

# **ACCELERATED WEATHERING METHODOLOGY FOR COOL ROOF COATING MATERIALS**

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## **ABSTRACT**

Lack of an accelerated aging methodology for rating and listing Cool Roof Coatings has slowed the introduction of new advanced materials into the cool roof coating market. To be a good Cool Roof Coating the coating first has to be able to withstand the weathering conditions present on roofs.

The current method of weathering evaluation for Cool Roof Coatings is to simply expose coating samples to the elements and measure TSR and Emissivity and report these findings at the end of three years and if the readings are within the published guidelines the product is listed.

This paper examines the utilization of a suite of existing ASTM protocols, which will deliver the necessary data to accurately correlate the durability and effectiveness of coatings, which will resist degradation caused by weathering with those samples aged in a natural environment.

This methodology will be complete after a period of 45 days as compared to the three year cycle currently utilized to have a product rated and listed.

The conclusion of this paper is that adoption of these protocols will be a great step forward in expediting the introduction of the latest technologies to market, which will encourage a new, broader range of manufacturers to enter the market with new, innovate, paradigm shifting technologies.

## Coating Failures

For cool roof coatings to deliver on the promise of long term energy savings and reduction of Urban Heat Island Effect they must first be a good coating and provide long term environmental service along with TSR and Emissivity. To this end it will be instructive to examine the causes of coating failures.

While coating failures may occur for number of reasons, they can generally be categorized into four main categories:

- Coating manufacturer related or caused
- Owner/specifier related or caused
- Coating applicator related or caused
- Environmental service related or caused.

Service environment related failures is critical to the success of cool roof coatings

After the coating work has been properly completed, the coated item is subjected to environmental exposure. If all other factors have been done correctly, including the selection of the proper coating material and its surface preparation, application, curing, shipping and handling, and erection, premature failure still may occur. Principal reasons for such failures are listed below:

- A. Exposure to excessive moisture (such as ponding water), or temperatures (hot and cold) than anticipated.
- B. Exposure to different or more concentrated chemicals than anticipated.
- C. Exposure to abrasion, impact or mechanical damage.
- D. Combinations of the above.

Unanticipated exposure conditions -- may stress the coating system beyond its ability to perform in a given environment. If these exposure excursions are transient, and occur unknowingly, it may be very difficult to trace the cause of the coating failure.

Unless there is physical evidence of coating degradation that may be traced to an exposure excursion (such as high heat, chemical attack or physical damage), the cause of failure may be difficult to determine.

Normal environmental effects that cause or contribute to coating deterioration are:

- Internal stresses-coating drying and curing.
- External stresses-Vibration, flexing, mechanical damage.
- Solar energy.
- Heat.
- Permeation (water, chemicals, oxygen).

Internal Stress-coating drying and curing:

Internal coating stresses build up during drying, curing and upon aging. Curing stresses are caused by solvent (or water, if a water-based coating) evaporation causing a volume loss, and cross-linking resin polymerization, which shrinks the coating film. Drying of a coating (unless it is 100% solids with no volatile solvents or materials) results in a volume decrease as the water or solvent evaporates into the atmosphere. As the coating initially gels, but remains soft after initial drying, stress is minimal because the resin is still deformable. However, as the coating dries further, and commences to cross-link, stress increases as the resin becomes harder and less deformable. Low molecular weight plasticizers added to keep the resin soft and relatively flexible may in time volatilize causing embrittlement, and stress. Thick, highly cross-linked resins (such as polyester and vinyl ester resins) have greater stresses than less cross-linked resins, or thinner coating systems. Over time, cross-linking and solvent evaporation and plasticizer migration and volatilization continues, further embrittling and stressing the coating film.

In extreme cases, disbonding and/or cracking and splitting of the coating may occur, usually initiated at stress points such as edges or damage to the coating. Internal stresses can be relieved by proper pigmentation, and pigment distribution throughout the coating film. Good cleaning and surface profiles can also help to mitigate that effect of the stresses on the adhesion of the system. When applying additional coats to an existing system, if the old coating has insufficient adhesion, stresses from the new coating will disbond the existing material.

External Stress-vibration, flexing, substrate expansion/contraction:

External stresses on a coating usually affect an applied coating to a greater extent than internal stresses, although the combination is cumulative. Significant stress results when solar heating/cooling occurs and the substrate, often a metal, expands when heated, and contracts when cooled. Depending upon formulation, pigmentation and thickness, the coating usually does not expand or contract at the same rate, in which may cause cohesive splitting of the coating or adhesive disbonding from the substrate or between coats.

Impact, abrasion and mechanical damage are other types of external stresses to a coating system. These influences are most usually sudden, localized and abrupt relative to the other stresses. Impact of a coating from dropped tools, stones or other types of mechanical damage may chip and break the coating film. Such damage is greatest when the coating is brittle or is below the glass transition temperature  $T_g$ .

Abrasion results from scraping, scuffing and erosion due to moving particulate such as sand, or slurries. The coating is worn down by continued abrasion, and wear-through may occur. Hard brittle coatings are more susceptible to abrasion damage than softer more rubbery coatings. Abrasion resistant pigments such as aluminum oxide, sand, quartz garnet and other hard materials may be added to a coating to increase abrasion resistance.

Solar energy:

Emitted energy from the sun is approximately 9% in the ultraviolet region, 45% in the visible range and remaining 46% in the infrared range.

The ultraviolet light range (10 to 400 nm wavelength) has the shortest wavelength, and is most destructive to polymeric materials such as coatings. Light has sufficient energy to disrupt and break covalent bonds in organic molecules. There is sufficient radiation and penetration of ultraviolet (UV) as low as 280 nm to cause deterioration of coatings.

UV radiation below 280 nm is not considered detrimental because it is absorbed by water vapor and other small molecules in the atmosphere. Frequencies of radiation energy most harmful to polymeric systems are those from the violet and blue part of the visible light spectrum. The visible light spectrum ranges from 400 to 780 nm. Longer wavelengths much above 400 nm are not as detrimental to polymers. Ultraviolet energy may break covalent bonds and form free radicals in the polymer, which results in a shortening of its molecular chain length.

Higher altitudes have higher levels of UV light. Additionally, higher altitudes may also be drier, and accordingly there may be less radiation absorption by moisture in the atmosphere. Similarly, an arid environment with clear skies may result in more intense UV light, and greater polymeric degradation.

Conversely, combinations of water vapor, smog and chemical contamination from industrial environments may reduce UV damage due to UV absorption.

However, the synergistic effect of these atmospheric contaminants on a polymer such as a coating may be much greater than that of UV alone. UV radiation, in combination with water on the surface (which concentrates the radiation) and chemical contamination provides the greatest potential for UV-polymeric coating degradation.

Heat energy:

The addition of heat to material increases the vibration of atoms comprising a resin polymer. Heat energy is more uniform throughout a polymer than solar radiation, which concentrates on the outer surface. If sufficient heat is applied, molecular vibration within a polymer may increase to such a degree that chemical bonds break. When that happens, free radicals are formed, and the molecular weight of the polymer is shortened. Free radicals may further react with portions of the molecular chain, shortening it. The effect is essentially the opposite of cross-linking, and free radical scission, or bond breaking, results in a lesser ability of the polymeric resin to resist moisture and chemical permeation. If even more heat is applied, whereby the polymeric material darkens, and ultimately may become friable with a total loss of physical properties.

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Permeation of a coating by moisture and chemicals in a service environment is a major factor in the deterioration of the coating. Coatings are specifically formulated and tested to resist certain environments in immersion or atmospheric conditions.

Pigments and resins are selected for suitability in the conditions for intended use. Water in liquid or vapor is present in almost all exterior environments

Polarity, gives water its surface tension, and enables it to more readily dissolve other polar materials. Coatings often contain polar groups such as ester, ether and carbonyl groups that will attract water. Similarly, polar solvents, such as oxygenated solvents (ketones, acetates and others) will also attract water if they are retained in a coating film.

Once water enters the coating film, it may force resin covalent bonds further apart, and adhesive bonds to the substrate may be swelled and/or broken. The volume of the coating may increase as much as 20-50% when in contact with water.

Water swelling of a coating occurs with virtually all coating materials except those that are tightly cross-linked with a high cross-linking density.

Chemicals may also permeate a coating with water. Acids and alkalis dissolved from anhydrides by water will permeate a coating film. , The strength of the acid is a function of the excess of hydrogen ions (H<sup>+</sup>) over the hydroxyl ion. , An alkali's strength is a function of the hydroxyl ion excess (OH<sup>-</sup>) over that of the hydrogen ion.

Acid and alkali attack of coatings is a well-known phenomenon, and can be avoided by careful choice of tightly cross-linked resins and resistant pigments in the coating. However, permeation of water, salts and solvents, all of which are of neutral pH (not acidic or alkaline) are also destructive.

Unfortunately, each of these environmental stresses may occur in combination with each other, and any or all may aggravate a coating system that is compromised by deficiencies in coating manufacturing, the coating specification, or surface preparation and coating application. Sometimes all the things that can go wrong do go wrong. When that happens, the coating failure occurs quickly, and can be corrected as a work-in-progress. Usually, however, only one or two things go wrong, but those deficiencies are often sufficient to cause a coating system that otherwise would be protective and long lasting to break down prematurely months or years after the original application. Too often the cost to remediate and repair or replace a coating system that has failed prematurely is greater than the cost of the original coating installation, especially when down time of the structure is considered.

### **History of Accelerated Coating Tests**

Architectural and maintenance coating companies have utilized accelerated weathering tests for a number of years to help predict in service coating performance.

Salt spray was first used for corrosion testing around 1914. In 1939, the neutral salt spray test was incorporated as ASTM B117.1 This traditional salt spray specifies a continuous exposure to a 5% salt fog at 35°C. During the course of 80 years of use, there have been many modifications and refinements to B117.

In spite of all these refinements, there has long been general agreement that "salt spray" test results do not correlate well with the corrosion seen in actual atmospheric exposures. Nevertheless, B117 has been generally accepted as *the* standard corrosion test method and is still widely specified for testing painted and plated finishes, military components and electrical components.

As the demand for improved corrosion protection increased, engineers and scientists attempted to develop test procedures to more accurately predict the corrosion of materials. In England, during the 1960's and 1970's Harrison and Timmons<sup>2, 3</sup> developed the cyclic Prohesion TM test, which has been found especially useful for

industrial maintenance coatings. More recently, the Society of Automotive Engineers (SAE) and The American Iron and Steel Institute (AISI) have been studying cyclic testing for automotive applications. Their progress has been encouraging and is well documented. Japanese researchers have also developed a number of cyclic corrosion test methods. The result of this explosion of research has been something of a mass movement away from static salt spray toward cyclic corrosion tests (CCT).

Of the many cyclic corrosion test procedures under study, one in particular is of special interest for cool roof coatings. This is the Combined Corrosion/Weathering Cycle developed by Skerry and his associates at the Sherwin Williams Company in the USA. Sherry's work was based on combining the British Prohesion test with QUV accelerated weathering.

## **WHAT IS CYCLIC CORROSION TESTING?**

Cyclic corrosion testing is intended to be a more realistic way to perform salt spray tests than traditional, steady state exposures. Because actual atmospheric exposures usually include both wet and dry conditions, it makes sense to pattern accelerated laboratory tests after these natural cyclic conditions.

Research indicates that, with cyclic corrosion tests, the relative corrosion rates, structure and morphology are more similar to those seen outdoors. Consequently, cyclic tests usually give better correlation to outdoors than conventional salt spray tests. They are effective for evaluating a variety of corrosion mechanisms, including general, galvanic and crevice corrosion.

Cyclic corrosion testing is intended to produce failures representative of the type found in outdoor corrosive environments. CCT tests expose specimens to a series of different environments in a repetitive cycle.

## **ASTM 5894**

### **ASTM D5894 - 10 Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal**

#### **Significance and Use**

The outdoor corrosion of painted metals is influenced by many factors, including: corrosive atmospheres, rain, condensed dew, UV light, wet/dry cycling, and temperature cycling. These factors frequently have a synergistic effect on one another. This practice is intended to provide a more realistic simulation of the interaction of these factors than is found in traditional tests with continuous exposure to a static set of corrosive conditions.

No single exposure test can be specified as a complete simulation of actual use conditions in outdoor environments. Results obtained from exposures conducted according to this practice can be considered as representative of actual outdoor exposures

Accelerated exposure tests are fundamental to the specification and development of organic coatings for atmospheric service. For these tests to be useful, they must incorporate important destructive factors found in atmospheric service that cause the degradation of coatings and corrosion of substrates. These destructive factors include corrosive atmospheres, rain, condensation, sunlight, wet/dry cycling, and temperature cycling. Frequently, these destructive factors have a synergistic effect on one another. If one of the critical factors is absent from a test, real-life conditions will not be simulated, and the test will have little meaning.

While no single accelerated exposure test can duplicate all atmospheric conditions, an ASTM standard on accelerated testing offers an improved technique for simulating natural conditions to compare the relative durability of protective coatings.

This method, ASTM D5894-96, is titled Standard Practice for Cyclic Salt Fog/UV Exposure of Painted Metal (alternating exposures in a fog/dry cabinet and a UV/condensation cabinet).<sup>1</sup> The combination of a salt fog/dry cabinet and a UV/condensation cabinet produces the destructive factors to provide a more realistic simulation of relative coating performance.

ASTM D5894 is a comprehensive accelerated coating test method which replicates real world in service conditions, which are not produced in the long-standing salt fog method (ASTM B117) for testing of coatings.

The important distinctions of ASTM D5894 are three fold.

First, controlled wet/dry cycles ensure the dryness of the test specimens at the end of each dry cycle. Second, the test uses a relatively low-concentration electrolyte that incorporates ammonium sulphate and sodium chloride. Third, and most significant, UV/condensation cycles are integrated into the test.

The process of analyzing specimens—the final step in the accelerated corrosion/weathering test—follows standard evaluation methods.

The value of using cyclic salt fog/UV tests such as in ASTM D5894 to assess actual coating performance has been widely studied in the USA, for example, by The Sherwin-Williams Company the Cleveland Society for Coatings Technology and SSPC: The Society for Protective Coatings.

These studies have demonstrated how this testing regime is a more realistic simulation of surface morphology degradation, corrosion product(s) formation and relative coating pother accelerated testing methods. These studies show that the results of the cyclic fog/UV method were the most consistent with those observed from natural exposure testing.

An assumption sometimes made during the analysis of coated test samples is that laboratory results directly predict actual coating lifetime performance. In other words, acceleration factors are developed relating “x” number of hours of laboratory exposure to “y” number of months of actual exposure. Differences in actual weathering, such as variations in UV radiation, duration of wetness, temperature, and pollutants, however, to make extrapolations from the laboratory to real-life environments is not exact but predictive.

## **ASTM 1653**

### **ASTM D1653 - 03(2008) Standard Test Methods for Water Vapor Transmission of Organic Coating Films**

#### **Significance and Use**

One of the factors affecting the performance provided by an organic coating is its capability of resisting or aiding the passage of water vapor. Hence, the water vapor transmission characteristics of coatings are important in assessing their performance in practical use.

The purpose of these test methods is to obtain values of water vapor transfer through coatings that range in permeability from high to low.

Values of water vapor transmission rate (WVT) and water vapor permeance (WVP) can be used in the relative rating of coatings only if the coatings are tested under the same closely controlled conditions of temperature and relative humidity, and if their thicknesses are equal.

Test Method A—The Dry Cup Method is the preferred test method for obtaining values that relate to conventional dwellings where high relative humidities are not anticipated.

Test Method B—The Wet Cup Method is the preferred test method for obtaining values that relate to applications where high relative humidities are anticipated in the vicinity of the barrier material. In general, the more permeable a coating is to the passage of moisture as is typical of many water-reducible coatings, the greater its affinity for water and the greater the increase in transmission when tested in and exposed to high humidities. Absorption of water may make a coating less dense, thus allowing moisture to diffuse easily and cause a much higher moisture vapor transmission rate, (WVTR) than would occur in drier environments.

The values produced by Test Method B... Wet Cup Method is most relative to cool roof coatings. The ability of a coating to resist bulk water transfer is paramount to a coating to be able to resist the effects "ponding water" on a low sloped roof. Ponding water is the signal greatest problem for cool roof coatings to overcome on low sloped roofs.

ASTM C 1549

**ASTM C1549 - 09 Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer**

**Significance and Use**

The test method provides a means for periodic testing of surfaces in the field or in the laboratory. Monitor changes in solar reflectance due to aging and exposure, or both, with this test method.

This test method is used to measure the solar reflectance of a flat opaque surface. The precision of the average of several measurements is usually governed by the variability of reflectances on the surface being tested.

ASTM C 1371

**ASTM C1371 - 04a(2010)e1 Standard Test Method for Determination of Emittance of Materials Near Room Temperature Using Portable Emissometers**

**Significance and Use**

This test method provides a means for comparative periodic testing of low emittance surfaces in the field. In this way the effects of aging on the reflective properties can be monitored.

This test method covers a technique for determination of the emittance of typical materials using a portable differential thermopile emissometer. The purpose of the test method is to provide a comparative means of quantifying the emittance of opaque, highly thermally conductive materials near room temperature as a parameter in evaluating temperatures, heat flows, and derived thermal resistances of materials.

## **Conclusion**

The interaction of the suite of existing ASTM protocols discussed in this paper will significantly aid the adoption of new innovative cool roof technologies.

Evaluation of test samples via ASTM C1549 and ASTM C 1371 after being subjected to the accelerated weathering testing will be instructive in determining the relative success of a cool roof coating to meet aged TSR and Emissivity levels.

Today, with the reformulation of many protective coatings to comply with regulations on volatile organic compounds, an accurate acceleration test methods that correlates with actual atmospheric exposures is needed more than ever.

The adoption of the suite of existing ASTM protocols discussed in this paper can make the difference between selecting a cool roof coating system that affords effective protection and selecting one that fails.

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