New Generation Solar Reflective Shingles

Ming L. Shiao and Husnu M. Kalkanoglu
CertainTeed Corp., Roofing Group
Blue Bell, Pa., U.S.A.

Keywords

Asphalt shingle, roofing granule, cool roof, solar reflectance, weathering, color, performance, aging, aesthetics, coating, cool pigment

Abstract

Increasing energy costs and global warming have created strong demand for cool roofs that can reduce summer cooling energy for indoor comfort while reducing carbon footprints. Using white or light surface colors, a roof's solar reflectivity can be increased and a "cool roof" can be achieved. However, for many homeowners with asphalt shingles on their homes, color matters. Therefore, a new solution must be found so both requirements—energy management and aesthetics—can be fulfilled.

This paper discusses a new generation of shingles whose solar reflectivity does not depend on their light-colored surfaces. On the contrary, these shingles exhibit vivid, dark colors yet possess solar reflective behavior similar to their light-colored counterparts. The paper will present results on improving their shingles' solar reflectance through earth tone-colored roofing granules that achieve high solar reflectance. The microstructure/property relationships for these new solar reflective roofing granules will be presented and discussed to shed light on the potential benefits of enhancing solar heat reflectivity without sacrificing color strength. Field test data also will be presented; the results revealed these new generation solar reflective shingles can retain their solar reflectance after three years of outdoor weathering in various climates.

Authors:

Ming L. Shiao received his doctorate in materials science from the University of Massachusetts, Amherst, in 1993 and later joined CertainTeed Roofing Group as principal research engineer. Since then, he has published more than 16 technical papers and received presentation excellence awards in several symposiums. He has been granted 10 U.S. patents and is a member of Materials Research Society, American Chemical Society, Society of Plastic Engineers, American Water Works Association, and Solar Energy International. He currently is senior principal research engineer at CertainTeed.

Husnu Kalkanoglu received a bachelor's degree in chemical engineering from Robert College, Istanbul. Soon after obtaining his master's degree in polymer science and chemical engineering from the University of Cincinnati, he joined CertainTeed Roofing Group in 1982 as a research chemist working on polymer modification of asphalt. Kalkanoglu has held several technical positions at CertainTeed and in 2005 became vice president of research and development. He is an active member of ASTM International, Asphalt Roofing Manufacturers Association, Construction Specifications Institute, American Society of Chemical Engineers and Society of Rheology. He holds 37 U.S. patents and is dedicated to innovation in the areas of energy management and protecting the environment.

Introduction

Asphalt shingles, with their desirable aesthetics and proven performance, have been the roofing materials choice for U.S. residential housing market for more than half a century[1,2]. Currently, more than 60 percent of the U.S. residential roofing market is asphalt shingles or bitumen-based roofing materials[2]. These products typically are constructed by coating a reinforcement layer with molten bitumen and covering the surface with so-called “roofing granules” to protect the bitumen from harmful ultraviolet (UV) radiation while providing desirable colors[3]. Roofing granules typically are made from mineral particles that are translucent to UV radiation, such as naturally occurring minerals. However, roofing granules typically have high absorption of solar heat, so the shingles tend to have low solar reflectance. As a result, asphalt shingles can reach relatively high surface temperatures during hot summer days[4].

In recent years, there has been a strong demand for roofing materials that can reflect more solar heat, reducing the energy need for indoor cooling load[5]. This is particularly true for Sun Belt states and regions where energy costs are relatively high. Furthermore, there has been a growing trend in building codes by local building officials to mandate cool roof systems not only because of their energy benefits but also because of potential benefits to cut greenhouse gases for global warming reduction[6]. For asphalt shingles, this is particularly important because they represent the major residential roofing materials in North America. However, increasing asphalt shingles’ solar reflectance remains a significant challenge, not only because of the highly absorbing raw materials currently employed to make the products but also because of the rough granulated surface that tends to reduce reflectivity[7,8]. This is particularly true when considering the relatively dark earth-tone colors most homeowners prefer. Although one can achieve higher solar reflectance by using lighter colors or white paint, this approach becomes less effective in the residential roofing market because of aesthetic issues.

In this paper, we present a new generation of asphalt shingles designed to preferentially reflect solar heat from the solar spectrum while maintaining their color values in the visible spectrum through the use of functionalized roofing granules with engineered optical properties. The microstructure/property relationship of these highly reflective roofing granules is discussed and field testing data is presented to explain their potential benefits and uses in residential shingles for energy-efficient roofing materials.

Solar Reflectance of Industrial Standard Roofing Granules

The current art of making roofing granules typically consists of selecting a suitable mineral source, quarrying and crushing rock to a certain grading or size, dedusting and drying, coloring, curing and adding final surface treatment for shingle applications. The colors produced and used by the industry typically are in earth-tone colors and represent the color space from light gray to black. Typical CIE (*Commission Internationale de l'Eclairage*) Color System color data of current industrial standard roofing granules are tabulated in Table 1. Their solar reflectance values, as measured by ASTM C1549, "Standard Test Method for Determination of Solar Reflectance Near Ambient Temperature Using a Portable Solar Reflectometer," also are listed in Table 1. As you can see, the colors of these industrial standard granules mostly are far from the vibrant regime of the color space; even the so-called "white" color has only moderate lightness on the CIE color scale of L*. Because the lightness scale L* represents the light reflection in the visible light portion of the solar spectrum, one would suspect the L* scale may correlate well with the total solar reflectance. This is true for these industrial-standard roofing granules, and the excellent correlation (r^2=0.97) between L* and solar reflectance can be seen in Figure 1.

Table 1: Color and total solar reflectance of typical roofing granules

Color description	L*	a*	b*	Averaged percentage of solar reflectance
Black	22.91	-0.11	-0.67	4
Gray	31.34	0.05	0.32	6.2
Dark brown	26.90	5.66	8.08	5.9
Brown	39.97	13.29	18.98	15.0
Buff	41.50	10.67	21.19	15.4
Olive	36.25	0.33	5.75	10.0
Light gray	48.53	-3.66	2.84	16.8
Light buff	55.92	6.41	19.65	25.4
White	67.54	-0.44	1.28	31.3

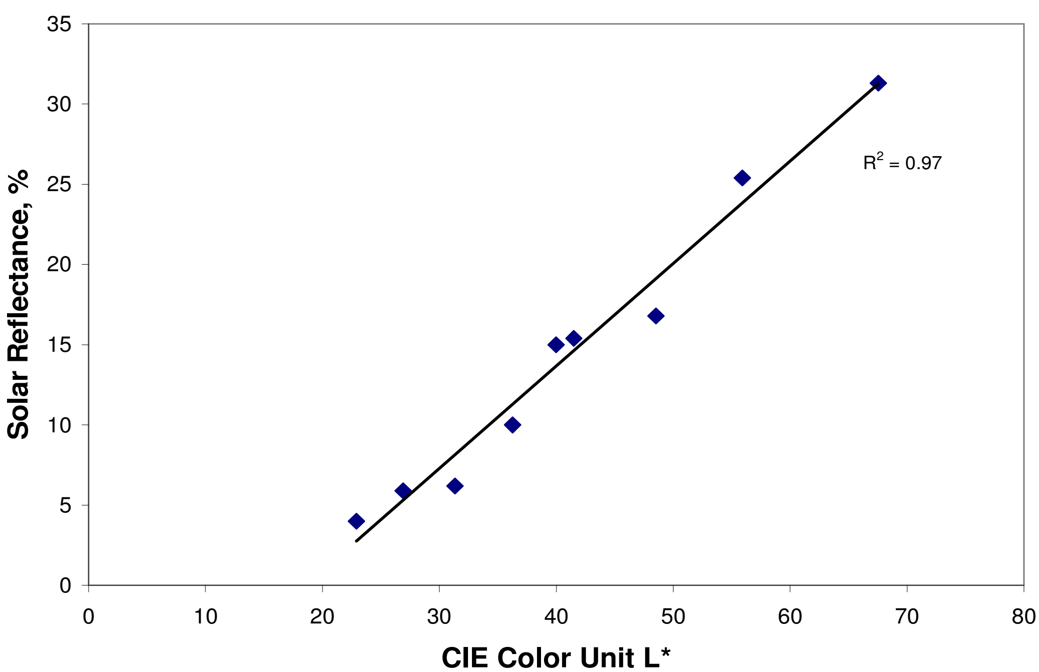

Figure 1: Solar reflectance vs. the lightness of typical roofing granules

Because of the manufacturing process of these industrial-standard roofing granules, they typically show limited coating coverage, or patchy surfaces, as they are examined under an optical microscope (see Figure 2). As a result, the solar heat will be partially absorbed by the mineral particle, which has relatively low solar reflectance in resemblance of typical earth materials. Furthermore, a roofing granule's surface derived from crushed minerals tends to have high surface roughness, as shown in the scanning electron micrographs of Figure 3. Therefore, the resulting roofing granules will tend to absorb significant solar heat and may contribute to the so-called Heat Island Effects[5,6]. This represents a significant challenge for improving the solar reflectance of these industrial-standard roofing granules, particularly in view of the darker color space the market prefers.

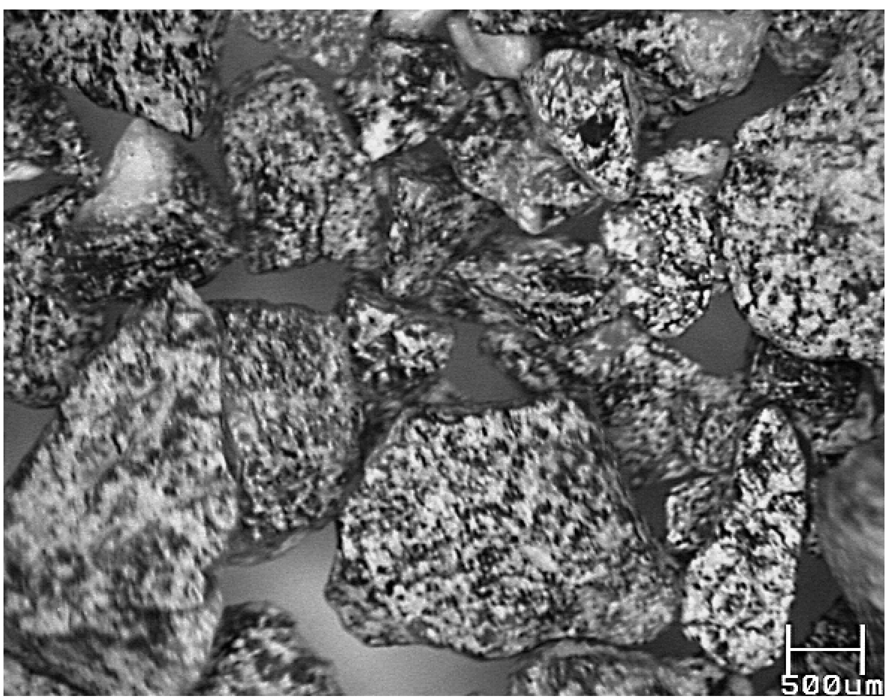

Figure 2: Optical micrograph of a standard light gray-colored roofing granule showing patchy surface coating coverage resulting in low solar reflectance

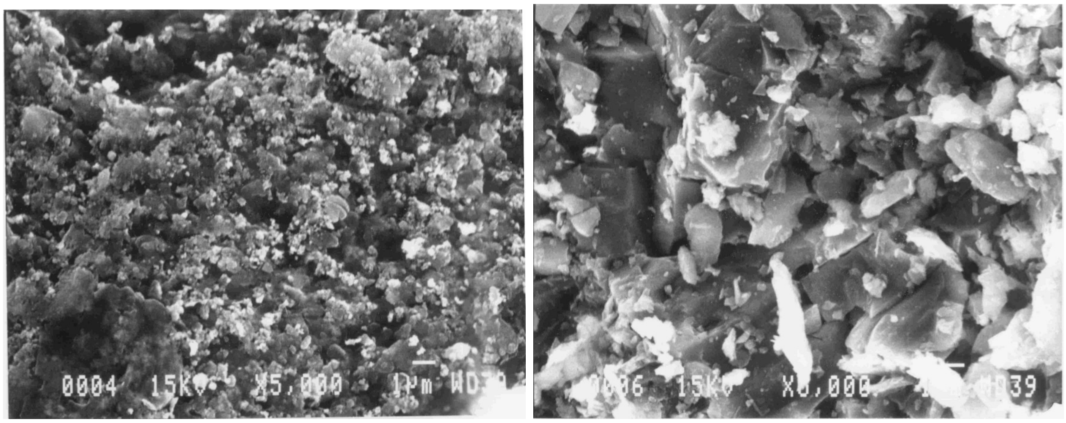

Figure 3: Scanning electron micrographs of the surface of mineral particles in typical roofing granules showing high surface roughness

New Generation of Solar Reflectance Granules

To improve the solar reflectance of current roofing granules, it is necessary to engineer the color coatings so they can function as a heat-reflecting surface to the solar radiation spectrum. Figure 4 shows a typical hemispherical solar irradiance and you can see that the near infrared (NIR) portion, which does not contain color information, represents a significant 53 percent of total solar energy. Therefore, it would be necessary to reflect a substantial portion of the NIR solar radiation so a roofing granule's total solar reflectance will be improved while not affecting the color. Such an approach has been suggested by Levinson et al,[9] who also established the database for colorants considered to be "cool pigments."[10]

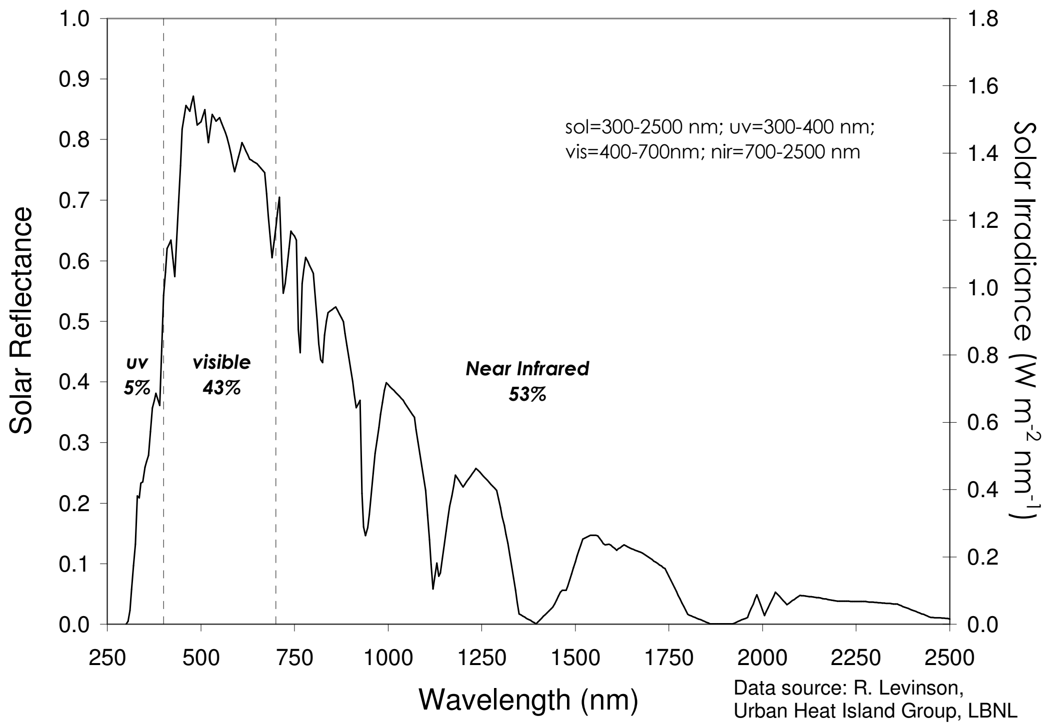

Figure 4: Hemispherical solar irradiance

For roofing granules, incorporating so-called cool pigments can increase solar reflectance; however, it is also necessary to consider other factors, such as the color coating efficiency, surface roughness of the mineral particles and the manufacturing process of shingle making. As previously mentioned, the color coating in roofing granules typically is not uniform, leaving a large portion of the mineral surface still exposed to direct solar heat, thereby reducing the benefits of using cool pigments. One solution is to use a white base coating or white prime coat to cover the mineral surfaces before finishing with a top color coat, and this has been practiced by some roofing granule manufacturers. However, this approach often leads to a “wash out” color effect because the white base coat now is replacing the dark mineral surfaces as the background in a patchy coating coverage application. Figure 5 shows micrographs with a typical example of such products and their overall color effects compared with a standard nonsolar reflective granule in a similar color family. When compared with industrial standard, nonsolar reflective roofing granules, the solar reflective granules show improved solar reflectance; however, this is at the cost of losing color strength in the deep earth-tone range, such as those with L*<35.

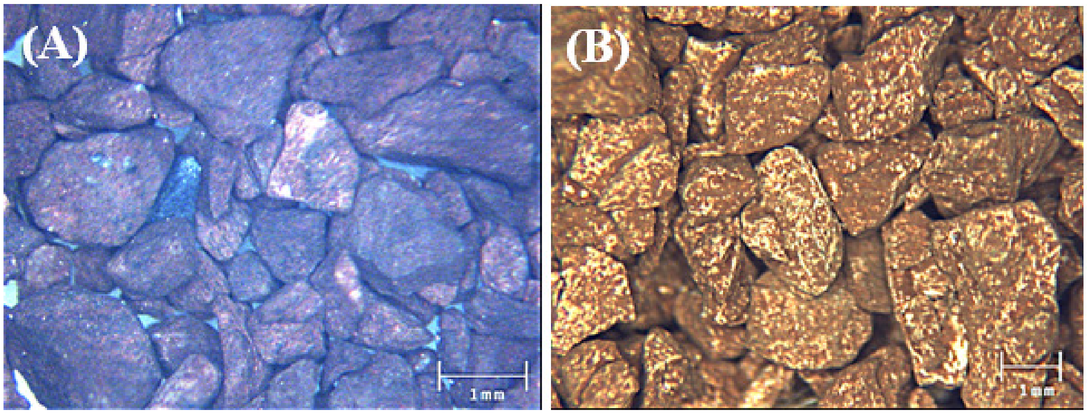

Figure 5: Example of solar reflective roofing granules with white base coat that improves the total solar reflectance in the expense of color strength. (A) Industrial-standard granule in brown color, and (B) solar reflective granules with a white base coat.

Figure 6 shows solar reflectance as a function of lightness for three roofing granule types in a range of colors: standard nonsolar reflective granules, solar reflective granules with a white base coat and next generation solar reflective granules. Notice in Figure 6 that the solar reflectance of granules produced by using a white prime coat when traditionally manufacturing roofing granules tends to follow a similar linear relationship with L* but at a reduced slope. As a result, the improvement on solar reflectance with this approach will be reduced as the color space expands. This suggests the use of white base coat followed by a top color coat to improve a roof granule's solar reflectance may be limited in its efficiency to reach higher solar reflectance.

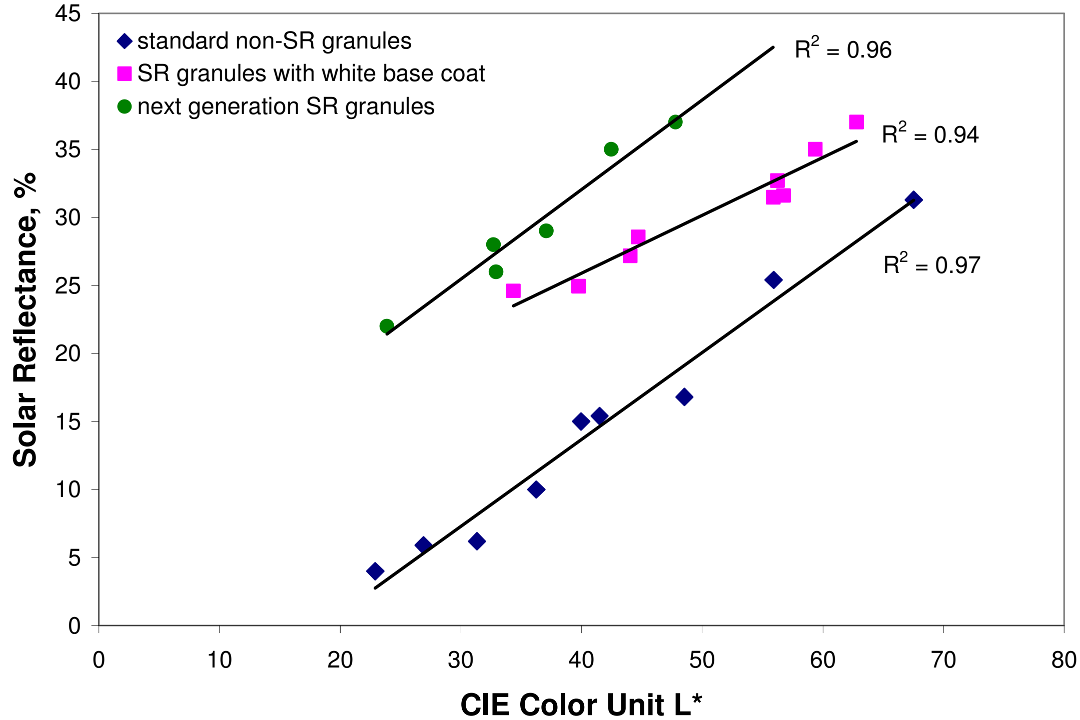

Figure 6: Solar reflectance vs. the lightness L* for typical nonsolar reflective granules, solar reflective granules based on white base coat and new generation solar reflective granules

To further improve solar reflectance without sacrificing color strength, it is necessary to consider the surface characteristics of the mineral particles, coating efficiency and manufacturing processes. By optimizing these parameters, the authors have been able to further improve roofing granules' solar reflectance without affecting the final color. Compared with industrial-standard, nonsolar reflective granules, these new generation solar reflective granules have similar color space yet much higher solar reflectance. Their solar reflectance also is graphed in Figure 6 as a function of lightness L*. These new generation solar reflective granules can reach darker color space with L*<35 while retaining high solar reflectance. Also, they appear to have a linear relationship and slope of L* versus solar reflectance similar to the non solar reflective granules, indicating they are capable of improving solar reflectance efficiently with the same color strength as those of the industrial-standard, non solar reflective granules. When examined under a microscope, these granules have similar color aesthetics (see Figure 7) compared with the industrial standard, non-solar reflective granules. Furthermore, when these new generation solar reflective granules were applied to the shingle-making process, it was found that one can produce solar reflective shingles that closely match the traditional shingle color yet can meet the ENERGY STAR® requirement for residential cool roof systems. An example of such a shingle† is shown in Figure 8.

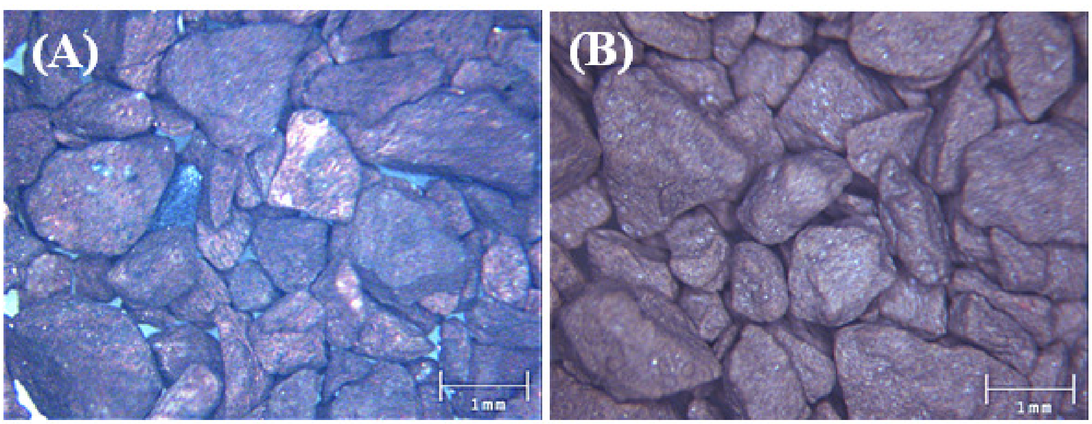

Figure 7: Example of new generation solar reflective granules (B) compared with standard nonsolar reflective granules (A) showing the improved color strength

† : Landmark Solaris Max Def shingle in Weathered Wood color from CertainTeed Corp., Valley Forge, Pa.

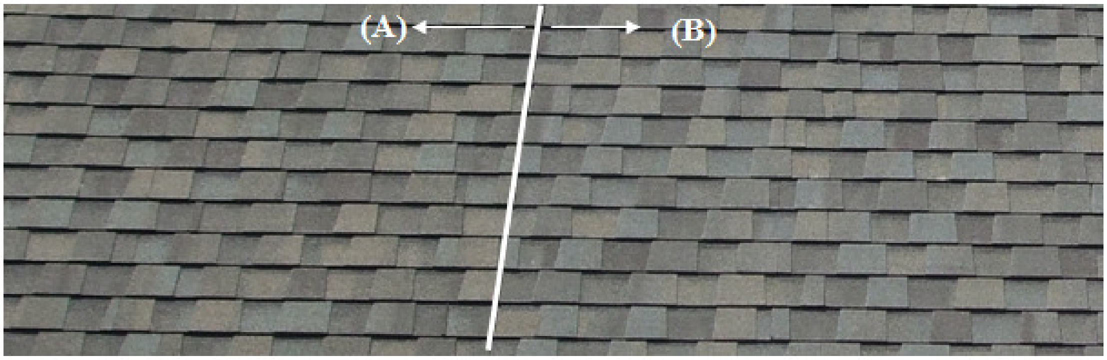

Figure 8: Example of asphalt shingles with new generation solar reflective granules (B) compared with standard non-solar reflective granules (A) showing the closely matched color space and texture for the aesthetics

Field Performance of Shingles with New Generation Solar Reflective Granules

To test the field performance of the new generation solar reflective granules, asphalt shingles made with the granules were exposed to outdoor weathering in farms with three distinct climates: a hot, dry climate (Phoenix, AZ); hot, wet climate (Tampa, FL); and relatively cold, wet climate (Detroit, MI). Their color**s** and change**s** in solar reflectance were recorded during a three-year period, and the results are shown in Figure 9. It is clear from the data the solar reflectance of these new generation solar reflective granules did not degrade during the time period. In fact, the shingles' overall total solar reflectance increased during three years of exposure in all three climates.

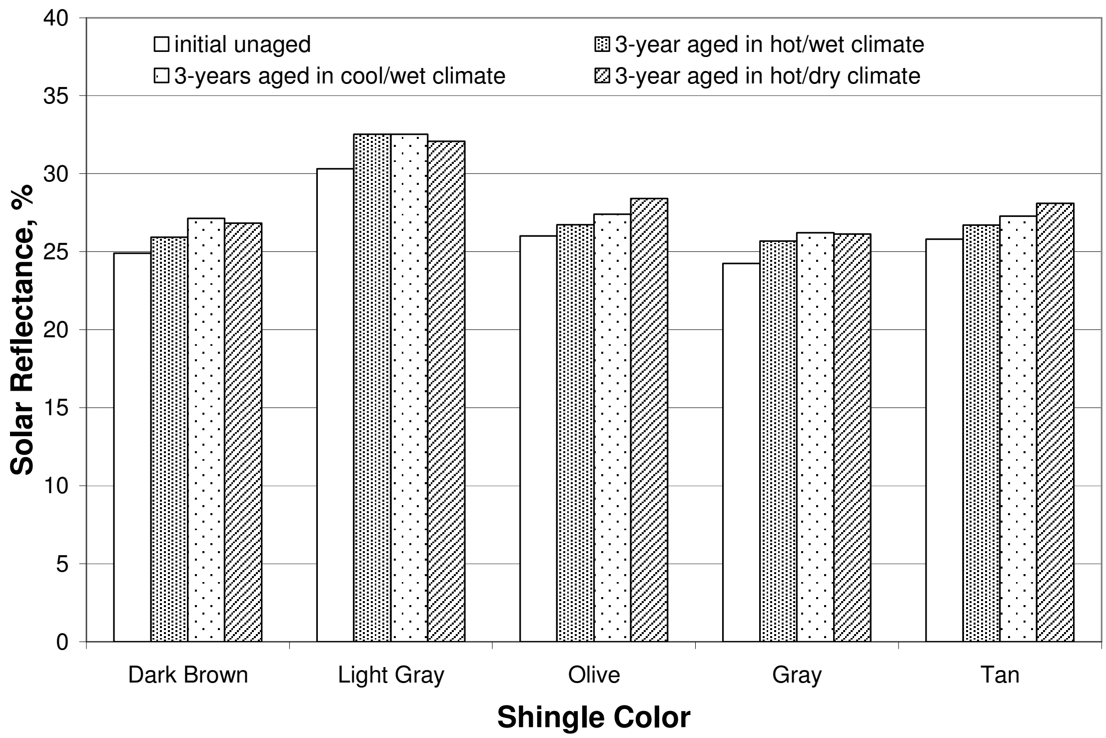

Figure 9: Weathering data of the new generation solar reflective shingles

To further understand this phenomenon, the shingles' exposed surfaces were examined under a light microscope and compared with the unexposed, initial shingles with the same solar reflective granules. The results are shown in Figure 10. It appears that no particular evidence of degradation in the color coating can be seen. However, the surface appears to be covered by microscopic particles, particularly in areas between the roofing granules. Further analysis indicated these particles are likely to be airborne dust. As a result, the total solar reflectance is found to slightly increase because the dark, absorbing areas of the bitumen between granules were found to be covered by the dust. Therefore, the exposed bitumen area was found to be weathered so the airborne particles typically found in air can cover the surface and increase the surface solar reflectance from asphalt at less than 5 percent to typical airborne dust at approximately 15 percent. The net result can be seen in the slight increase of 2-3 percent in shingles' total solar reflectance.

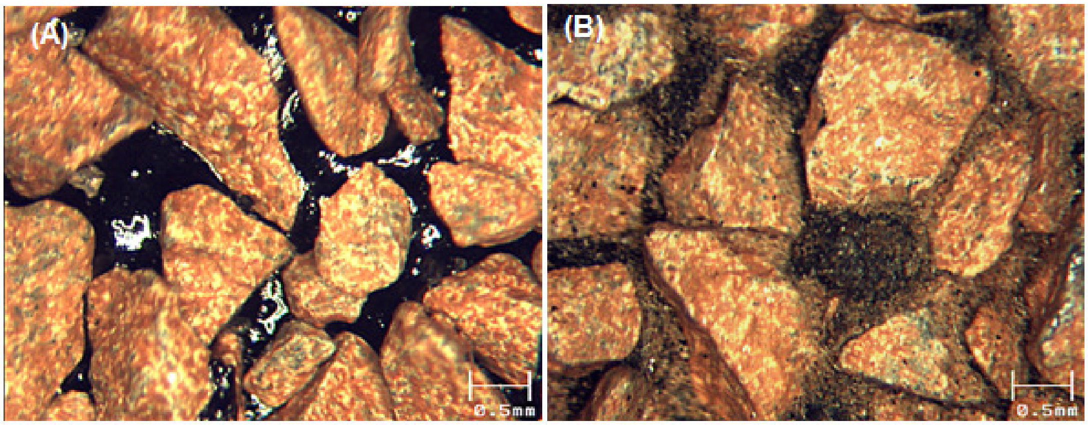

Figure 10: Observation of the surface of a three-year aged shingle with solar reflective granules (B) compared with the initial, unexposed shingle (A)

Summary and Conclusion

We have demonstrated that asphalt shingles can achieve high solar reflectance in traditional earth-tone colors by improving the solar reflectance values of the surface roofing granules. This new generation of solar reflective roofing granules is shown to be an effective solution for residential cool roof applications when homeowners also demand dark, vivid colors. Field testing data revealed that the weathering performance of these new solar reflective granules is comparable to traditional roofing granules and their solar reflectance is equal or better than their initial stage after three years of aging in three distinct climates.

Acknowledgement

The authors are thankful to Dr. Gregory Jacobs for his helpful input and proofreading. Also, contributions from Jennifer Sharp and Dr. Keith Hong to this study are greatly acknowledged.

References

1. M.J. Noone, W.K. Blanchard, Proc. 10th Conf. on Roofing Tech., April, 1993, (NRCA, Gaithersburg, MD), pp. 23-33
2. W.C. Cullen, ibid., pp. 6-12
3. Residential Asphalt Roofing Manual, The Asphalt Roofing Manufacturers Association (Calverton, MD), 1997
4. Shiao, M.L., Nester, D.A., and Terrenzio, L.A., *Roofing Research and Standards Development, Vol. 5, ASTM STP 1451* (W.J. Rossiter and T.J. Wallace, Eds., ASTM International, West Conshohocken, PA, 2003)
5. H. Akbari, R. Levinson, L. Rainer, Energy and Building 37 (2005) pp. 1007-1016
6. H. Akbari, S. Menon and A. Rosenfeld, *Climatic Change*, 94 (2009), pp. 275-286.
7. P. Berdahl, H. Akbari, J. Jacobs, F. Klink, Solar Energy Materials and Solar Cells, Volume 92, Issue 4, April 2008, pp. 482-489
8. Levinson, R., H. Akbari, P. Berdahl, K.Wood, W. Skilton, and J. Petersheim, *Solar Energy Materials & Solar Cells* 94 (2010), pp. 946-954
9. R. Levinson, P. Berdahl, H. Akbari, W. Miller, I. Joedicke, J. Reilly, Y. Suzuki, M. Vondran, Solar Energy Materials & Solar Cells 91 (2007), pp. 304–314
10. R. Levinson, P. Berdahl, H. Akbari, Solar Energy Materials & Solar Cells 89 (2005), pp. 351–389