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COOL-COLOR ROOFING MATERIAL ATTACHMENT 6: TASK 2.5.3 REPORTS - ACCELERATED WEATHERING TESTING

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Accelerated Weathering of Roofing Materials Having New Solar-Reflective Cool Colors

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ABSTRACT

Accelerated weathering tests are used to obtain a "quick look" at material durability at a much faster rate than outdoor weathering. Since the primary stresses on roofing are solar ultraviolet radiation, moisture, and heat, these elements are incorporated into industry standard tests. We describe some of these standard tests, and outline their strengths and weaknesses. New solar-reflective cool roofing materials are emerging, that are non-white or even dark in color. These materials have enhanced reflectance in the near-infrared portion of the solar spectrum when compared with older standard materials. Accelerated testing of the new materials suggests that the durability will be similar to conventional materials in maintenance of color, gloss, and solar reflectance. The new solar-reflective cool roofing materials showed low variability in fade resistance and mechanical properties.

INTRODUCTION

Cool nonwhite pigmented coatings with high reflectance in the near infrared (NIR) spectrum have been enthusiastically adopted by premium coil coaters and metal roofing manufacturers. BASF Industrial Coatings launched "Superl SP II™ ULTRA-Cool®," a line of cool colored silicone modified polyester coatings. Coil-coater Steelscape recently introduced Spectrascape MBM, a cool Kynar coating for the metal building industry. A third industrial partner, Custom-Bilt, switched the majority of its metal roofing products from conventional pigmented colors to infrared reflective cool color pigments. In just a few years, infrared reflective pigments have helped premium coil coated metal roofing double sales and capture 8 percent of the roofing market (F. W. Dodge 2002). However other roof products like clay and concrete tile and especially asphalt shingle products can also exploit the use of infrared reflective pigments termed from here on as cool roof color materials (CRCMs). 3M Company recently introduced 3M™ Cool Roofing Granules for use in the shingle industry which allow asphalt shingle manufacturers to offer products which take advantage of infrared reflective cool color pigments. Our goal is to demonstrate that CRCMs offer a wide range of durable colors that can provide the larger asphalt shingle market and also the clay and concrete tile markets with a solution to the dual roofing demands for the aesthetics of darker colors and the energy efficiency of white. However, durability performance of shingle and tile products must be demonstrated for homebuilders to adopt tile and asphalt shingle roof products.

Roof products typically undergo degradation from oxidation reactions that result from any combination of the following processes: melt degradation, thermal degradation, and photo-degradation. Of these processes, photo-degradation due to ultraviolet (UV) light and/or xenon-arc exposure is of primary importance for roofing systems. Our objective for this task is to conduct accelerated fluorescent and xenon-arc testing and report on the photo-stability of painted metal, clay and concrete tile and asphalt shingle products.

Fade resistance of roof products with CRCMs

The color of a roof product must remain fade resistant or the product will not sell. Industry judges fade resistance by measuring the spectral reflectance and transmittance of a painted or coated surface and converting the measures to color-scale values based on the procedures in ASTM E308-02 (ASTM 2001). The color-scale values for CRCMs (L_{CRCM}, a_{CRCM} and b_{CRCM}) are compared to standard colors ($L_{Standard}$, $a_{Standard}$ and $b_{Standard}$) and the color differences (ΔL, Δa, and Δb), which represent the luminance of color, are calculated from:

- $\Delta L = L_{CRCM} - L_{Standard}$, where $\Delta L > 0$ is lighter and a $\Delta L < 0$ is darker;
- $\Delta a = a_{CRCM} - a_{Standard}$, where $\Delta a > 0$ is redder and a $\Delta a < 0$ is greener; and
- $\Delta b = b_{CRCM} - b_{Standard}$, where $\Delta b > 0$ is more yellow and $\Delta b < 0$ is bluer.

Manufacturers of premium coil coated metal use a total color difference (ΔE) to specify the permissible color change between a test specimen and a known standard. The total color difference value is described in ASTM D 2244-02 (ASTM 2002), and is a method adopted by the paint industry to numerically identify variability in color over periods of time; it is calculated by the formula:

$$\Delta E = \left[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2\right]^{1/2} \quad (1)$$

Typically, premium coil-coated metal roofing is warranted for 20 years or more to have a ΔE of 5 units or less for that period. ΔE color changes of 1 unit or less are almost indistinguishable from the original color, and depending on the hue of color, ΔE of 5 or less is considered very good.

Gloss retention of roof products with CRCMs

Gloss is a measure of the percent of specular reflectance resulting from incident visible light. Specular reflectance makes a surface appear shiny or mirror-like as opposed to having a matte type finish which results from diffuse reflectance. The higher the gloss the greater is the percentage of incident light that is reflected specularly. However, it is important to note that gloss is strictly an aesthetic characteristic indicating the form in which visible light is being reflected; it is not a measure of solar reflectance. One of the aesthetic features of asphalt shingles is that they provide primarily diffuse reflectance which eliminates the glare that tends to make any color roof appear white from certain angles in direct sunlight.

A roofing product must also retain its luster or the product will not sell. Industry judges gloss retention by measuring the initial gloss of a painted surface as compared to the same painted surface weathered at a selected time interval at a selected angle.

$$\Delta Gloss = G_{initial} - G_{weathered}$$ where $\Delta G > 0$ is a loss of luster and a $\Delta G < 0$ is a gain of luster

Ultraviolet radiation can degrade the binder and pigment of a coating system causing it to look "washed out" or "chalked" and lose its gloss. While all types of paint systems will lose some degree of gloss over time, the lower quality systems generally lose their luster much earlier than superior grades. The binder in top quality acrylic latex paint systems will be more resistant to UV radiation than paint systems containing oil or alkyds which absorb radiation causing their binder to break down.

INDUSTRY EXPOSURE DATA —PVDF WITH CRCMS

BASF shared their data for accelerated fluorescent exposure testing of their new line of cool-colored coatings. Masstones[1] with and without CRCMs and of the same color were applied to polyvinylidene fluoride (PVDF) galvanized steel samples and exposed to UV irradiance to observe differences in fading and gloss retention. Samples were exposed to upwards of 10,000 hours of fluorescent UV light using the ASTM G154-04 protocol with a UVB-313 lamp that emits significantly more irradiance below 300 nm than does sunlight. The sample color, hours of exposure and the value of the total color change and the present reduction in gloss are shown in Figure 1. The results show that pigment stability and discoloration resistance of the cool pigments are as good as those commercially available (Fig. 1). The fade resistance of the cool-colored blue and yellow masstones is much improved over the respective standard color. Blue, especially a blue tint, has historically been known to fade; however, the cool colored masstone blue shows excellent fade resistance. The retention of gloss from the original color is also shown to verify performance of the larger-sized cool pigments as compared to standard production pigments. A higher gloss paint is often preferred because it provides a homeowner greater wear and therefore reduced maintenance costs. The gloss retention findings are very important because, the larger the particle, the greater is its effect on film smoothness, which affects the scattering of light. The larger the size of a pigment particle the greater is the drop in gloss of a paint finish; however, the cool pigments actually show a slightly higher retention in gloss as compared to their counterparts and they therefore again perform as well as if not better than present production-painted metals.

Painted metals were also exposed to three years of natural sunlight in Florida following ASTM G7-97 (ASTM 1997). Test data showed excellent light fastness of the CRCM masstones[1] exposed in the field. For the CRCM black masstone the fade resistance is much improved over the standard color. Tints (especially blue) have historically been known to fade; however, 50/50 tints of the CRCMs field tested in Florida also showed excellent fade resistance (Table 1). The highest total color change was observed for the CRCM black tint, which is still indistinguishable from the original color. As example, a standard black had a $\Delta E \sim 3.5$ as compared to the CRCM black which had only a 1.51 ΔE.

[1] Masstones represents the full color of the pigment while tints are blends of colors.

Table 1. Color Difference for 50/50 tints of the CRCMs exposed to natural sunlight for three years in Florida. (ΔE based on International Commission on Illumination (CIE L*A*B) Index)

	Total color difference (ΔE)				
Years	Green	Yellow	Brown	Black	Marine Blue
1	0.55	0.21	0.47	0.19	0.46
2	0.42	0.25	0.70	0.67	0.50
3	0.53	0.14	0.99	1.51	0.76

The xenon-arc accelerated weathering tests were previously reported by Miller et al. (2002) and showed that after 5000 hours of xenon-arc exposure all PVDF metal painted with CRCMs clustered together with $\Delta E<1.5$, which is considered a very good result. The Florida exposure data, fluorescent light exposure data by BASF and the xenon-arc results are promising and show that premium coil-coated metals with CRCMs fade less than do the conventional pigmented paints of the same color whose performance is well characterized. Therefore it is easily understood why CRCMs have been so successfully introduced into the market by the metal roof industry. Painted metal has an excellent opportunity to exploit the use of cool pigments; however, further study is needed to understand the light absorbing processes which may lead researchers to develop even better coating processes with even higher fade resistance for premium coil-coated metals.

EXPOSURE TESTING OF TILE, METAL AND ASPHALT SHINGLE WITH CRCMS

Shepherd Color Company and 3M Company provided time in their weatherometers for evaluating the effect of ultraviolet light exposure and xenon-arc exposure on the fading of various CRCM roof products. Clay tiles were provided by Maruhachi Ceramics of America; no conventional pigmented clay colors were available for test comparisons. Painted PVDF metal samples with and without CRCMs were provided by BASF and Steelscape. Shingles were provided by U.S. companies preferring that their products' identity remain confidential; however, the data for shingles with and without CRCMs is provided in coded format.

Sample Preparation and Weatherometer Protocol

The asphalt shingle samples were cut to a size of 0.07m x 0.07 m (2.75" x 2.75") from each of the different regions of the shingle. The metal and tile samples were 3½ in by 3½ in and were used as received. The samples were placed in sample holders for mounting in a xenon arc and a fluorescent UV light weatherometer and subjected for 5000 hours of accelerated weathering. The weatherometers maintain the temperature, moisture, and light. 3M conducted the xenon-arc accelerated weathering in accordance with ASTM G-155 using cycle 1 as described in G-155 in Table X3.1 Common Exposure Conditions. The Shepherd Color Company conducted the fluorescent accelerated weathering in accordance with ASTM G154-04 using cycle 4 as described in G 154 in Table X2.1 Common Exposure Conditions. A UVB-340 lamp was used for simulating direct solar UV radiation; it has no UV output below 300 nm, which is the cutoff wavelength for terrestrial sunlight.

Samples were measured for color, solar reflectance and gloss initially and after every 1000 hours of exposure. These data are provided in Appendix A.

Solar Reflectance (SR) Instruments

Solar reflectance was measured using a Device and Services Solar Spectrum Reflectometer Model SSR-ER. The instrument uses a tungsten halogen lamp to diffusely illuminate the sample and measures the radiation reflected at a 20 degree angle from normal with four filtered detectors covering the solar spectrum. The relative response of the detectors to the light source is designed to approximate the solar spectrum. The four signals are weighted in appropriate proportions to yield the air-mass 1.5 near-normal-hemispherical solar reflectance, or more simply "solar reflectance."

Color Measurements

3M measured color using a Hunterlab Labscan XE model LSXE colorimeter set up with D65 illuminant and a 10 degree observer. The CIELab scale was used and results recorded as L*, a*, and b* luminance measures. Shepherd Color Company used a MacBeth Color Eye (CE 7000) setup for CIELab scale readings with D65 illuminant and a 10 degree observer.

Gloss Meter

Shepherd and 3M both used BYK Gardner Micro-TRI-gloss 4520 instruments for gloss measurements. Gloss was measured at a 60 degree angle for all samples and the reflected light was measured photo-electrically using the BYK 4520 reflectometer. The instrument conforms to the standards DIN 67530, ISO 2813 and ASTM D 523.

FLUORESCENT UV LIGHT EXPOSURE RESULTS

The solar reflectance, total color change, and gloss of clay and concrete tile and painted metal coupons were measured after 1000 hour increments of fluorescent UV exposure (Fig. 2, 3 and 4 respectively). The red clay and dark brown clay (ironwood) and the terracotta concrete and chocolate brown concrete all showed marginal drops in solar reflectance over the 5000 hour duration of UV exposure (Fig. 2). The chocolate brown and terracotta concrete tiles have CRCM coatings provided by American Rooftile Coatings. The solar reflectances of these samples are much higher than those of their conventional pigmented counterparts having the same color, and their reflectance is just as stable as those of their counterparts after the 5000 hours of UV exposure. Also the total color change of the concrete tiles with CRCMs shows them as fade resistant as their conventional counterparts (Fig. 3). A noticeable drop in gloss (indicative of a loss of luster) is however observed after 3000 hours of UV exposure for the concrete coupons with CRCMs (Fig. 4). Results for the painted metal coupons are very similar to the independent testing conducted by BASF (Fig. 1). The total color change measured at 2000 hours for the brick red metal with CRCMs (Fig. 3) appears spurious because later measures at 3000, 4000 etc hours follow trends observed in the standard brick red coupon (Fig. 3).

Asphalt Shingle Exposure Results

The asphalt shingles with CRCMs had an initial solar reflectance of about 0.26 and a thermal emittance of 0.90. Their counterparts with conventional color pigments had initial solar reflectance values ranging from 0.06 to 0.11 (see Appendix A) and the thermal emittance was 0.89. The fluorescent light exposures did not adversely affect the solar reflectance of the shingles with CRCMs and they maintained their reflectance just as well as the standard production shingles (Fig.5). The CRCM shingles coded A and E had a total color change (ΔE) less than 1.5

after the 5000 hours of UV exposure (Fig. 6). In contrast, their conventionally pigmented counterparts had ΔE's that were 50% higher for Code A and 100% higher for Code E. The ΔE for the Code C shingle with CRCMs exceeded ΔE of 2 after 1000 hours, then it dropped below 1.0 after 5000 hours. Reasons for the behavior are unknown; however, overall the data clearly shows that the shingles with CRCMs when subjected to direct solar UV radiation perform just as well as standard products accepted on the open market. The CRCM asphalt shingles do not lose solar reflectance, and they remain fade resistant.

A granule manufacturer forwarded some data for roofing granules applied on an asphalt-coated panel and exposed to natural weathering at a south Florida exposure site. Table 2 lists the pigment, months of exposure, the initial granule color and the total color change after exposure. The results again show the cool pigments perform as well as or even outperform the conventional pigments. The ΔE for the Ferro pigments is roughly half that measured for the standard production pigments, which indicates that the cool colored coatings have improved retention of color over the 2 to 4 years of natural exposure testing.

Table 2. Granules exposed to natural sunlight in south Florida and painted with and without cool colored coatings.

Pigment	Exposure (months)	Initial Color of Asphalt-Coated Panel			Color Change after Exposure ΔE
		L*	a*	b*	
Carbon Black	18	22.0	0.4	-0.2	**2.4**
Black Iron Oxide	42.5	22.9	2.7	3.6	**1.6**
Ferro V-778	58	26.0	2.1	2.6	**0.8**
Ferro O-1765B	23.5	22.7	1.5	0.7	**0.9**

XENON-ARC EXPOSURE RESULTS

The solar reflectance, total color change and gloss of clay and concrete tile and painted metal coupons were measured after 1000 hour increments of xenon-arc exposure (Fig. 7, 8 and 9 respectively). There is no noticeable loss in solar reflectance in the painted metal and concrete samples. The BASF Ultra-Cool samples held their own against the painted metals with conventionally-pigmented colors (Fig. 7). The terracotta and chocolate brown coatings applied by American Rooftile Coating also maintained their high level of solar reflectance (Fig. 7). An exception occurs with the red clay and ironwood (brown) clay tiles. Here solar reflectance is observed to drop but then begins to increase as exposure continues past about 3000 hours (Fig. 7). The change in total color with time for the red clay tile does not seem consistent and may be spurious. It shows ΔE values exceeding 5.0[2]. The painted metal yielded the lowest total color changes (ΔE < 2.0 after 5000 hours). Total color changes of the concrete tile with CRCM coatings was not very different from the standard pigmented tile (Fig., 8) and the CRCM tile showed comparable fade resistance under xenon-arc exposure. Conventional and CRCM painted metal samples both showed similar losses in gloss (loss of luster). Gloss of the coated concrete

[2] Typically, coil-coated metal roofing panels are warranted for 20 years or more and specify ΔE of 5 units or less for that period.

coupons is all well-behaved (Fig. 9). The terracotta and chocolate brown coatings applied by American Rooftile Coating maintained their luster.

Asphalt Shingle Exposure Results

Xenon-arc testing of the CRCM asphalt shingles showed slight increases in solar reflectance through 3000 hours of exposure (Fig. 10). Solar reflectance increased from 0.27 to 0.29 before leveling at about 0.28 for the Code A shingle with CRCMs. The standard shingles are also showing slight increases in solar reflectance as exposure progresses. Some oxidation of hydrocarbons in the shingles is evidently occurring and is possibly affecting surface reflectance in a positive manner. Total color change of the shingles with CRCMs are very comparable to their standard production counterparts and again show the CRCM shingles perform just as well (Fig. 11). The total color change is less than 3.0 after 5000 hours of exposure, which can be visually distinguished yet is still considered good.

CONCLUSIONS

Xenon-arc and fluorescent light exposures were conducted to judge the effectiveness of CRCMs in painted metal, clay tile, concrete tile and asphalt shingle roof products. Test results were very promising and showed that new cool pigmented concrete, clay, painted metal and asphalt shingle roofs maintain their solar reflectance as well as their standard production counterparts. Total color change is reduced or at least similar and the new cool pigmented products have similar if not improved fade resistance and gloss retention.

The asphalt shingles when heated will undergo chemical changes and changes in visible and solar reflectance. Elevated temperature, for example as provided by solar absorption in dark materials, can accelerate deleterious chemical reactions and hasten the diffusion of low molecular weight components. Since photo-degradation is a complex process that depends upon material type, including additives and impurities, it is difficult to generalize about how photo-degradation should be altered by increased temperatures. Intuitively, one would expect that higher temperatures would assist photo-degradation. However, photo-degradation of the asphalt shingle products was not observed for these accelerated exposure test results. Solar reflectance of the asphalt shingles with and without CRCMs showed slight increases in solar reflectance. Note that increases were larger for the cool pigmented shingles. Total color change among cool pigmented and conventional pigmented shingles was very similar indicating once again that the new infrared reflective products are ready for market.

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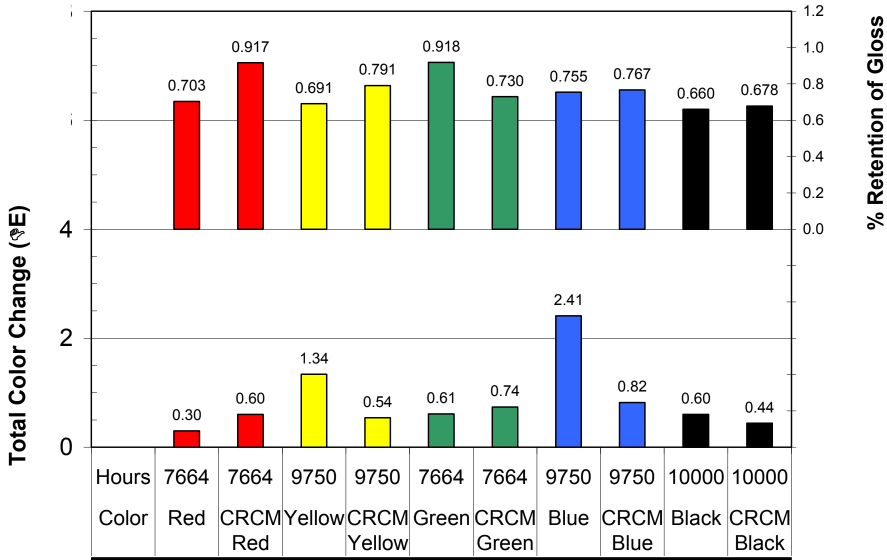

Figure 1. The total color change and the retention of gloss for masstones tested under fluorescent UV light using ASTM G154 protocol. (Data courtesy of BASF).

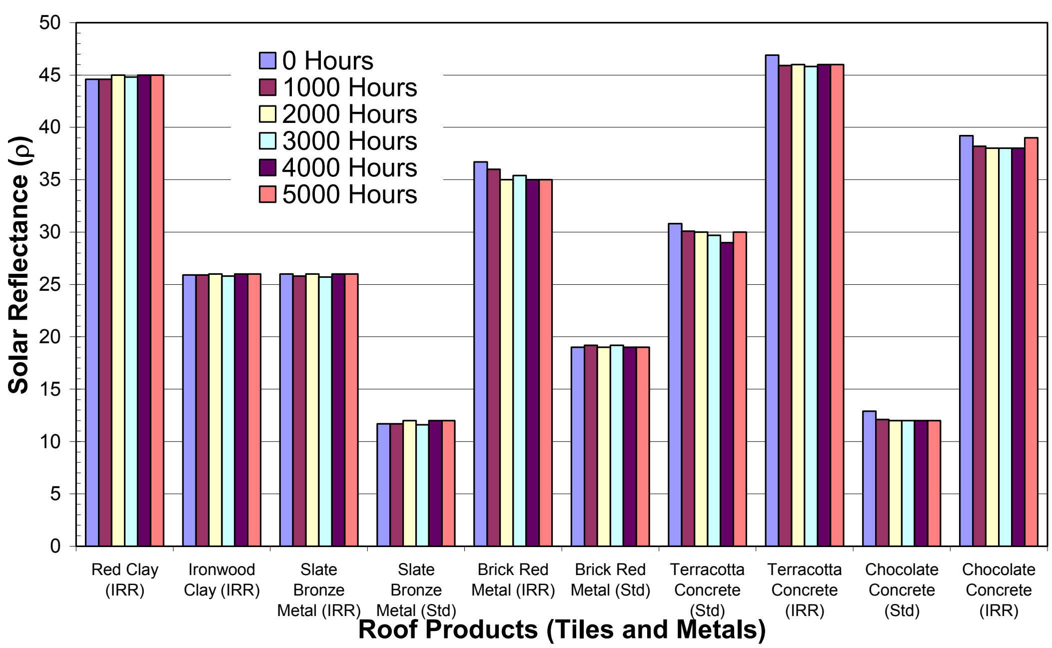

Figure 2. The solar reflectance of tiles and painted metals under fluorescent UV light using ASTM G154-04 protocol. (Data by Shepherd Color Company).

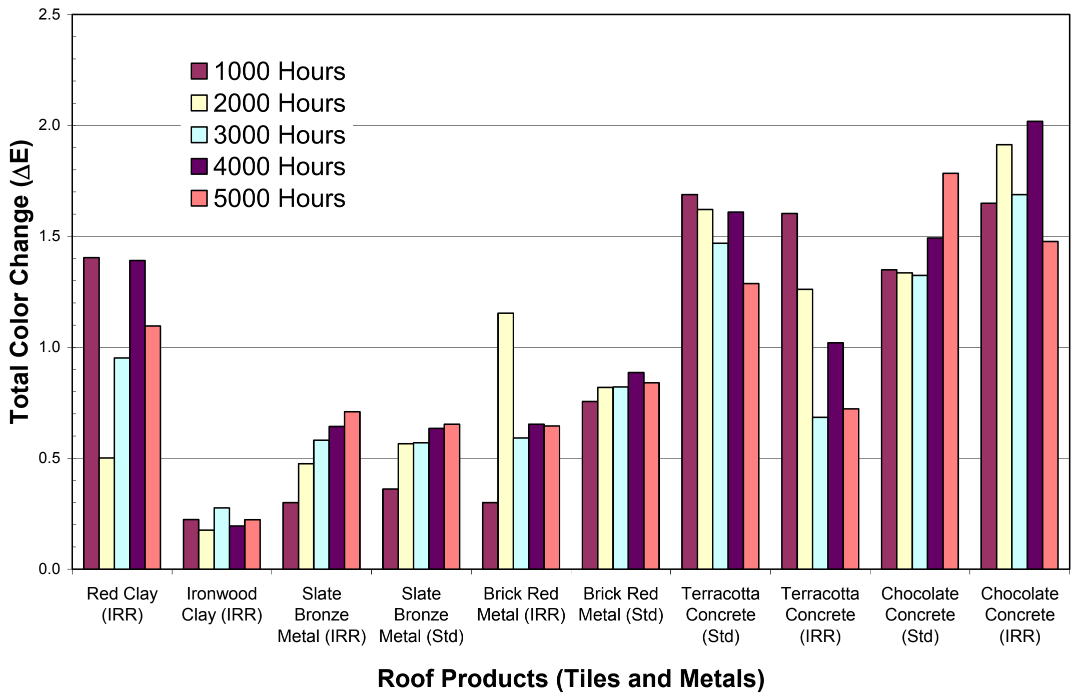

Figure 3. The total color change of tiles and painted metals under fluorescent UV light using ASTM G154-04 protocol. (Data by Shepherd Color Company).

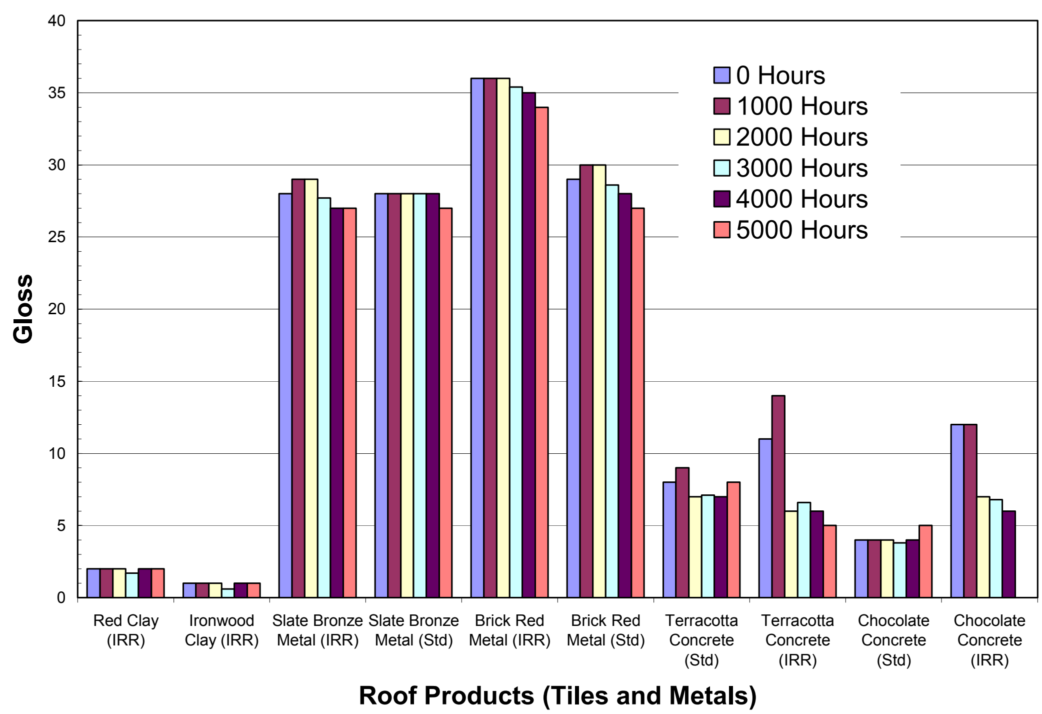

Figure 4. The gloss of tiles and painted metals under fluorescent UV light using ASTM G154-04 protocol. (Data by Shepherd Color Company).

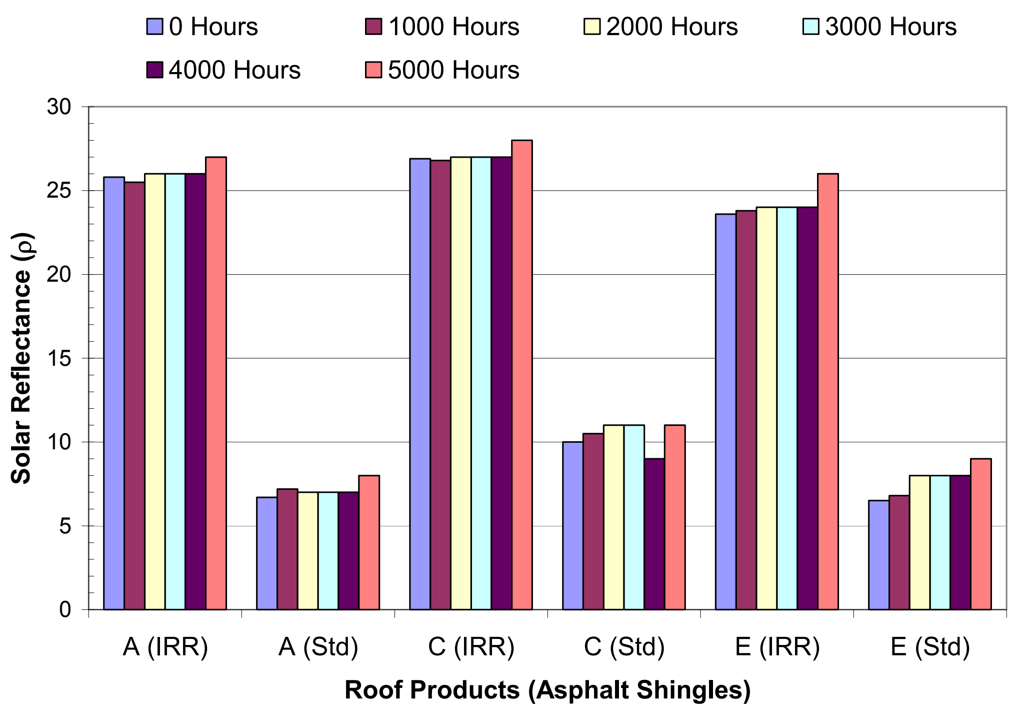

Figure 5. The solar reflectance of asphalt shingles under fluorescent UV light using ASTM G154-04 protocol. (Data by Shepherd Color Company).

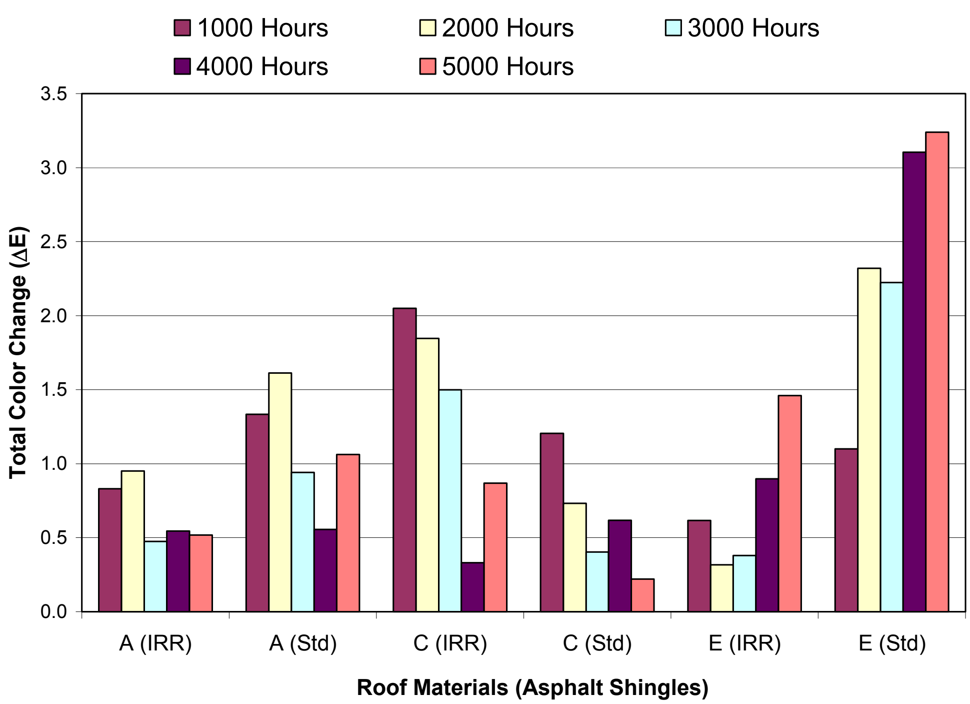

Figure 6. The total color change of asphalt shingles under fluorescent UV light using ASTM G154-04 protocol. (Data by Shepherd Color Company).

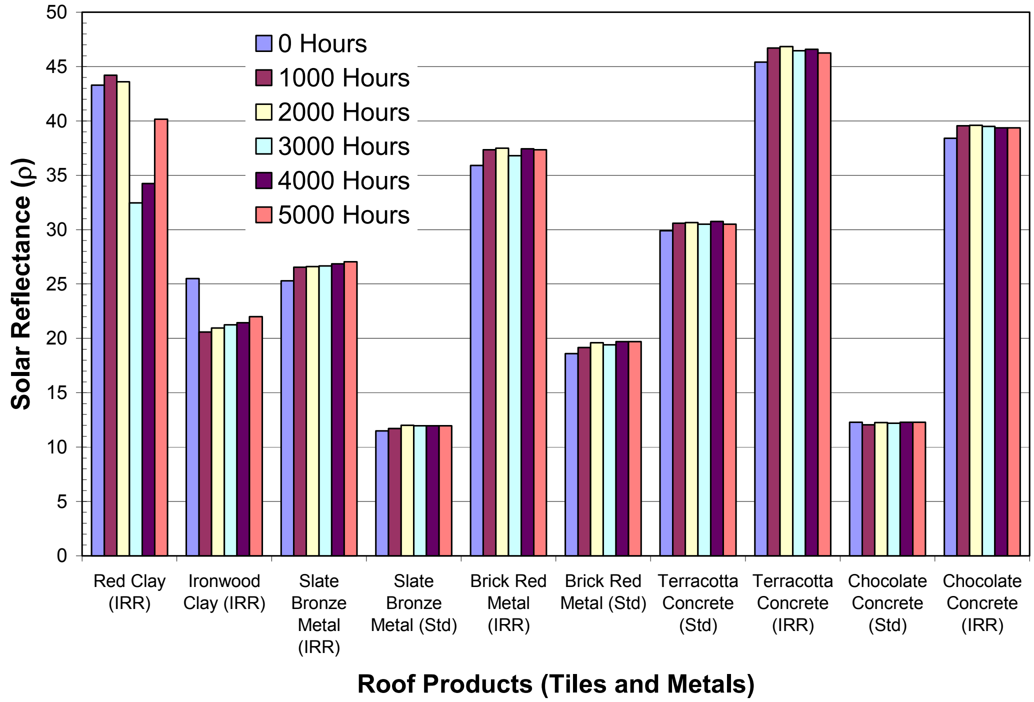

Figure 7. The solar reflectance of tiles and painted metals under xenon-arc light using ASTM G-155 protocol. (Data by 3M Company).

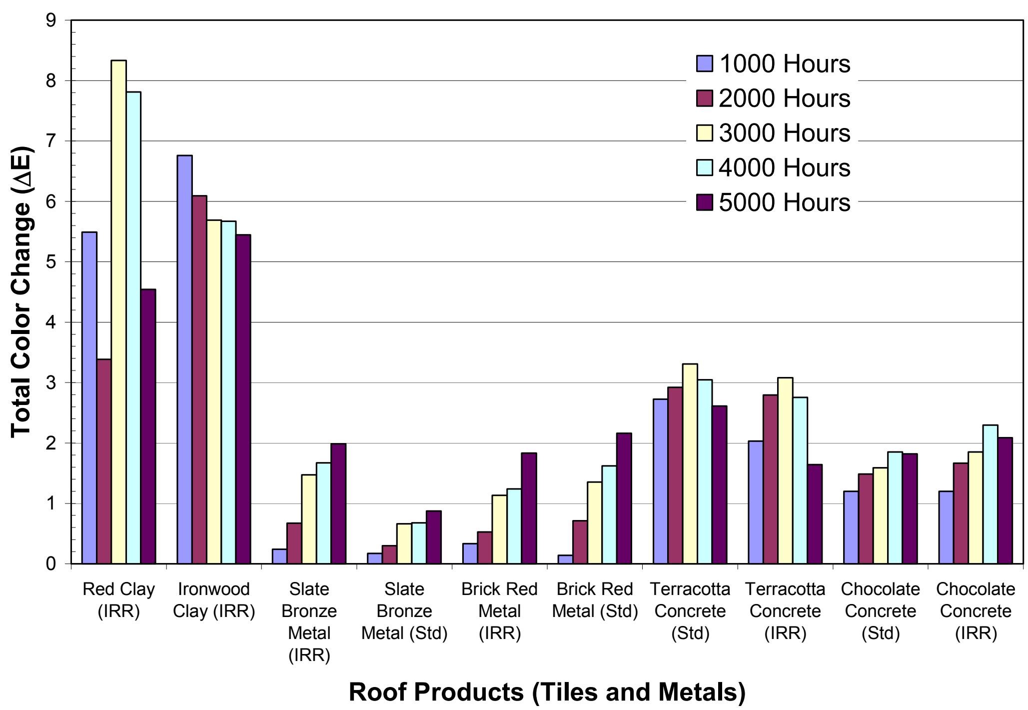

Figure 8. The total color change of tiles and painted metals under xenon-arc light using ASTM G-155 protocol. (Data by 3M Company).

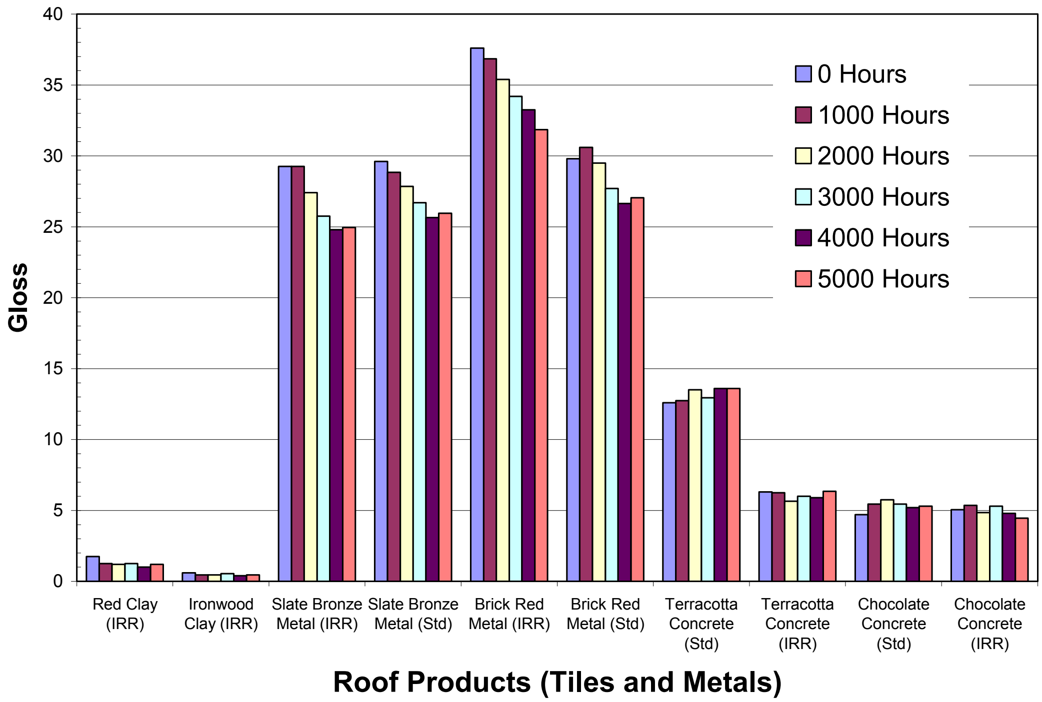

Figure 9. The gloss of tiles and painted metals under xenon-arc light using ASTM G-155 protocol. (Data by 3M Company).

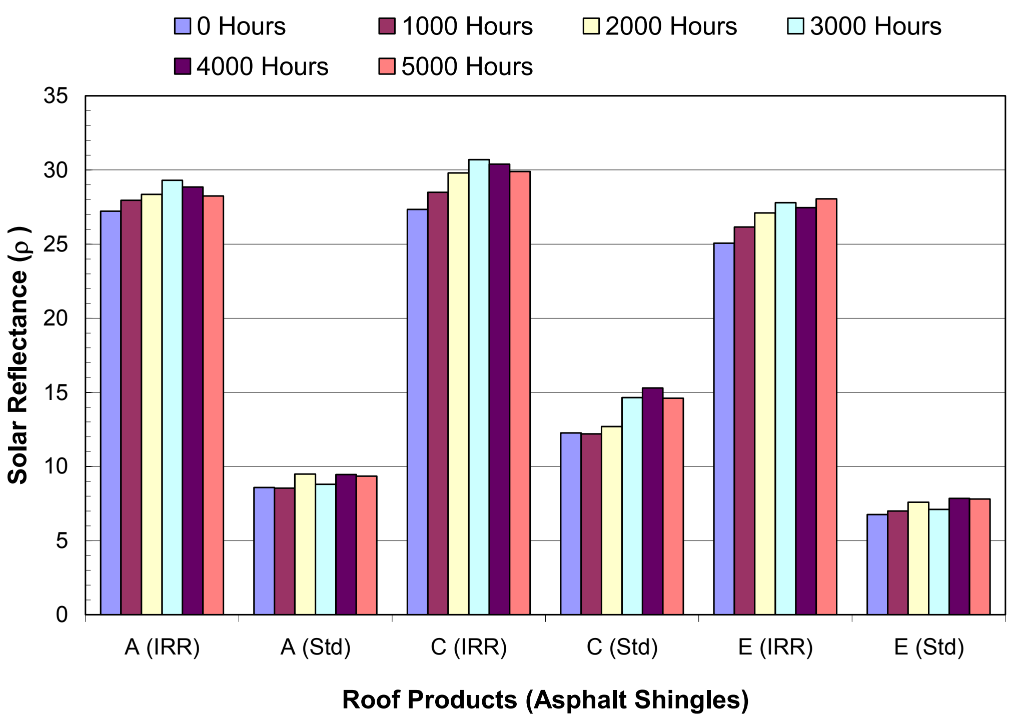

Figure 10. The solar reflectance of asphalt shingles under xenon-arc light using ASTM G-155 protocol. (Data by 3M Company).

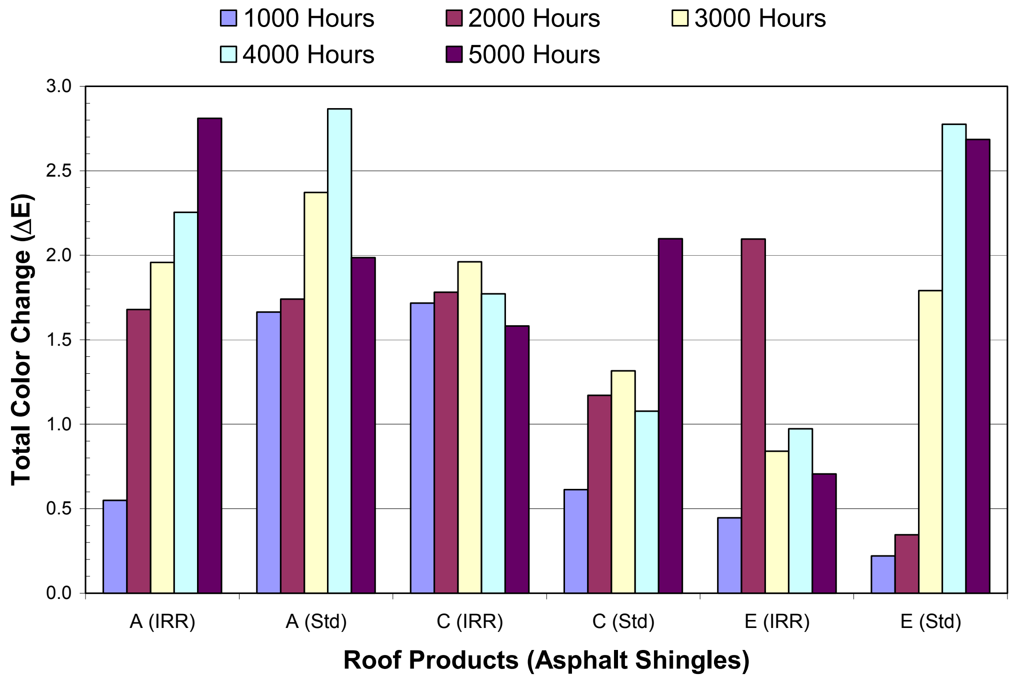

Figure 11. The total color change of asphalt shingles under xenon-arc light using ASTM G-155 protocol. (Data by 3M Company).