Evaluation of Glass Bubbles for Solar Heat Reflection in Wat

erborne Acrylic Elastomeric Roof Coatings

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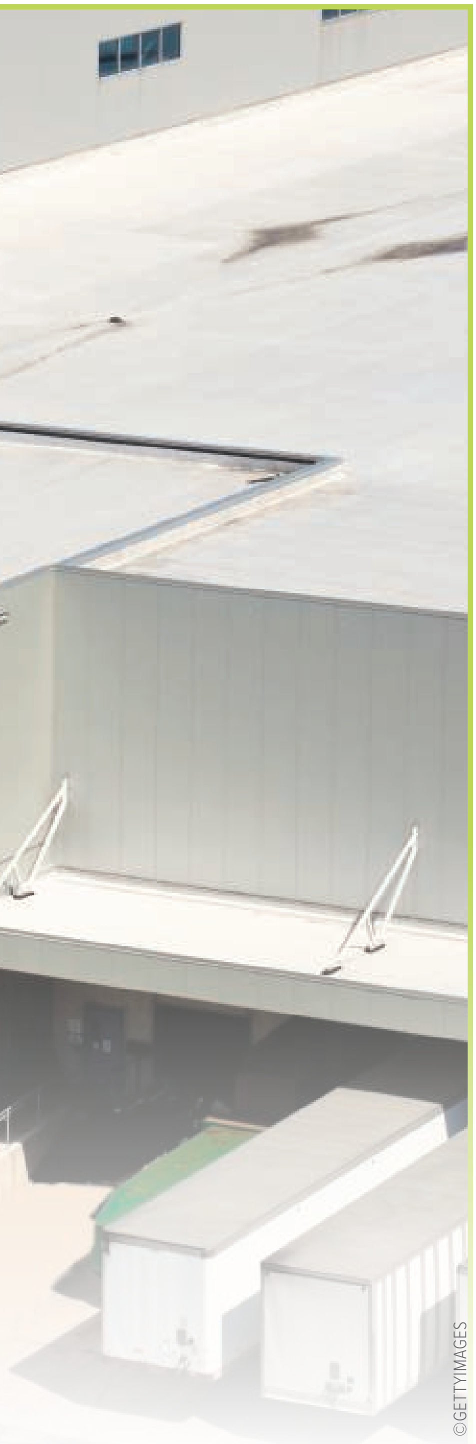

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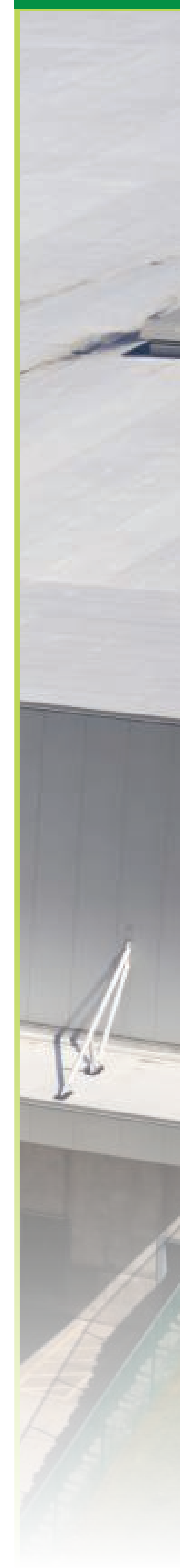


The expanding residential building market has placed a higher demand on electricity for cooling in warmer climate regions. This demand has created opportunities for coatings companies to investigate solar heat reflective coatings as a means to combat the increasing energy costs. Two popular areas being investigated in the architectural arena are roof and wall coatings. Typically, solar heat reflective coatings are characterized by a high solar reflectance and high emittance values in the thermal infrared region. Waterborne white elastomeric and aluminum pigmented asphalt are two types of coatings used for this evolving market. There are many binder types within the elastomeric class. This study focuses on utilizing a 100% acrylic-based binder in a white pigmented formulation.

The spectral distribution for solar irradiance is divided into three regions: UV (200–400 nm—5% of sunlight energy), Visible (400–700nm—45% of sunlight energy) and Near-IR (700–2500 nm—49% of sunlight energy and felt as heat). Approximately 96% of the sunlight's radiation falls in the 400–2500 nm range, so analysis of the data in this region is of particular interest.

Solar reflectance values are typically >80% for coatings formulated specifically as "cool" roof paints, which means they absorb and/or transfer <20% of the incident energy. The thermal emittance is a measure of how easily a surface will give up heat, and a high emittance surface will give off heat more readily and thus reach equilibrium at a lower temperature. This makes it desirable to also have a high emittance value for exterior coatings. The total solar reflectance (TSR), is a weighted average of how well a material reflects energy at each specific solar energy wavelength. ASTM standard C1483 defines an RCC (radiation control coating) as a liquid applied coating having a solar reflectance of 0.8 and an ambient temperature infrared emittance of at least 0.8.

Emittance and total solar reflectance properties are used together to calculate a solar reflectance index (SRI), which is typically zero for a black surface and 100 for a white standard. SRI values can exceed 100 by definition in the calculations for cool materials. The SRI values can be entered into standard energy calculator cost modules to calculate overall potential energy savings. Other factors have to be taken into consideration when using these calculators, such as insulation values, geographical region, and current energy costs, to name a few.

Typically, rutile titanium dioxide is used to achieve very effective scattering of incident visible and infrared radiation due to its high refractive index and particle size relationship to these specific wavelength bands.

Glass bubbles are another option to consider when formulating solar heat reflective coatings.* These particles are hollow, varying strength-low density, water resistant, soda-lime borosilicate glass. The bubbles have commercial applications in many industries such as oil and gas, automotive, and paints and coatings. Their hollow structure ideally gives them different light scattering efficiencies due to the differences in refractive indices from other materials in the matrix, such as binders and other additives.

This article evaluates the effect of three different grades of glass bubbles versus a conventional filler and a commercial solid microsphere blend in a 100% acrylic elastomeric latex system. Comparisons are made to a commercial waterborne acrylic elastomeric roof coating. Properties such as solar reflectance, emissivity, and thermal benefits are examined as they relate to potential energy savings for white elastomeric waterborne latex roof coatings. A brief evaluation of accelerated exterior weathering and dirt pick-up resistance (DPUR) is also conducted. Evaluation of other performance properties of elastomeric roof coatings are outside of the scope of this study and will be saved for future studies. These include elongation, water vapor permeance and absorption, flame retardancy, and fungi resistance, to name a few.

*3M™ Glass Bubbles. See footnote in *Table* 1.

TABLE 1—Paint Formulations

		$CaCO_3$ (CONTROL)	GB3	GB1	CMB	GB2
MATERIAL	WPG	AMOUNT (GAL)	AMOUNT (GAL)	AMOUNT (GAL)	AMOUNT (GAL)	AMOUNT (GAL)
WATER	8.34	18.23	18.23	18.23	18.23	18.23
DISPERSANT	10.00	0.50	0.50	0.50	0.50	0.50
POTASSIUM TRIPOLYPHOSPHATE	21.15	0.07	0.07	0.07	0.07	0.07
CELLULOSIC THICKENER	11.61	0.30	0.30	0.30	0.30	0.30
DEFOAMER	7.10	0.28	0.28	0.28	0.28	0.28
MICROBICIDE	8.33	0.18	0.18	0.18	0.18	0.18
WETTING AGENT	8.97	0.22	0.22	0.22	0.22	0.22
TITANIUM DIOXIDE	32.33	2.32	2.32	2.32	2.32	2.32
ZINC OXIDE	46.82	0.96	0.96	0.96	0.96	0.96
CALCIUM CARBONATE	22.70	18.72	0	0	0	0
100% ACRYLIC ELASTOMERIC BINDER	8.70	54.60	54.60	54.60	54.60	54.60
DEFOAMER	7.10	0.21	0.21	0.21	0.21	0.21
COALESCENT TEXANOL[a]	7.91	0.76	0.76	0.76	0.76	0.76
MILDEWCIDE	8.60	0.28	0.28	0.28	0.28	0.28
AMMONIA (28%)	7.69	0.13	0.13	0.13	0.13	0.13
GLASS BUBBLE 3[b]	3.84	0	18.72	0	0	0
GLASS BUBBLE 1[b]	1.04	0	0	18.72	0	0
COMMERCIAL MICROSPHERE BLEND	6.1	0	0	0	18.72	0
GLASS BUBBLE 2[b]	1.84	0	0	0	0	18.72
PROPYLENE GLYCOL	8.66	1.62	1.62	1.62	1.62	1.62
WATER	8.34	0.61	0.61	0.61	0.61	0.61
TOTALS		99.99	99.99	99.99	99.99	99.99

(a) Texanol™ is a trademark of Eastman Chemical.
(b) Glass Bubble 1 (GB1) = 3M™ Glass Bubble K1, Glass Bubble 2 (GB2) = 3M Glass Bubble S22, Glass Bubble 3 (GB3) = 3M Glass Bubble iM16K - 3M Company.

EXPERIMENTAL METHODS AND MATERIALS

A list of white paint formulations used for this study are shown in *Table 1*.

The standard control formulation contained 2.3 vol % of TiO_2 and 18.7 vol % of calcium carbonate on a wet basis. On a dry basis, this equated to 5.3 vol % TiO_2, 35.3 vol % $CaCO_3$, 56.7 vol % of acrylic binder, and approximately 2.7 vol % other ingredients. The finished paint contained 52% NVV, had a total PVC of 42%, matte (<5 gloss), and a viscosity of 100–125 Krebs units (KU). Application parameters such as viscosity, levelling, and defoaming can be adjusted with appropriate additives. The VOC was approximately 50 g/L for this formulation. Subsequent formulations containing the glass bubbles or commercial microsphere blend (CMB) were made by substituting the same amount on a volume basis to keep the pigment volume concentration (PVC) contributions the same from the other pigments and fillers. The glass bubbles and CMB were added at the end of the formulation (after paste and letdown combined) to minimize breakage. The general properties of the fillers evaluated are shown in *Table 2*.

Three different grades of glass bubbles were selected to cover a broad range of densities, strengths, and particle sizes. Calcium carbonate was chosen because it is commonly used in these types of formulations and was utilized in the commercial paint example for comparison. The CMBs and $CaCO_3$ are solid, non-spherical particles, as opposed to the glass bubbles that are hollow sodium borosilicate glass, and spherical in nature. All paints were applied to black/white Leneta form 3B opacity charts or 3003 H14 aluminum mill finish panels (6 in. x 12 in.) using various drawdown applicator bird bars and cast film methods to give the desired film thickness. The target dry film thickness was 15–20 mils (380–508 microns). In some cases, this required more than one coat. The accelerated weathering testing was conducted at lower dry film thicknesses (50–100 microns). Paints were allowed to dry for a minimum of 3 to 7 days depending on the test. *Table 3* references the test methods used for these studies.

TABLE 2—General Properties of Evaluated Fillers

PRODUCT	TARGET CRUSH STRENGTH, psi (90% Survival)	TRUE DENSITY g/cc	PARTICLE SIZE DISTRIBUTION (Microns by Volume)		
			10%	50%	90%
CALCIUM CARBONATE	HARDNESS 3–4 MOHS SCALE	2.72	—	AVERAGE =12 MICRONS	—
GB3	16,000	0.46	12	20	30
GB1	250	0.125	30	65	115
CMB (SOLID PARTICLES)	7,000 (>98%)	0.73	—	AVERAGE=100 MICRONS	—
GB2	400	0.22	20	35	65
COMMERCIAL W/B ELASTOMERIC PAINT	N/A	N/A	N/A	N/A	N/A

TABLE 3—Test Methods

TEST TYPE	TEST METHOD
OPACITY	ASTM D2805
GLOSS	ASTM D523
DRY FILM THICKNESS	POSITECTOR 6000 GAUGE[a]
SOLAR REFLECTANCE	ASTM E903/G173
SOLAR REFLECTANCE INDEX	COMPUTER MODEL BASED ON ASTM E1980
THERMAL EMITTANCE	ASTM C1371 (TOTAL HEMISPHERICAL- AT AMBIENT TEMP 72°-78°F)—PORTABLE UNIT
INFRARED LAMP TEST	3M TEST METHOD
REFLECTANCE (BRIGHTNESS)	ASTM E1347—COLOR FLEX® EZ INSTRUMENT[b]
QUV WEATHERING	1000 H—PROPRIETARY METHOD
DPUR	DIRT PICK-UP RESISTANCE (24-H DRY DIRT/0-70 MICRON/75°F&20-30%RH)

(a) PosiTector® 6000 is a registered trademark of DeFelsko Corporation;
(b) ColorFlex® EZ Instrument is a registered trademark of Hunter Associates Laboratory, Inc.

RESULTS AND DISCUSSION

Opacity, Gloss, and Thickness

The opacities ranged from 99–101 for all samples. At the higher film deposition used in this study (15–20 mils), it was possible to formulate with lower levels of TiO_2 (2.3 vol %) and still maintain acceptable substrate hiding power. The gloss for all samples was < 5 on a 60° meter indicating a matte designation for all samples. The initial reflectance values were 92.7, 87.7, and 89.1 for the $CaCO_3$, CMB, and commercial paint, respectively. These values were much lower than the glass bubble samples (GB1=94.9, GB2=94.8, GB3=95.6), indicating that the GB samples yield an initial brighter/whiter appearance.

Solar Reflectance

The total solar reflectance was measured using a Perkin Elmer Model

FIGURE 1—Solar reflectance on white Leneta paper.

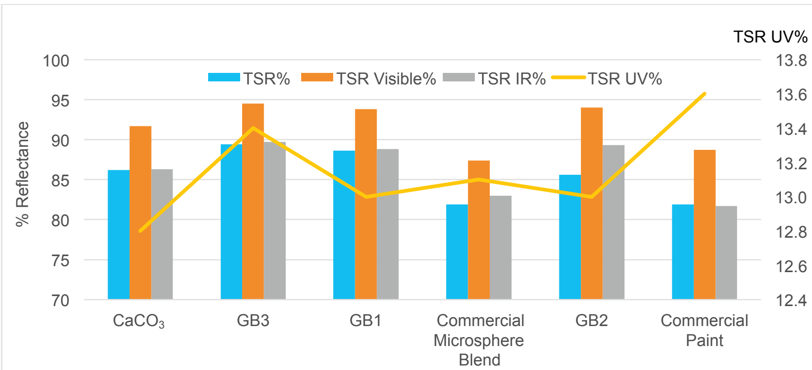


FIGURE 2—Solar reflectance on black Leneta paper.

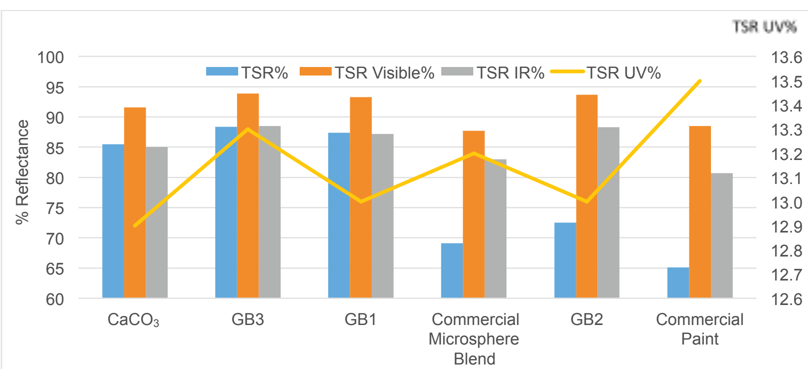
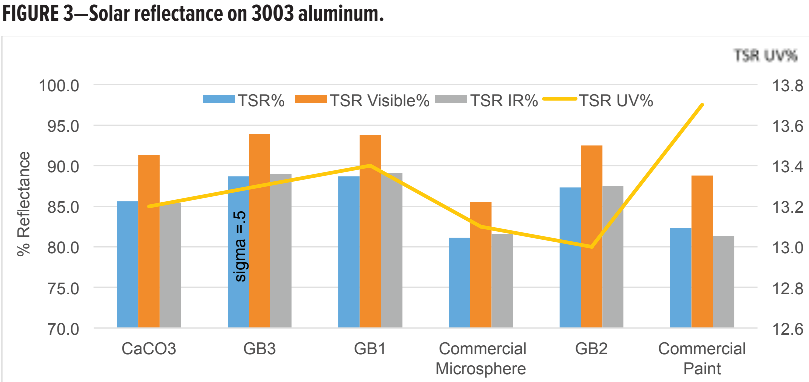


FIGURE 3—Solar reflectance on 3003 aluminum.



950 spectrophotometer,* which was modified to measure UV-Vis-NIR using an integrated sphere. ASTM methods E903/G173 and mathematical programs were used in the calculations to obtain TSR for each coating on various substrates. The results are shown in *Figures 1-3*.

Overall, all of the samples performed well for solar reflectance properties as indicated by the TSR values exceeding 80% on the aluminum and white substrates. The GB grades (especially GB3) performed very well, averaging 3–6% higher TSR values. A look at the total spectral distribution (*Figure 4*) shows that the glass bubble grades perform well over the entire solar spectrum, especially in the visible and near IR regions. It should be noted that the strength of the glass bubble grade is a critical selection factor due to processing and application variations. The larger/lower crush strength bubbles need to be evaluated under specific processing conditions to ensure survival. GB3 offered both a smaller size and higher strength; thus, it may be a better fit for many formulators who may use spray type applications.

Thermal Emittance Test

Emissivity testing was conducted using a portable unit along with black and stainless steel calibration chips. The results are shown in *Figure 5*.

All emissivity values were >90% for the samples tested. The data was entered into a Solar Reflectance Index calculator,[1] and the overall results are listed in *Table 4*. A theoretical calculated roof surface temperature is also included for each corresponding SRI value. Data indicates that the highest solar reflectance and lowest calculated roof surface temperature are obtained with the glass bubble materials.

In this particular study, both the largest bubble (GB1) and the smallest bubble (GB3) exhibited similar results for solar reflection and emissivity. The GB1 sample, however, did yield a

*Perkin Elmer Lambda™ 950 Spectrometer is a trademark of PerkinElmer Inc.

rougher and slightly tackier surface compared to the GB3 sample. Scanning electron microscopy (SEM) of the dried paint film also showed a higher percentage of bubble breakage in the GB1 film versus GB3, which has a much higher crush strength.

Infrared Heat Lamp Test

A laboratory experiment was developed to evaluate thermal benefits of these solar heat reflective paints on the inside roof temperature of building structures. The 3003 aluminum painted panels were exposed to a 250W/R40 reflector/120V red heat lamp bulb for a period of (one) 1 h. The samples were 6 cm x 5 cm, and the bulb was placed 10 cm from the substrate. A type K thermocouple and logger were attached to the backside of the aluminum chip that was placed on a ceramic plate with a small hole cut for the thermocouple. Temperature values collected for 40 min and one h are shown in *Table 5*. All of the glass bubble modified paints yielded average temperatures 5–10°F lower than the other paints evaluated in this study. In some cases, the temperature delta was as high as 15–20 °F cooler when comparing to a commercially available paint system.

GB3 Loading (PVC) Study

Glass Bubble 3 has shown some interesting properties for solar and heat reflection in addition to processing and appearance benefits. A second study was conducted to evaluate the effects of higher and lower bubble loading on these same properties. Two additional paints were made at a 28 and 55 PVC, which corresponds to 20 and 50% volume loading in the dried paint film. The results are shown in *Table 6*. There were no significant differences in the SRI values, but further studies using the infrared lamp test indicate lower overall backside temperatures with increased bubble loading as shown in *Figure 6*. Depending on the bubble loading, the temperature varied from 7–15°F cooler than the corresponding paint with calcium carbonate filler.

FIGURE 4—Cumulative solar reflectance spectral curves.

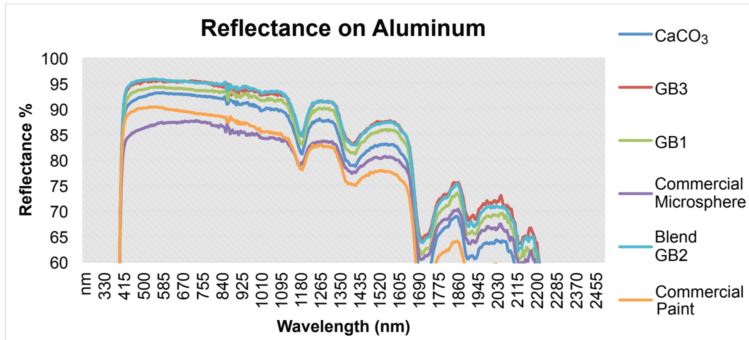


FIGURE 5—Emissivity test results.

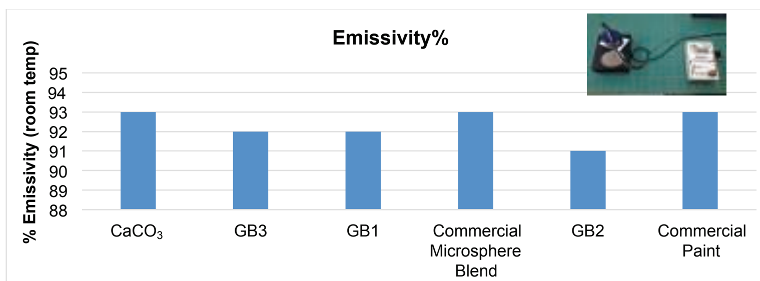


TABLE 4—Solar Reflectance Index Results

SAMPLE	THERMAL EMITTANCE	TOTAL SOLAR REFLECTANCE	SOLAR REFLECTANCE INDEX (SRI)[1]	CALCULATED ROOF SURFACE TEMP (°C)
$CaCO_3$	0.93	0.856	108	41.4
GB3	0.92	0.887	113	39.8
GB1	0.92	0.887	113	39.8
CMB	0.93	0.811	102	43.8
GB2	0.91	0.873	111	40.6
COMMERCIAL	0.93	0.823	104	43.2

TABLE 5—IR Heat Lamp Test Results

IR LAMP TEST SAMPLE	OVERALL AVG. TEMP (°F)	AVG. TEMP AFTER 40 MIN	Δ (°F) FROM $CaCO_3$
$CaCO_3$	154.4	167.9	REFERENCE
GB3	145.6	158.3	-9.6
GB1	149.6	161.0	-6.9
CMB	155.6	168.3	+0.4
GB2	150.5	161.3	-6.6
COMMERCIAL PAINT	161.9	175.9	+8.0

Accelerated Weathering Studies

Aluminum painted panels were subjected to 1000 h of an accelerated QUV weathering test. Gloss and color were measured in addition to the reflectance ratio after a 24-h DPUR test. Results are shown in *Table 7*.

All of the paints exhibited good weathering properties after 1000 h QUV. The sample with $CaCO_3$ and the commercial paint exhibited the greatest gloss loss at 38 and 19%, respectively. Minimal color change was noted on all samples except the commercial paint, which had a DE of 1.57, most of which came from the yellowness index (Db). GB3 yielded the lowest DE and highest reflectance ratio after testing. Thus, it had the cleanest/brightest visual appearance. It is surmised that the increasing size of the particles contributes to the higher dirt attraction, thus lowering the % reflectance recovery after the dry dirt test. GB1 and the CMB exhibited the roughest surface appearance due to size. In addition, GB1 samples actually yielded softer feeling films, which was not desirable for this evaluation.

Additional Experiment: Using Glass Bubbles as a Post-Addition Additive

As a final experiment, GB3 and the commercial microsphere blend were post-added to the commercial paint sample at a level approximately equal to 18% by volume (wet) of the paint. Samples were tested in the same manner as previously described for solar reflectance and thermal comparisons. Results are shown in *Figures 7* and *8*.

Overall results show that the post addition of glass bubbles (GB3) can improve solar reflectance and thermal characteristics. It should be noted that this article only addresses the benefits of solar reflection as with the painting of outside structures and does not consider any insulative benefits of interior coated systems.

In all cases, all grades of glass bubbles were added under low speed agitation using a propeller type blade. Previous studies have shown that the addition of glass bubbles under a Cowles or high shear type agitation subjects them to a higher incidence of breakage.

FIGURE 6—IR heat lamp test curves for Glass Bubble 3.

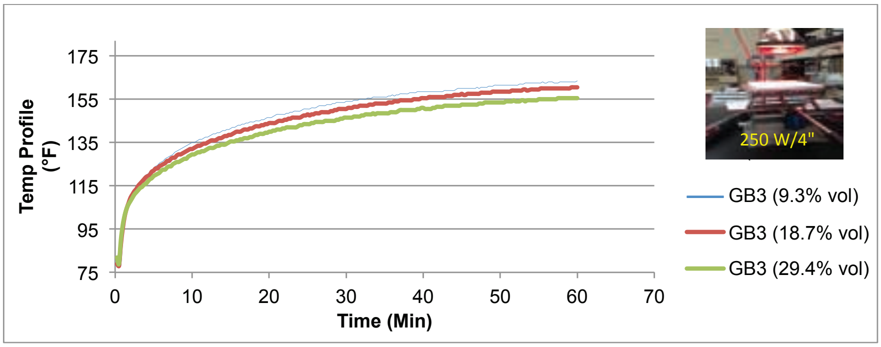


Table 6—GB3 Volume Loading Study Test Results

SAMPLE	VOL % WET	VOL % DRY	PAINT PVC	THERMAL EMITTANCE	TOTAL SOLAR REFLECTANCE	SRI
GB3	9.3	20	28	0.93	0.879	112
GB3	18.7	35	45	0.93	0.887	113
GB3	29.4	50	55	0.92	0.883	112

TABLE 7—Accelerated Weathering Studies Test Results

SAMPLE	% 60° GLOSS LOSS	TOTAL COLOR CHANGE (DE)	DPUR (% REFLECTANCE RECOVERY AFTER QUV AND 24-H DRY DIRT TEST)
$CaCO_3$	38	0.40	96.2
GB3	0	0.27	97.0
GB1	0	0.45	94.5
CMB	4	0.42	96.2
GB2	0	0.37	95.2
COMMERCIAL PAINT	19	1.57	95.5

Energy Savings

Various energy savings calculators have been developed to estimate potential energy savings associated with "cool roof" coatings. One such calculator can be found at the following website: http://web.ornl.gov/sci/roofs+walls/facts/CoolCalcEnergy.htm.

It should be noted that this is only one example of a cost calculator that can be used. The operator must input many specific data values such as R value, SR, Infrared Emissivity, energy costs, equipment efficiencies, and geographical location, and the computer module will in turn calculate potential annual net savings based on heating and cooling factors. This calculator works primarily for low slope roofs, and the results are given as potential annual savings relative to black roofs.

FIGURE 7—IR heat lamp test results for post addition of fillers to commercial paint.

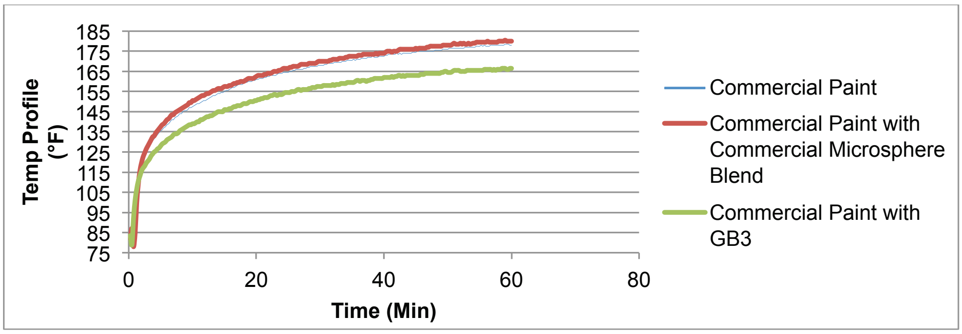


FIGURE 8—Cumulative solar reflectance spectral curves for post addition of fillers to commercial paint.

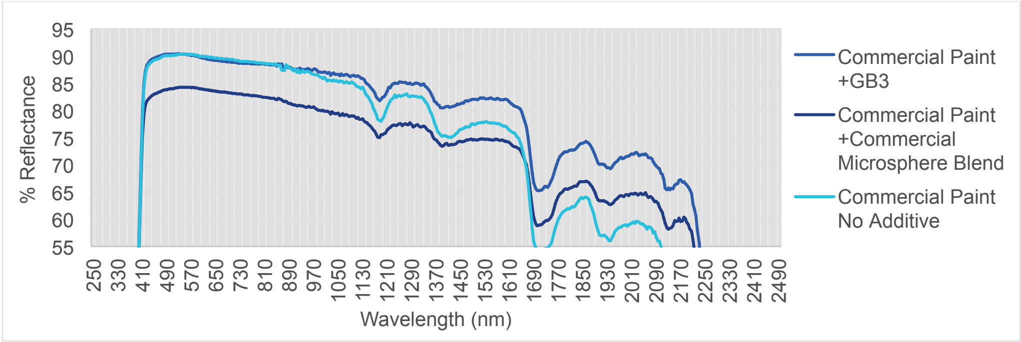


TABLE 8—Energy Cost Calculation Example

SAMPLE	TSR	EMITTANCE	ENERGY COST ($/KWH)	SAVINGS OVER BLACK ROOF ($/FT2/YEAR)
$CaCO_3$	85.6	93	0.2	0.407
GB3	88.7	92	0.2	0.421
GB1	88.7	92	0.2	0.421
CMB	81.1	93	0.2	0.384
GB2	87.3	91	0.2	0.412
COMMERCIAL PAINT	82.3	93	0.2	0.391

Formulators must consider raw material costs vs potential energy savings to determine the optimal formulation parameters. An example for the materials evaluated in this study are shown in *Table 8*. In this example, an R value of 10 was used and an air conditioning efficiency of 2 was used. The location used was Miami.

SUMMARY

In this study, all of the white paints generally exhibit industry acceptable initial solar reflectance index values,[2] and thus offer varying degrees of potential savings over a black roof baseline. Paints made with glass bubbles offered the highest degree of potential energy savings based on the fillers studied in this experiment. This study does not take into account the other parameters that qualify an acceptable elastomeric roof coating such as elongation, water resistance, etc. Final formulations need to be tested for all specified properties to determine final acceptance per customer specifications. New studies have suggested maintaining certain minimum SRI values after actual outdoor weathering intervals. These

and other studies such as the impact of glass bubbles on the solar reflectance of colored paints may form the basis for future studies. The white elastomeric paints in this study target low sloped roofs such as those utilized in industrial applications. Higher sloped roofs using other colors for residential applications could potentially benefit from these same materials.

White elastomeric waterborne acrylic roof coatings made with glass bubbles can offer formulators an alternative to other conventional fillers used in these coatings. The smaller glass bubbles offer increased solar reflectance and thermal advantages, which in turn could result in energy savings. The smaller bubbles also offer higher strength which could be beneficial for higher pressure applications such as airless spraying. In addition, the smaller bubbles yield a smoother appearance and good dirt pick-up resistance. The magnitude of these benefits needs to be evaluated by each formulator for their particular application and formulation.

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Notes

ASTM Methods: D523, D2805, E903, G173, E1980, C1371, E1347, G154, C1483

1. Solar Reflectance Index calculated using following: Tool coded by Ronnen Levinson, Heat Island Group, Lawrence Berkeley National Laboratory (http://HeatIsland.LBL.gov). For assistance, contact Hashem Akbari@H_Akbari@LBL.gov, or Ronnen Levinson at RMLLevinson@LBL.gov.
2. RCMA-Reflective Roof Coatings and LEED V4-Nov. 2015.

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