment of flat roofs. In Europe almost half of the roofing jobs are related to repair and maintenance and because bituminous roofing is a significant segment in Europe, it is important to understand how to improve the sustainability of existing roofs. In this paper white reflective acrylic maintenance coatings are applied over aged bitumen-based roofs and allowed to weather for 6 years. Test cut samples are analyzed chemically and via optical and scanning electron microscopy techniques and compared to uncoated areas subject to the same weathering. A mechanism for the weathering of bituminous roofing materials is proposed, and the effect of acrylic maintenance coatings in reducing the adverse effects of weathering is also clearly elucidated and documented. The economic, environmental and health benefits of such white reflective roof coatings applied over bitumen and other roofing surfaces is reviewed.

Contents

Introduction

The main bituminous roofing products include bitumen shingles, built-up roofs and modified bitumen membranes using either styrene-butadiene-styrene (SBS) or atactic polypropylene (APP). In order to more completely understand the effect of elastomeric acrylic coatings on bitumen-based roofing materials, the composition of bitumen and the mechanism of bitumen degradation must first be understood. Bitumen is a fuel oil distillation by product which is economical, waterproof and easily transformed into many different forms used in roofing applications.

Bitumen can be delivered in solvent as bitumen cutback, as a water dispersed emulsion, in molten bitumen form with reinforcement (i.e. built-up roofs), as granulated shingles (popular in the US) and compounded with APP or SBS to make modified bitumen roll roofing (popular in Europe).

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Worldwide bitumen demand for roofing in 2010 was approximately 3.6 billion square meters, a 35% share of the overall roofing segment. In Europe, the estimated quantity of bitumen used for roofing applications in 2010 covered approximately 400 million square meters, representing approximately 31% of the overall roofing market.

Bitumen can be described as a thermoplastic material with relatively poor thermo-mechanical properties because it is brittle at low temperatures (< 10°C) and soft at high temperatures (> 60°C). The thermo-mechanical properties of bitumen are essentially dependent on its composition. In general, bitumen is considered a mixture of literally hundreds of hydrocarbon species with minor amounts of functional groups such as oxygen, nitrogen, sulfur, vanadium, and nickel. The hydrocarbons are subdivided into two broad groups, namely, asphaltenes and maltenes.
The asphaltenes are highly polar aromatic hydro-carbons which often have the highest molecular weight and stiffness, whereas maltenes consist of low-molecular-weight saturates, aromatics, and resins responsible for many of the flexibility characteristics of bitumen.

From a viscoelastic perspective, bitumen also constitutes a highly complex material, varying from a viscous character to an elastic character according to the loading time and temperature. At low temperatures or high loading frequencies, conventional bitumen behaves as a glasslike, elastic solid, whereas at high temperatures or low loading frequencies, it behaves as a viscous fluid. Bitumen presents a time-temperature dependence involving applied stresses and resultant strains, exhibiting a response with both elastic and viscous components [2].

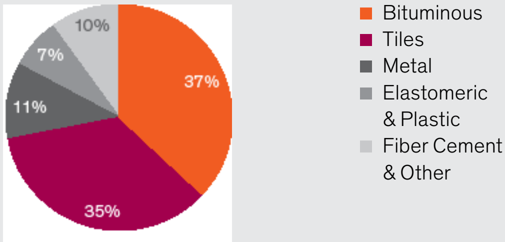

Figure 01: World Roofing Demand – split by product ~ 10 billion m^2

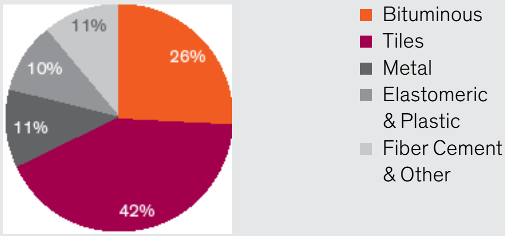

Figure 02: European Roofing Demand – split by product ~ 1.5 billion m^2

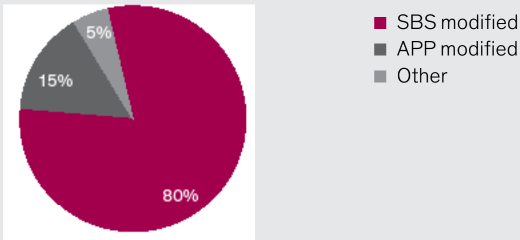

Figure 03: Bitumen roofing products, European demand – split by material

From a durability perspective, bitumen is subject to high thermal conditions due to increased light absorbance because it is dark in color. In some geographies, roofs consist of black bitumen which can exceed temperatures of 80°C during the midday of summer. It is well known that elevated temperatures can cause an increase in chemical degradation rates such as oxidation, crosslinking and chain scission of higher molecular weight species. An additional weathering component is the slow volatization of low molecular weight fractions from the bitumen. These fractions are present in fresh bitumen and act as plasticizers to improve the flexibility of the roofing material but over time are lost as the bitumen membrane is exposed to heat and sunlight. The loss of these fractions reduces the mass and volume of bitumen after weathering causing cracking. Bitumen is also subject to degradation from high UV exposure due to the natural absorbance of sunlight by the aromatic fractions of bitumen. This high energy causes the molecules to vibrate and ultimately to break chemical bonds. This is observed as bitumen 'chalking'. Bitumen modification using atactic poly-propylene (APP) or styrene-butadiene-styrene (SBS) polymers have increased the softening point and durability of modified bitumen membranes but degradation still occurs.

One simple method to measure bitumen degradation is to separate the bitumen into fractions which are soluble in aliphatic hydrocarbon solvents and those which are soluble in aromatic solvents. This method is the basis for the Corbett fractionation technique and is referenced in American Society of Testing Materials ASTM D-4124 and U.S. Patent 3,432,321. Using this fractionation method, the bitumen components which are soluble in aliphatic hydrocarbon (i.e. maltenes) can be separated from those which are soluble in aromatic solvents (i.e. bitumenenes). Performing a mass balance analysis of different fractions can determine the quantity of bitumen retained after exterior weathering.

Built-Up Roof Investigation

A controlled study was conducted evaluating the effect of weathering on glass-reinforced, unmodified hot bitumen (Type III) built-up roofing (BUR). In this experiment, a 20 dry mil (0.51 mm) elastomeric acrylic coating was applied to the bitumen sample prior to weathering. The coated bitumen and a separate, uncoated bitumen sample were exposed at the Dow Chemical Company Research Exposure Facility at Spring House, PA. The samples were weathered for six years after which the bitumen samples were extracted using the Corbett Fractionation technique where aliphatic and aromatic solvents selectively remove specific bitumen components. The results in Table 01 show the amount of heptane soluble bitumen fractions extracted after weathering relative to the unweathered control. Measurements show that weathering of all bituminous materials, whether coated or uncoated involves some loss of heptane soluble material during the extraction step. Importantly, the bitumen with coating applied prior to weathering has retained over 20 % more bitumen fraction than the bitumen sample without coating. The level of fines, including inorganic filler and matt weight is relatively constant among the samples indicating similar initial sample size.

	Unweathered	Weathered	Coated weathered
Heptane soluble, Wt %	51.7 ± 1.8	40.8 ± 4.0	51.2 ± 4.1

Table 01: Built-up roof extraction analysis

Figure 05: Cross section, coated weathered / Built-up roof surface (coating removed) 300X

Figure 04: Cross section, uncoated weathered / Built-up roof surface 300X

Built-Up Roof Microscopy Study

Weathering induced surface degradation can be observed in the bitumen samples when examined by Scanning Electron Microscope. The uncoated weathered built-up roofing shows craters, and significant pitting and chalking (Figure 04). In Figure 05, the weathered coated bitumen sample was treated to peel the coating away for bitumen viewing. Although the bitumen under the coating shows minor cracking, the bitumen surface is very smooth without pitting or chalking having been protected by the acrylic coating.

Mechanism of Coating Protection

The experimental data from the rooftop exposures of built-up bitumen roofs clearly show the retention of valuable bitumen fractions and the service life extension properties of an acrylic elastomeric roof coating. It is theorized that the acrylic coating increases the longevity by two separate mechanisms. First, while bitumen is subject to degradation by the UV radiation component of the sunlight, acrylic polymeric materials are transparent to UV radiation. As such, they do not absorb this intense radiation and are not subject to the polymeric degradation seen in less durable chemistries like aromatic urethanes and butyls. However, the acrylic material must be formulated with UV blocking pigments in order to protect the substrate (in this case the bitumen and base mat) from degradation. These pigments are usually titanium dioxide (TiO_2) and zinc oxide (ZnO), as was the case in this study.

A second mechanism proposed is that the acrylic coating provides a water-resistant barrier over the existing bitumen built-up membrane. While it is well known that acrylic coatings are "breathers" if having a US perm rating of > 1 grain/hr·ft^2·in-Hg (metric perm of 0.84 g/24 hr·m^2·mm-Hg), when used alone they are not considered vapor retarders but they are able to resist penetration of bulk water. The acrylic roof coating prevents contact of bulk water with the bitumen membrane, thus preventing low molecular weight bitumen fractions from leaching out of the bitumen. Moreover, the coating prevents intimate contact of water with the membrane and, more importantly, with the reinforcing mat, scrim or felt, thus eliminating the formation of ice and freeze/thaw induced dimensional changes in the membrane. In the past water infusion into the organic felt would also cause degradation of the mat via biological attack. This specific problem would be eliminated by using glass as the mat for bitumen roofing.

The introduction described the generally accepted mechanism for bitumen degradation, citing the contribution of heat. When the acrylic coating is pigmented with white pigments, the color of the dried coating will reduce the temperature of the roofing assembly by 8 – 28°C, and reduce the rate of the bitumen degradation. This will further prolong the life of the coated roof. Because the acrylic coating is applied at 0.5 – 0.8 mm), it acts more like a fully adhered functional membrane than merely a housepaint type of coating. The mechanical properties are approximately 250 % elongation and 250 psi (1.72 N/mm^2) tensile strength at room temperature and 100 % elongation and 600 psi (4.14 N/mm^2) at -17°C. Studies conducted by the Dow Chemical Company have demonstrated that greater than 75 % of initial elongation properties were retained even after 5 years exterior exposure. As such, the coating actually provides an asphalt compatible component which increases asphalt membrane durability, similar to the reinforcing scrim or mat.

Thus, acrylic reflective roof coatings applied to black bituminous roofing products can increase the lifespan of these products by reducing surface temperature, maintaining flexibility and decreasing exposure to UV degradation. There are several chemistries and compositions of materials available for white reflective roof coatings but liquid applied acrylic roof coatings have been available for decades and provide a variety of sustainable features, many documented by roof coatings manufacturers and the Department of Energy in the United States.

Energy Savings Predictions and Calculations

The United States Department of Energy (DOE) has spearheaded research in energy savings through its national laboratories such as Lawrence Berkeley National Lab (LBNL) and Oak Ridge National Lab (ORNL). There are many focal points for energy research at the DOE, some through increased energy savings by greater efficiency of appliances (e.g. air conditioners, water heaters, etc) and electronic devices (computers, televisions, light switches, power chargers) as well as building envelope components (windows, insulation, roofing products). These products fall under the Energy Star program, which is designed to allow manufacturers to promote the Energy Star logo if products have advantages in energy efficiency over other products. Statistics have shown that Energy Star products command higher prices for manufacturers as well as providing energy cost savings.

LBNL and ORNL have designed many scientific test procedures and statistical analysis methods to measure the improvement in energy consumption of various products. The DOE has also developed a website calculation program to predict energy savings potential of highly reflective low and steep slope roofing products such as thermoplastic and PVC membranes, metal roofs, bitumen shingles and white roof coatings. The calculator can predict energy savings depending on the albedo or solar reflectivity which is primarily related to the reflectance of visible and infrared light from the roof. The Cool Roof Calculator predictive program uses a set of algorithms and inputs to assign heating and cooling contribution to new roofing products based on location. The DOE Cool Roof Calculator contains a database of heating degree/cooling degree days for 243 mostly US cities and several in Canada and the Caribbean. Variable factors in the calculator are solar reflectance, infrared emittance, heating and cooling energy costs, R-Value of insulation and plenum and seasonal energy efficiency ratio (SEER) of heating and cooling equipment which can be entered into the online program.

Case 1

Calculated Energy Savings Worldwide Locations

The calculation of potential energy savings for white reflective roofs using DOE's Cool Roof Calculator would be valuable to predict energy savings worldwide. However, only US locations are listed in the Department of Energy's database for heating and cooling days. Heating degree and cooling degree data are widely available on the internet for many major cities worldwide. These data were obtained for major non-US cities and matched to US cities with similar heating/cooling degree days in order to calculate energy savings of low slope cool roofs.

For calculation purposes several common input conditions were chosen: low slope roof design, white roof coatings as the reflective layer, average energy efficiency selection for heating and cooling units and R-10/U-value of 0.6 W/(m^2K) insulation thickness. Regional electrical, fuel oil and natural gas prices were used based on current data. In general estimates of energy savings using the software model should be viewed cautiously as savings results can vary widely based on assumptions and especially with varying fuel costs. The energy savings and potential payback figures for worldwide cities are listed in Table 02. As expected energy savings is greatest in cities with high numbers of cooling degree days and few heating degree days. In addition, low fuel cost in Saudi Arabia minimizes the energy savings in Riyadh even though the number of cooling degree days is quite high.

Location	Heating degree days	Cooling degree days	Savings in EUR / m^2 per year
Athens	2140	2802	2.03
Lyon	4605	731	0.83
Istanbul	3129	1475	1.39
Dubai	75	7072	1.96
Riyadh	865	6105	1.60

Table 02: Energy savings for cool roofs, worldwide locations

Case 2

Cool Roof Savings: Field Measurements

Two controlled buildings were constructed in the southern United States to directly measure energy usage and savings, one with a black bitumen roof and one with a white acrylic coating applied to the black bitumen. Results in Table 03 show that actual energy measurements provide an annualized energy savings of 12.8 % and a payback of 2.1 years for materials and labor. Interestingly, the DOE Cool Roof Calculator program generally predicted lower energy savings than the actual energy savings measured from the watt meter in the controlled study.

Location: Southern Mississippi, USA.

Construction: R-11 / U-value of 0.5 W / (m^2K) insulation Brick, single pane windows, R-11 in roof, no wall insulation, 23 m^2 roof, low slope.

Heating/Cooling: Electrical heat pump with watt meter. Energy cost at the time was 12.4 cents / Kwh. Measurements on roof were taken every 15 minutes for one year.

Real life costs / savings	Cool roof	Black roof
Roof temperature, summer, midday	41°C (106°F)	84°C (147°F)
Energy use per year	5447 Kwh	6243 Kwh
Kwh saved	796	none
% savings annually	12.8 %	
$ savings @12.4c/Kwh	$ 65.25	
Cost of coating + installation	$ 137	
Payback in years	2.1 *)	
Average lifespan of roof coating *)	10 – 15 years	

Table 03: White vs. black roofs: electrical use and cost savings, 23 m^2 roof size

*) The DOE calculator predicts an energy savings of 6 to 13 % depending on variable inputs. Coating lifespan depends on location, substrate and film thickness.

Case 3

Cool Roof Coating vs. New Roof

Acrylic reflective roof coatings, if chosen and applied correctly can be used to protect a roof and reduce the capital expenditure of a newly installed roof. Not all roofs are suitable for coatings and roof coatings are not available for all roofing substrates. The roof to be coated must be leak free and suitably prepared for white coating to be applied. This involves repairing penetrations, caulking flashings and renewing seams. The roof must then be suitable cleaned of dirt and residue to provide acceptable adhesion of the reflective roof coating to the roofing substrate.

The data in Table 04 shows that acrylic elastomeric cool roof coatings can extend the life of a roof at lower cost than installing a new roof. In addition, because the old roof is not removed, no landfill disposal costs are incurred.

10,000 m^2 roof	Cool roof	Black roof
Cost of Cool Reflective Roof Coating	$ 200,000	
Cost of new roof		$ 1,000,000
Net savings of cool roof vs. new roof	$ 800,000	
Payback in years	immediate	
Landfill cost savings	$ 27,000	
Expected longevity of roof coating to extend roof life *)	10 years	

Table 04: Roof maintenance with coating vs. roof tear-off

*) Dependant on substrate, location and coating thickness

Case 4

Reduced Size, New Air Conditioner Installation

Because reflective roof coatings cool the roof and the building in general, the air conditioning unit does not cycle on as frequently as on a black roof thus reducing energy costs. This is most evident on previously constructed roofs which are changed in color from black to white or a lighter color. There is an opportunity for additional cost savings when a new building is constructed. If the air conditioning unit is to be sized for a roof and the roof is a highly reflective white color, then it is possible for a smaller unit to be installed and work efficiently for that building than if the building roof were black. This results in lower capital expense (see Table 05) for the initial AC installation and lower annual running costs. The smaller AC unit is possible because the building's interior remains cooler and the air intake temperature for a white roof is at a lower temperature than the air intake over a black roof. The selection of a smaller air conditioning unit on a white roof, either for replacement or in new construction should be reviewed by a building science engineer and heating/ventilation/air conditioning (HVAC) professional.

10,000 m^2 Roof	Cool roof	Black roof
Cost of cool coating + installation	$ 120,000	
Cost of standard size air conditioner		$ 450,000
Cost of smaller AC with cool roof	$ 400,000	
Net savings upfront cost	$ 50,000	
Payback in years	2 – 4 years *)	

Table 05: Smaller air conditioner sizing with reflective roofs

*) includes 12 % annual energy savings for air conditioning cost

Case 5

Carbon Credits Offset with Cool Roofing

Use of reflective white roof coatings can reduce CO_2 and NOX emissions by reducing energy consumed for cooling purposes. Table 06 shows the CO_2 reduction levels and payback for using white reflective roof coatings.

State	CO_2 reduction (kg / m^2 CRA)	CO_2 payback period (years)
Florida	3.77	3.77
Nevada	3.64	3.64
Minnesota	3.09	3.09
Illinois	2.97	2.97
California	2.58	2.58
US Average	3.02	3.02

Table 06: Smaller air conditioner sizing with reflective roofs

Source: Department of Energy

Sustainability:

The following Economic, Environmental and Health Impacts can be realised:

1. Energy savings due to reduced air conditioning cooling load
2. Reduced initial construction cost due smaller or no AC unit need
3. Increased lifetime of existing roofs reducing maintenance costs for coating vs. tear-off and reroof
4. Reduced carbon emission and related carbon credits
5. Reduced landfill waste
6. Reduced heat island effect in large cities

Conclusion

The results described in this paper clearly demonstrate the effectiveness of acrylic coatings in prolonging the life of bituminous roofing materials used in low and steep slope roofing.

The mechanism elucidated show the actual degradation of bitumen is not merely due to changes in the maltenes/asphaltenes ratio, but is more complex with contributions from bitumen mass loss and UV degradation with time. Use of white roof coating delays bitumen mass loss and prevents UV degradation of bitumen.

Further analysis of the effectiveness of reflective white elastomeric roof coatings shows that lower roof temperatures, reduced summer air conditioning cost, lower maintenance cost with coating vs. new roofs is demonstrated and shows that lower roof temperatures, reduced summer air conditioning and lower maintenance with the application of a coating versus the installation a new roof all contribute to environmental advance whilst being of economical advantage at the same time.

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