Evaluation of a Ceramic Roof Coating

William H. Allen, Clemson University
Jay D. Harmon, Clemson University
Dale E. Linvill, Clemson University
Matthew V. Bramblett, Clemson University
EVALUATION OF A CERAMIC ROOF COATING

W. H. Allen, J. D. Harmon, D. E. Linvill, M. V. Bramblett

MEMBER ASAE
MEMBER ASAE
MEMBER ASAE
STUDENT MEMBER ASAE

ABSTRACT. Surfaces treated with a ceramic roof coating (CRC) marketed as AZTEC No. 100 were compared to untreated and white painted surfaces. Dry-bulb and black globe temperatures in the space below or behind the surface were the criteria for comparison. Comparisons included small horizontal panels with open sides, small unvented galvanized steel and styrofoam boxes, and an open-side steel poultry building. The CRC was effective in reducing temperatures in the enclosed test boxes, but less effective with open-side test panels and the open-side steel building. Tests also indicated the CRC is characterized by high emissivity (0.95) and reflectivity (0.87). The evidence indicates the CRC would be most effective with uninsulated, enclosed metal shell buildings, but ineffective with insulated and open-side or well ventilated buildings. Keywords: Ceramics, Roof coatings, Agricultural buildings.

OBJECTIVE

The objective was to determine the thermal effect of a CRC on the space enclosed by the treated surface. A secondary objective was to determine the reflectivity and emissivity of the CRC material.

The working hypothesis stated the CRC would reduce temperatures within enclosed uninsulated steel buildings, but would be less effective when applied to insulated and open sidewall buildings.

LITERATURE REVIEW

Several researchers have evaluated roof coatings applied to agricultural buildings. Van Wicklen et al. (1985) tested a white roof coating formulated of borosilicates, titanium, and transport agents on an enclosed broiler house having a 37 mm (1.5 in.) polystyrene foam insulation ceiling. The coating, marketed by Energywave Corporation of Iverness, Florida, was found to have a reflectance of 0.78. Interior air temperatures were decreased by 1.1 to 1.7° C (2 to 3° F) and attic temperatures were reduced more dramatically.

Czarick and Tyson (1990) tested a white elastomeric acrylic polymer marketed as Duracool on layer houses having 29-gauge metal roofing and 2.5 cm (1 in.) of beaded polystyrene insulation. Morgan (1990) reported this product to have a reflectance of 0.85. A 6% reduction in radiant heat flux occurred when using the coating on an enclosed building. However, no significant difference occurred when the sidewall curtains were open. The Duracool roof coating reduced roof metal temperature, but the reduction in heat load depended on the air exchange rate. The effect on interior air temperature and black globe temperature was minimal with large ventilation rates used in poultry production facilities. They concluded that Duracool is more suitable for uninsulated buildings with minimal air exchange.

Bottcher et al. (1990) tested a white roof coating containing ceramic particles that was marketed by Insulating Coatings Corporation of Iverness, Florida. A polystyrene insulated roof was compared to a coated roof...
with partially missing polystyrene insulation. The roof coating reduced the solar heat gain via the roof but did not eliminate the need for adequate insulation. During summer, the black globe temperature was greater in the treatment house than in the control house. This result was attributed to direct exposure to the bare underside of the treated roof surface. As defined by interior black globe temperature, the treatment was not as effective as the polystyrene insulation.

**EXPERIMENTAL EQUIPMENT**

Small panels and boxes were constructed and mounted on 61 cm × 61 cm (24 in. × 24 in.) plywood pallets (figs. 1 and 2). Black globe thermometers were located with centers 20.3 cm (8 in.) above the pallets. Pallets were placed on the ground 1.83 m (6 ft) on center in a single east-west row. The ground surface consisted of clay soil with moderate grass cover. Flat panels with open sides provided treatment only in the horizontal plane above the black globes. Unvented boxes provided treatment in the horizontal plane above and in four vertical planes around the globe. The plywood pallet provided the floor plane below the globes used with the panels. Foamboard was installed as the floor of the styrofoam boxes. The flat panels provided exposure for approximately 25 to 33% of the globe’s surface area (field of vision) while the boxes provided approximately 66 to 75%.

**UNINSULATED GALVANIZED ROOF PANELS**

Three horizontal panels 61 cm × 61 cm × 30.5 cm (24 in. × 24 in. × 12 in.) were constructed using standard 5-V galvanized steel roofing (fig. 1). The term 5-V describes the corrugation design. Each sheet has two inverted V-shaped corrugations at each edge for overlap with the adjacent panel. A fifth inverted vee is located between the edges. Two panels were treated while the mill finish of one untreated panel served as the control. A CRC labeled Aztec No. 100 was used as the primary treatment. A white roofing paint primer (WPC) was used as a white surface comparison treatment.

**INSULATED ROOF PANELS**

Two flat insulated panels were constructed by adding 1.9 cm (0.75 in.) thick (R-3.8) styrofoam insulation board under the 5-V galvanized steel (fig. 1). One panel was treated with CRC while the other remained untreated (mill finish) and served as a control. A WPC treatment was not included. For additional comparison, both the CRC treated and the insulated control were compared to the uninsulated control. The ends of all flat test panels remained open.
GALVANIZED STEEL BOX
Three, five-sided 41 cm × 41 cm × 41 cm (16 in. × 16 in. × 16 in.) boxes (fig. 2) were constructed of galvanized sheet steel. Treatments consisted of WPC and CRC surface applications while an untreated (mill finish) galvanized steel box provided control. The steel boxes were used to test the hypothesis regarding the application to uninsulated metal building shells.

STYROFOAM BOX
Two, five-sided 41 cm × 41 cm × 41 cm (16 in. × 16 in. × 16 in.) boxes (fig. 2) were constructed of 1.9 cm (0.75 in.) thick R-3.8 styrofoam insulation board. The material was identical to that used for the flat insulated panels. One box was coated with CRC while an untreated box provided control. A WPC treatment was not included. Unventilated styrofoam insulation board boxes were designed to test the hypothesis that an insulated building shell would negate the effect of surface treatments.

STEEL BUILDING
An open-side, steel-shell poultry building was used to compare the effect of the CRC to an untreated control. The building measured 12 m × 24 m (40 ft × 80 ft) with an 2.4 m (8 ft) eaves height. A cross wall divided the building at its midpoint into two 12 m × 12 m (40 ft × 40 ft) sections. The east section was treated with the CRC while the weathered galvanized steel surface of the west section provided control. The earth floor was covered with chicken litter. Ridge vents and a 4:12 slope were features of the galvanized steel gabled roof. Foamboard attached to the bottom side of the steel frame formed a ceiling.

PROCEDURE
Ambient air DBT was measured using thermocouple sensors shielded from exposure to direct sun and sky. Black globe thermometers provided an indication of the radiant temperature (and indirectly the radiant heat load) under panels and within the box enclosures. Thermocouples were used to measure air DBT within the confined space of the boxes. The data logger sampled all sensors once per minute and averaged and recorded at 30-min intervals. Data were recorded from August to December, 1990. Selected periods were evaluated during warm weather (summer) and during cooler weather (winter).

Temperatures during hours of peak solar insolation were of primary interest during summer trials. High ambient temperatures with peak solar radiation tested the ability of surface treatments to resist heat gain and provide cooler interior environments. Night hours were of special interest during cool weather trials. Conditions of cold ambient temperatures and negative ambient radiation tested the ability of the surface treatment to resist heat loss.

Black globe and dry-bulb temperature sensors were used to evaluate the thermal environment near the floor of the poultry building. The trial was conducted during the warm summer, comparing the east (CRC treated) and west sections of the building.

The emissivity of a clean, newly treated CRC surface was determined using an infrared thermometer. The determination was based upon equalizing the actual temperature of treated and blackbody surfaces exposed only to longwave and to diffuse shortwave radiation. Radiant temperatures measured by the infrared thermometer differed only due to emissivity. Equal temperature was attained by treating opposite sides of a single panel of sheet steel using CRC and a calibrated blackbody coating. The calibrated blackbody coating produced a surface having a known emissivity of 0.95. Thermal equilibrium between the panel and its surroundings was maintained during temperature readings. The true temperature of the blackbody was read first with an emissivity of 0.95 input to the infrared thermometer. The CRC surface emissivity was determined by varying the emissivity value input to the infrared thermometer until the true temperature reading was obtained.

Using procedures described by Iqbal (1983), the reflectivity of a clean horizontal CRC treated steel panel was determined using a flat surface pyranometer. The determination was made at 1:00 p.m. EST, 13 November 1991, with clear sunny weather. Pyranometer measurements of reflected radiation were compared to the measured incoming direct radiation. The resulting ratio was an approximation of the reflectivity of the CRC surface.

RESULTS AND DISCUSSION
SUMMER TRIALS
Julian Day 250, 7 September 1990, was chosen for evaluation representing warm season conditions. Julian Day 250 was characterized by a maximum ambient dry-bulb temperature of 36.8° C (98.3° F) and an afternoon rain shower at the test site. An official maximum temperature of 34.4° C (94° F) and 0.23 cm (0.09 in.) of precipitation was recorded at the Clemson University weather observation station.

Table 1 summarizes average temperature variations above ambient DBT for 13 daylight hours and 7 peak solar radiation hours. Figures 3 through 6 present the period 08:00 hours to 20:00 hours with the rain event obvious at 16:30 hours. Figure 7 repeats the data of figure 6 and extends the plot to a full 24-h period including the morning hours of Julian Day 251.

Uninsulated Galvanized Roof Panels. The CRC treatment was discernible with uninsulated roof panels (fig. 3 and table 1). Seven-hour DBT averages were compared. The control (mill finish) displayed an average rise of 5.7° C (10.2° F) compared to 5.4° C (9.8° F) and 4.8° C (8.7° F) for WPC and CRC surface treatments, respectively. Thus, the CRC treatment reduced radiant heating under the panel only 0.83° C (1.5° F) compared to the control and to the WPC panel.

Insulated Galvanized Roof Panels. Figure 4 and table 1 indicate no discernible temperature difference between the insulated control and CRC treated insulated panel. Each panel displayed an average 7-h BGT rise of 5.8° C (10.6° F) above ambient DBT. The uninsulated control displayed a rise of 5.7° C (10.2° F).

The uninsulated CRC treatment displayed a slight advantage over the insulated CRC treated panel as well as the WPC uninsulated panel and both controls. However, implementation of the sensor in an open side apparatus must be considered. The effect of the adjacent area
Table 1. Temperature rise above ambient dry bulb

<table>
<thead>
<tr>
<th>Treatment</th>
<th>8:00 - 20:00 Avg. $\Delta T$</th>
<th>10:00 - 16:00 Avg. $\Delta T$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-V Galv. Panels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galv BGT *</td>
<td>4.1</td>
<td>5.7</td>
</tr>
<tr>
<td>WPC BGT</td>
<td>3.8</td>
<td>5.4</td>
</tr>
<tr>
<td>CRC BGT</td>
<td>3.5</td>
<td>4.8</td>
</tr>
<tr>
<td>5-V Panel + Styro</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galv BGT *</td>
<td>4.1</td>
<td>5.7</td>
</tr>
<tr>
<td>Galv Insul BGT *</td>
<td>4.2</td>
<td>5.9</td>
</tr>
<tr>
<td>CRC Insul BGT</td>
<td>4.4</td>
<td>5.9</td>
</tr>
<tr>
<td>Galv Steel Box</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Galv BGT *</td>
<td>5.1</td>
<td>8.2</td>
</tr>
<tr>
<td>Galv Insul BGT *</td>
<td>5.6</td>
<td>9.1</td>
</tr>
<tr>
<td>CRC Insul BGT</td>
<td>5.0</td>
<td>1.4</td>
</tr>
<tr>
<td>Foam Box</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Foam BGT *</td>
<td>6.4</td>
<td>10.3</td>
</tr>
<tr>
<td>Foam DBT *</td>
<td>5.2</td>
<td>8.7</td>
</tr>
<tr>
<td>CRC BGT</td>
<td>1.7</td>
<td>3.3</td>
</tr>
<tr>
<td>CRC DBT</td>
<td>1.2</td>
<td>2.7</td>
</tr>
</tbody>
</table>

* Control treatments

CRC Ceramic coat  DBT  Dry bulb temperature
WPC White paint coat BGT  Black globe temperature
5-V Galvanized steel roof Styro  Styrofoam board
Summer trial, Julian Day 250, 1990

(ground, grass, and other structures and objects) diluted the effect of the test panel on the measured BGT. Such a small difference (approximately 1° C (1.8° F)) may be spurious. Therefore, only ventilated structures without insulation or radiation shielding may experience a significant reduction in internal temperatures due to exterior surface treatments. If insulation or radiation shielding is part of the building system, the effect of exterior surface treatments may be indiscernible.

Galvanized Steel Boxes. Table 1 presents 7-h averages for treatments and control. CRC black globe and dry-bulb temperatures rose only 1.4°C (2.5° F) and 1.8°C (3.3° F), respectively. Corresponding BGT and DBT averages for the WPC treatment ran 5.1°C (9.2° F) and 5.7°C (10.2° F), respectively, and 8.2°C (14.7° F) and 9.1°C (16.3° F) for the control. The success of the CRC treatment in reducing temperatures of the interior space is evident in

---

**Figure 3—Galvanized uninsulated panels.**

**Figure 4—Galvanized insulated panels.**

**Figure 5—Galvanized steel boxes.**

**Figure 6—Styrofoam boxes.**
The explicit effect of the CRC treatment on the steel box may be due to the large percent of the globe surrounding provided by the box. In addition, lack of ventilation within the box allowed heat to accumulate. The data provides incontrovertible evidence that the CRC treatment is effective in resisting heating due to solar radiation incident on an unvented uninsulated shell.

The DBT within the steel boxes slightly exceeded the black globe temperature within the same space during day hours. This result was unexpected and may have resulted from inaccuracies of the extension grade thermocouple wire. A thermal diode created by the relative emissivities of the black globe and the interior surface of the metal box is a possible explanation.

Styrofoam Board Boxes. The CRC treatment was found to be effective in reducing black globe and dry-bulb temperature rises above ambient DBT within the unvented styrofoam box (figs. 6 and 7). Average 7-h black globe and dry-bulb temperature rises above ambient DBT were 10.3°F (18.5°C) and 8.7°F (15.6°C), respectively. Corresponding rises for the control were 3.3°F (5.9°C) and 2.7°F (4.8°C) (table 1). Thus, the CRC treatment was effective with the insulated box although less effective than with the CRC-treated galvanized steel box. The former was contrary to the initial hypothesis while the latter was unexpected. The insulated floor may have aided heat accumulation within the styrofoam box.

Figure 7 extends data from the styrofoam box (fig. 6) to a 24-h period. As expected, all internal black globe and dry-bulb temperatures equalize with ambient DBT without incident solar radiation.

WINTER TRIALS

Responses were measured, recorded, and analyzed for cooler weather using the same panels, boxes, treatments, and controls as during the warm weather trials. The CRC surfaces were no longer new and clean. Dust and other contaminates had produced a surface having a tarnished, off-white appearance. Night hours were of special interest because the effect of cooler temperatures on performance of the treatments were of primary interest. Figures 8 and 9 describe the temperatures related to the uninsulated and insulated roof panels, respectively. The panels also show responses during night hours similar to corresponding hours during summer trials (fig. 7). Figures 10 and 12 describe the temperatures related to the galvanized steel...
Dry Bulb and Black Globe Temperatures
Winter Trial, Julian Days 334/335, 1990

Figure 11—Galvanized steel box and 12 h of data.

Figure 13—Styrofoam box and 16 h of data.

and styrofoam boxes, respectively. During daylight, relative performances of treatments and controls were similar in all cases to the summer trials.

All figures (8, 9, 10, and 12) show a definite change in the temperature characteristics beginning near 05:00 hours on Julian Day 335. The unknown cause is referred to as an event. The pre-event performance of the styrofoam and galvanized steel boxes differ from the post-event performance (figs. 10 and 12). Figures 11 and 13 detail the pre- and post-event performance differences for figures 10 and 12, respectively, by concentrating on the 21:00 to 9:00 hours interval and increasing the temperature scale.

Temperatures within the steel box (control) slightly exceeded ambient DBT during the pre- and post-event period. However, the WPC and CRC treatments were suppressed below the ambient DBT during the pre-event period. During the post-event period the treatment temperatures rose slightly above ambient DBT and equalled the control (fig. 11). Figure 13 reveals performance by both styrofoam boxes to be similar to that of the WPC- and CRC-treated galvanized steel boxes. A probable explanation is the existence of clear sky before the event and cloud or fog cover during the post-event hours.

The reaction of the experimental apparatus to the event affirms the sensitivity of the unsophisticated sensors to environmental changes. The pre-event versus post-event performance is evidence of high emissivity of the treatment surfaces. The depressed temperatures during the pre-event period are very similar to that of a blackbody and black globe thermometer. The combination of high reflectivity and high emissivity could theoretically lead to colder surface temperatures and increased heat loss during cold clear nights. Results of the laboratory tests of CRC characteristics are discussed below.

An additional observation is noted from figures 10 and 11. During the night hours of the winter trial, the black globe temperature exceeded the DBT within the steel box enclosure. This reaction is opposite that observed during the summer trials. While this phenomenon is not the subject of the research, the response is both interesting and unexplained.

STEEL BUILDING TRIAL

Dry-bulb and black globe temperatures near the floor of the steel poultry building did not differ between the control and CRC-treated ends of the building. Failure to detect a difference between black globe temperatures measured near the floor of the respective ends of the building may be due to shielding by the ceiling. All surfaces, insulated or not, act as radiation shields. The ceiling within the building would intercept and absorb radiation emitted by the underside of the hot roof. The ceiling would reflect and re-emit part of the heat energy back to the roof.

An internal radiation shield has the potential to negate the effects of a marginal radiant heat load from a roof to the floor below. The roof of an open-side building accounts for only part of the total radiant heat incident on an object near the floor. The percent of the surrounding represented by the roof depends upon the building width, height, and sensor location. Results obtained with the poultry building are consistent with results of trials using the horizontal test panel.
CRC CHARACTERISTICS

The emissivity of a clean, newly applied CRC surface was found to be equal to that of the calibrated surface (0.95). Thus, the CRC surface will readily re-emit energy, thereby cooling the material to which it is applied. The reflectivity of a clean CRC-treated steel roof panel was determined to be 0.87. This degree of reflectance compares to 0.85 for aluminum, 0.46 for aluminum paint, 0.35 for new galvanized steel, and 0.08 for very dirty galvanized steel. The CRC treatment creates a surface exhibiting good heat dissipation via a high emissivity and good resistance to radiant heating via high reflectivity. Performance should degrade with time as the surface acquires dust and other contaminants.

CONCLUSIONS

The following conclusions were drawn:
1. The CRC surface treatment is most effective when applied to an uninsulated metal shell building. Uninsulated open-sided buildings and shade canopies may be appropriate applications for the CRC.
2. The CRC exhibits high emissivity and high reflectance when clean. These characteristics could lead to increased heat loss during cold, clear sky conditions.
3. The effect of and the need for the CRC treatment may be negated or reduced by ventilation and intervening thermal barriers, respectively. Ventilation appears to be the most important variable.
4. Enclosed buildings dependent upon air conditioning may be more likely to benefit than open, well-ventilated structures with non-recirculating ventilation systems.
5. Effectiveness of the WPC treatment was similar to but not equal that of the CRC treatment.

REFERENCES