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SELECTIVE PAINT DEVELOPMENT

Technical Progress Report, December 5, 1978—July 31, 1979

By
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August 1979

MASTER

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Honeywell
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Minneapolis, Minnesota

U.S. Department of Energy

Solar Energy

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TECHNICAL PROGRESS REPORT

For the period 5 December 1978 - 31 July 1979

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AUGUST 1979

Prepared for
The Solar Heating and Cooling
Research and Development Branch,
Office of Conservation and Solar Applications
United States Department of Energy

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FOREWORD

This is the second technical progress report describing the paint coatings work performed at Honeywell Inc., Systems and Research Center, for U.S. Department of Energy under Contract No. DE-AC04-78CS14287. The work has been supported by the Solar Heating and Cooling Research and Development Branch, Office of Conservation and Solar Applications, U.S. Department of Energy. The contract also includes black chrome development, which has been completed and the Final Report will be submitted separately.

The authors acknowledge the guidance provided by Mr. Stanley W. Moore of Los Alamos Scientific Laboratory, who is the Project Monitor.

Dr. R.J.H. Lin is the Project Principal Investigator. The paint coating work was performed by W.D. McKelvey, P.B. Zimmer, G.W. Nelson, R.L. Bentley, and W. Polec.

ABSTRACT

Eighteen hundred square feet of aluminum foil were coated with thickness-sensitive selective paint. The feasibility of a high speed, large-scale roller coating technique was demonstrated. Coating thermal stability, weathering and humidity resistance, and effects of pigment particle size on coating optical properties were studied. Thickness-insensitive paint with urethane binder was evaluated. A medium scale (1 kg) of thickness-insensitive paint solution was prepared which achieved an α_s of 0.90 and ϵ of 0.35.

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SECTION I

INTRODUCTION AND SUMMARY

INTRODUCTION

The objective of this program is to improve the performance of and to develop large-scale application techniques for solar selective paint coatings.

Selective paints with solar absorption (α_s) of 0.92 and emittance (ϵ) of 0.10 have been developed by Honeywell in a previous program for DOE (Reference 1). In the last reporting period of the present program, the abrasion resistance of the selective paints was significantly improved. A thickness-insensitive paint with $\alpha_s = 0.90$ and $\epsilon = 0.30$ which can be applied to any substrate, including non-metallic, has also been developed (Reference 2). In this reporting period, efforts have concentrated on durability testing and development of large-scale production.

SUMMARY

Eighteen hundred square feet of aluminum foil were coated with thickness-insensitive selective paint. The best optical properties are $\alpha_s = 0.90$ and $\epsilon = 0.25$. It was demonstrated that a high speed, large-scale roller coating technique is capable of producing a uniform, several micron-thick paint coating, which is the key factor in achieving the required low emittance. Optical properties will be further optimized.

Coating thermal stability, weathering and humidity resistance, and effects of pigment particle size on coating optical properties were studied. New inorganic pigments were tested but were found not to achieve the required optical performance.

Thickness-insensitive paint with urethane binder was evaluated. The optical performance of this formulation is not as good as that using silicone binder. Abrasion resistance was also tested for thickness-insensitive paint using various binders and aluminum flakes. A medium-scale (1000 gm) of thickness-insensitive paint solution was prepared which achieved an α_s of 0.90 and ϵ of 0.35.

SECTION II

THICKNESS SENSITIVE PAINTS

In this reporting period, paint coating development has concentrated on investigating coating thermal stability, new pigments, solution stability, pigment particle size, and large volume scale-up demonstration.

PAINT COATING PREPARATION

Experimental paint coatings were formulated using conventional paint coating techniques. Appropriate quantities of pigment and binder were combined with solvent to achieve the desired pigment volume concentration (PVC). The mixtures were ball milled using high density Al_2O_3 grinding media in polyethylene bottles to minimize contamination. During milling, pigment agglomerates are reduced to smaller agglomerates and discrete particles. Milled paint solutions were then either applied by spraying or dipping to clean aluminum substrates, cured and measured for optical properties.

MEASUREMENTS OF OPTICAL PROPERTIES

Solar absorptance was measured with a Gier-Dunkle MS-251 solar reflectometer and emittance with a Gier-Dunkle DB-100 infrared reflectometer without a filter to provide emittance values at 100°C.

THERMAL STABILITY

Outgassing of absorber paints is a potential problem for collectors. The thermal stability of urethane and silicone binder materials, which were used in selective paints, were tested to evaluate their temperature limits of

application.

A new one-component aliphatic urethane was developed by Deft Chemical and designated (03-X-59). This material is composed of urethane components very similar to the two-component urethane (MIL-C-83286), except reaction sites are chemically blocked until a temperature of 225°F is reached, at which time curing occurs. A study of binder weight loss as a function of temperature was performed on both one and two-component urethanes. The tests were run with coatings on thin sheets of aluminum to provide maximum surface area. It is evident from Figures 1 and 2 that both materials fail to reach a minimum weight loss quickly at any temperature. The one-component urethane (03-X-59) does reach thermal stability faster, but color degradation above 250°F occurred.

Because both aliphatic urethanes have failed to reach minimum weight loss quickly, a heat treating schedule was explored. The schedule employed heating at 400°F for 30 minutes prior to thermal exposure. Figures 3 and 4 show the results after the short period of heating. The two-component urethane (MIL-C-83286) shows no weight loss from exposure to 250°F. The one-component urethane (03-X-59) is thermally stable with no weight loss from exposure to 225°F with slight weight loss at temperatures above 225°F. A slight color degradation also appeared for the one-component urethane. These maximum temperatures for the binders before weight loss begins are compatible with the average working temperature of a typical flat plate collector at 200°F. In conclusion, heat treating the binder prior to thermal exposure minimizes weight loss which could occur.

Weight loss tests were also made on silicone binders. These materials have been used extensively throughout the solar coating development. Silicone binder SR-125 (General Electric), and DC-808 (Dow Corning) were exposed to temperatures of 350-500°F. The silicones show excellent thermal stability below 400°F, but begin to lose weight at elevated temperatures as shown in Figures

FIGURE 1. WEIGHT LOSS VS HIGH TEMPERATURE EXPOSURE FOR DEFT CHEMICAL URETHANE (MIL-C-83286) CURED FOR 24 HOURS AT 70°F AND NO HEAT TREATMENT

FIGURE 2. WEIGHT LOSS VS HIGH TEMPERATURE EXPOSURE FOR DEFT CHEMICAL URETHANE (03-X-59)
CURED FOR 24 HOURS AT 70°F AND NO HEAT TREATMENT

FIGURE 3. WEIGHT LOSS OF DEFT CHEMICAL (MIL-C-83286) TWO COMPONENT URETHANE BINDER AFTER BEING CURED 24 HOURS AT 70°F THEN HEAT TREATED ½ HOUR AT 400°F

FIGURE 4. WEIGHT LOSS OF DEFT CHEMICAL (03-X-59) ONE COMPONENT URETHANE BINDER AFTER BEING CURED 24 HOURS AT 70°F THEN HEAT TREATED $\frac{1}{2}$ HOUR AT 400°F

5 and 6. The silicone binders would still be compatible to the work temperature of the collector.

ABRASION RESISTANCE

The abrasion resistance of thickness-sensitive solar selective paint coatings was evaluated. A series of thickness - sensitive coatings were prepared having PVC's ranging from 20 - 30; 23 and 28 percent solids; and were coated at dip rates of 2 and 4 inches/min. Optical properties were measured before and after exposure to abrasion. The abrasion test consisted of rubbing cheesecloth over the coated surfaces for 1750 cycles. The cheesecloth was in layers over a stiff bristle brush under 4.4 oz/in². A comparison was made using 30 PVC F-6331 formulated with urethane and silicone binders. The data is recorded in Table 1. It is evident from Table 1 that 30 PVC F-6331/urethane coatings offer the best resistance to abrasion exposure, although, their original optical properties are not as good as the silicone coatings. It can be seen that the silicone binder DC-808 fails abrasion resistance exposure which is apparent from a solar absorptance loss of 0.60. The SR-125 binder offers the best overall optical properties.

Table 1 also shows a comparison studied on F-6331/SR-125 coatings consisting of PVC's of 30, 26 and 20; percent solids of 28 and 23; and dip rates of 2 and 4 inches/min. The 26 PVC coating at 23 percent solids and dip rate of 2 inches/min shows the best abrasion resistance of those tested. The change in solar absorptance was 0.03 and emittance 0.01 after 1750 cycles of abrasion.

FIGURE 5. WEIGHT LOSS VS HIGH TEMPERATURE EXPOSURE FOR GENERAL ELECTRIC SR-125
CURED FOR 1 HOUR AT 500°F

FIGURE 6. WEIGHT LOSS VS HIGH TEMPERATURE EXPOSURE FOR DOW CORNING DC-808
CURED FOR 1 HOUR AT 500°F

TABLE 1. OPTICAL PROPERTIES OF SOLAR SELECTIVE THICKNESS-SENSITIVE PAINT COATINGS BEFORE AND AFTER 1750 CYCLES OF ABRASION¹

Coating	Percent Solids	Dip Rate inches/min	Before		After	
			α_s	ϵ	α_s	ϵ
30 PVC F-6331/Urethane	28	2	.88	.21	.88	.21
	28	4	.88	.26	.90	.27
	23	2	.86	.11	.89	.12
	23	4	.87	.15	.90	.16
30 PVC F-6331/DC-808	28	2	.87	.08	.74	.18
	28	4	.90	.17	.88	.25
	23	2	.83	.04	.24	.04
	23	4	.87	.07	.26	.10
30 PVC F-6331/SR-125	28	2	.91	.11	.88	.15
	28	4	.91	.18	.88	.22
	23	2	.89	.06	.85	.08
	23	4	.90	.08	.87	.11
26 PVC F-6331/SR-125	28	2	.92	.28	.89	.30
	28	4	.93	.37	.90	.39
	23	2	.91	.12	.88	.13
	23	4	.92	.18	.89	.20
20 PVC F-6331/SR-125	28	2	.88	.21	.88	.21
	28	4	.88	.26	.90	.27
	23	2	.86	.11	.89	.12
	23	4	.87	.15	.90	.16

1 Gardner Straight Line Washability and Abrasion

NEW PIGMENTS

An effort was made to develop a backup pigment to replace F-6331. Two candidates were evaluated; CrO_2 from DuPont and L 5062-2-1 from Harshaw. The chromium dioxide (CrO_2) pigment has a needle shape and is a dipole capable of being magnetically oriented perpendicular to the substrate. It was believed that oriented particles would act as a light trap by absorbing incident radiation.

A coating of 30 PVC CrO_2 /urethane was formulated with a particle size of 2 - 4 μm . The coating was applied by spray to aluminum substrates and placed beneath magnets for orientation while curing. Optical properties were measured for both magnetic and non-magnetic oriented coatings. Results are recorded in Table 2.

It was believed that larger particle size would enhance attraction of particle-to-magnetic orientation and create a more efficient light trap. A 30 PVC CrO_2 /urethane coating was formulated with 40 - 50 μm pigment particle size. Results from Table 2 show that high absorptance was achieved, but emittance remained unacceptable.

A coating of 50 PVC CrO_2 /urethane was prepared in an attempt to reduce the urethane binder and thus improve emittance. Hopefully, this would give the CrO_2 pigment more versatility for being magnetically oriented. Solar absorptance was improved but emittance remained unacceptable which is evident from Table 2.

The high emittance of CrO_2 pigment was an indication that it was not as

TABLE 2.
OPTICAL PROPERTIES OF MAGNETICALLY ORIENTED
CrO₂/URETHANE SELECTIVE PAINT COATINGS

SELECTIVE COATING	COATING THICKNESS ¹	MAGNETIC		NORMAL	
		α_s	ϵ	α_s	ϵ
30 PVC CrO ₂ (2-4 μ m)	Light	.75	.71	.83	.77
	Medium	.76	.71	.87	.80
	Wet	.87	.81	.92	.84
30 PVC CrO ₂ ~(40-50 μ m) ²	Light	.90	.84	.91	.82
	Medium	.91	.83	.91	.83
	Wet	.91	.83	.92	.82
50 PVC CrO ₂ (10-12 μ m) ²	Light	.93	.84	.93	.83
	Medium	.93	.84	.93	.83
	Wet	.93	.84	.93	.83

¹ Application done by spray.

transparent in the infrared region as believed. This was verified by comparing the transmittance of CrO_2 and F-6331 pigments of (2.5 - 50 μm) on the Perkin-Elmer Model 457 spectrophotometer. The CrO_2 pigment was shown to be 1/4 as transparent as F-6331, which accounts for the high emittance value. As a result of these tests, CrO_2 pigment has been eliminated as a possible candidate for low-cost, high-performance solar paint coatings.

A 28 PVC L 5062-2-1/SR-125 paint coating was formulated and dip applied at rates of 1 - 5 inches/min. The coating was evaluated for optical properties and compared to the 28 PVC F-6331/SR-125. As can be seen from Table 3, the coating using L 5062-2-1 pigment offers very good infrared emittance compared to the coating using F-6331 pigment, although, solar absorptance is about 30% lower. Harshaw is attempting to improve their material by increasing solar absorptance and keeping emittance low. New samples have been received and will be evaluated.

EFFECT OF PIGMENT PARTICLE SIZE

Solar paint coatings have been prepared by ball milling procedures to reach a maximum particle size (grind) of 2 - 4 μm . An investigation was performed to relate particle size to optical properties at different dipping rates. According to Table 4, it can be seen that there is no need to achieve a grind of 2 - 4 μm to get good optical performance. As particle size increases, solar absorptance also increases, which will rebalance the optical efficiency due to high emittance values.

COATING THICKNESS

Solar paint coatings developed to date are very dependent on coating thickness. A special dip coating machine provides control of the test panels into and out of the coating solution with a smooth, uniform motion. The coating is so

TABLE 3. COMPARISON OF OPTICAL PROPERTIES OF 28
PVC F-6331/SR-125 AND 28 PVC L-5062-2-1/
SR-125 PAINT COATINGS

Dip Rate, In/Min	F-6331 Coating		L-5062-2-1 Coating	
	α_s	ϵ	α_s	ϵ
1	.92	.32	.65	.12
	.92	.28	.61	.08
2	.93	.36	.63	.10
	.93	.36	.63	.09
3	.93	.40	.66	.10
	.93	.40	.65	.11
4	.93	.42	.67	.13
	.93	.42	.66	.13
5	.94	.44	.68	.15
	.94	.44	.70	.16

TABLE 4.

EFFECTS OF VARIOUS PARTICLE SIZES OF
30 PVC F-6331/SR-125 ON OPTICAL PROPERTIES

APPLICATION TYPE	OPTICAL PROPERTIES FOR EACH PARTICLE SIZE									
DIP RATE (in/min)	2 μ m		6 μ m		10 μ m		13 μ m		20 μ m	
	α_s	ϵ	α_s	ϵ	α_s	ϵ	α_s	ϵ	α_s	ϵ
1	.90	.14	.91	.16	.91	.17	.92	.19	.92	.20
	.90	.12	.90	.11	.91	.11	.92	.15	.92	.14
2	.90	.10	.91	.13	.91	.13	.92	.16	.92	.15
	.90	.11	.91	.13	.91	.13	.92	.16	.92	.16
3	.90	.13	.91	.16	.92	.16	.92	.17	.92	.19
	.90	.12	.91	.18	.92	.17	.92	.19	.92	.20
4	.90	.16	.91	.21	.92	.21	.92	.22	.93	.22
	.90	.17	.91	.21	.92	.21	.92	.22	.93	.23
5	.90	.22	.91	.25	.92	.27	.92	.25	.93	.27
	.90	.22	.91	.25	.92	.26	.92	.27	.93	.27

thin (~ 0.1 mil) that the eddy current thickness tester cannot measure it. Two alternate methods were used for measuring the thickness of 30 PVC F-6331/SR-125 solar paint coating with a dip rate of 2 inches/minute. The light shadow method, using an optical microscope, gave a thickness of 0.086 mil ($2.18 \mu\text{m}$). SEM analysis of a cross-section view reported an average thickness of 0.088 mil ($2.24 \mu\text{m}$). The average thickness is reported as 0.087 mils ($2.21 \mu\text{m}$).

SOLUTION STABILITY

A test was performed to determine the rate that $10 \mu\text{m}$ particles are settling from the coating solution. The settling rate of a 26 PVC F-6331/DC-808 coating was determined. This was accomplished by periodically measuring the solids content of the coating 1/2 inch from the top of a 6-inch deep container. The pigment density is 4 - 5 times that of the binder and tends to settle first. The change in solids as a function of time would thus provide a rough measure of settling. It is evident that further improvement is needed to reach the goal of no appreciable settling in eight hours. Figure 7 shows the percent solids settled beginning at 25 percent as a function of time. After eight hours of settling, 4.5% solids had settled from solution. Significant streaking of the coating was observed when applied to substrates. With the use of an agitation system such as pumps, vibrators or stirrers, the problem of settling can be minimized.

A study was performed on the effect that settling of the solar absorbing pigment particles has on optical performance. The paint coating investigated was a thickness-sensitive 30 PVC F-6331/SR-125 (25% solids) milled to $8 \mu\text{m}$ particle size. The paint coating was left standing without any agitation or stirring for 8 hours, at which time, it was applied to 1" x 2" aluminum panels. Optical properties were measured before and after eight hours of settling and are shown in Table 5. Lower emittance values were obtained

FIGURE 7. RATE OF SETTLING OF 26 PVC F-6331/DC-808 SOLAR
SELECTIVE PAINT BEGINNING AT 25% SOLIDS

TABLE 5. OPTICAL PROPERTIES OF 30 PVC F-6331/SR-125 BEFORE AND AFTER 8 HOURS OF SETTLING

Dip Rate inches/min	Optical Properties			
	Before		8 Hours	
	α_s	ϵ	α_s	ϵ
2	.91	.20	.89	.17
3	.91	.22	.89	.14
4	.92	.28	.92	.27
5	.93	.31	.93	.23

after settling because of lower percent solids in the solution and thus resulted in thinner coatings.

WEATHER AND HUMIDITY RESISTANCE

The weathering durability of thickness-sensitive paint coatings was evaluated. The etched aluminum substrates used for the coating surface were etched with sodium hydroxide (caustic soda) at various exposure rates to improve coating adhesion. A 30 PVC F-6331/SR-125 solar paint coating was applied by dip coating at 4 in/min. Accelerated weathering and humidity exposure were utilized to determine durability. The results are shown in Tables 6 and 7.

From Table 6 it can be seen that after 3051 hours of accelerated weathering, the only dramatic change in optical properties was in emittance. Emittance increases of 13% for unetched and of 7-12% for etched substrates was observed. Solar absorptance remained fairly constant, changing only 2 - 8%. Longer etch times correlate well with greater changes in α_s and ϵ . It is apparent that etching will improve coating adhesion. Substrates show good resistance to humidity exposure as can be seen from Table 7. It should be noted that these tests are very severe since no protective cover glass was used during exposure.

DURABILITY OF FOIL/ADHESIVE/SUBSTRATE SYSTEM

Small scale samples have been exposed to accelerated weathering to evaluate potential corrosion of the aluminum foil-adhesive-steel interfaces. After 864 hours of testing no corrosion of the steel substrate or the aluminum foil could be detected. Investigation of adhesive thickness variations and edge effects, as well as further environmental testing is needed to verify commercial and residential applicability of the system. The effect of pinholes in

TABLE 6. OPTICAL PROPERTIES OF 30 PVC F-6331/SR-125 AFTER ACCELERATED WEATHERING¹

Etching Time, Min.	EXPOSURE ² (HOURS)							
	Before		809		2288		3051	
	α_s	ϵ	α_s	ϵ	α_s	ϵ	α_s	ϵ
0	.91	.23	.90	.31	.90	.34	.89	.36
5	.91	.15	.90	.18	.88	.23	.88	.23
7	.91	.15	.89	.18	.85	.25	.84	.25
9	.91	.16	.90	.21	.88	.29	.85	.28
11	.91	.16	.90	.20	.90	.24	.89	.24
13	.91	.15	.89	.18	.88	.22	.88	.22
15	.91	.15	.89	.19	.85	.22	.80	.22
20	.91	.16	.90	.18	.89	.23	.87	.23
25	.91	.16	.89	.18	.87	.26	.85	.26
30	.91	.16	.89	.20	.87	.27	.84	.28

1 Atlas Twin Arc Weather-O-Meter, Model XVDL, accordance with Federal Test Method Standard 141, Method 6152.

2 500 Hours of Accelerated Weathering Approximately Equals Three Years of Exterior Exposure

TABLE 7. OPTICAL PROPERTIES OF 30 PVC F-6331/SR-125
AFTER HUMIDITY TEST¹

Etching Time, Min.	EXPOSURE (HOURS)							
	Before		816		2304		4968	
	α_s	ϵ	α_s	ϵ	α_s	ϵ	α_s	ϵ
0	.91	.23	.90	.23	.89	.25	.89	.29
5	.91	.15	.90	.15	.89	.15	.89	.19
7	.91	.15	.90	.16	.90	.16	.89	.17
9	.91	.16	.90	.16	.90	.16	.89	.17
11	.91	.16	.90	.17	.90	.18	.88	.23
13	.91	.15	.89	.16	.89	.16	.89	.17
15	.91	.15	.90	.16	.90	.20	.89	.17
20	.91	.16	.90	.17	.90	.18	.90	.20
25	.91	.16	.90	.18	.90	.18	.90	.17
30	.91	.16	.89	.16	.90	.20	.90	.33

¹ MIL-STD-810B Humidity Test

the adhesive layer must also be determined.

SCALE UP OF FOIL COATING PROCESS

A large volume scale-up of a 26 PVC F-6331/DC-808 paint coating was made. In all, 1800 sq. ft. (2 ft. x 900 ft.) of aluminum foil in roll form was coated. The purpose of this pilot production was to provide optical data and demonstrate the feasibility for commercial application techniques. United Coating and Laminating, Inc., St. Paul, performed the operation using their Revaplast Reverse roll laminator manufactured by the Bruderhaus Company.

Process

The laminating process involved coating the aluminum foil by a reverse-roll technique. The coating roller was rotating continuously in a paint trough to a depth of 1/8 inch. The trough held a maximum of 3 gallons to a depth of 3 inches. Because there was no agitation in the trough, sedimentation of the (8 μ m) solar selective pigment soon became a problem. A concentration gradient developed causing a binder enriched coating layer on top. Due to the fairly low infrared transparency of the binder, emittance values tend to be high. This does not check with the settling test reported earlier where the emittance decreased. This is due to the thickness the paint coating was applied, which limits the show-through of the low emitting aluminum foil substrate. This was the first and major problem that occurred. After the aluminum foil was coated, it continued on through an 18 foot long oven with a maximum curing temperature of 270°F. The Dow Corning DC-808 silicone binder requires a cure temperature of 500°F for 1 hour. Therefore, the oven acted only as a solvent removal chamber and not a curing oven. Although this was known in advance, the sole purpose was to demonstrate the feasibility for commercial application. The coated aluminum foil was cured in the laboratory. It was noted that after curing, emittance was improved about 3%.

Thickness

The minimum thickness control setting on the coating machine was 1 mil. Optical properties were shown to be unacceptable at that thickness, therefore, the roller was adjusted manually until the paint coating looked visually acceptable. Although the thickness was unknown, it was held constant throughout the process.

Results

Table 8 contains the optical properties of coated foil for various coating rates and concentrations. The coating applied at 65 ft/min using a 17.3% solids paint formulation showed the best optical properties, $\alpha_s = 0.90$ and $\epsilon = 0.25$, but because of settling and thickness control problems, no specific trends can be seen. The large scale effort did show the feasibility of producing a coating which is thin enough to result in acceptable emissivities. Future work will concentrate on optimizing the optical properties of the coatings and on developing a method of applying a low-cost pressure sensitive adhesive to the back of the aluminum foil.

TABLE 8. OPTICAL PROPERTIES FROM A PILOT SCALE-UP PRODUCTION
OF A SELECTIVE SOLAR PAINT ON ALUMINUM FOIL

Coating ¹ Rate (ft/min)	% SOLIDS									
	25.5		17.3		15.0		13.8		11.2	
	α_s	ϵ	α_s	ϵ	α_s	ϵ	α_s	ϵ	α_s	ϵ
18	.92	.41	.89	.23	.91	.45	.91	.40	.91	.46
25	.92	.38	.90	.27	.91	.46	.91	.52	.92	.43
36					.92	.53				
50	.93	.50	.89	.24						
65			.90	.25						
80			.89	.32						
100			.89	.30						

1 Revaplast Laminator, Bruderhaus Co.

SECTION III

THICKNESS INSENSITIVE PAINTS

There is a great need to reduce or eliminate the need for thickness control of solar paint coatings. This would give paint coatings wider versatility for commercial and residential applications. It was believed that incorporation of highly reflective metallic particles, such as aluminum, in the existing solar paint would accomplish this. A number of aluminum flake pigments from Alcoa Company were selected to provide a wide range of particle size. Both 30 PVC F-6331/SR-125 and 30 PVC F-6331/urethane coatings were formulated with 10 to 30 percent aluminum flake. One set of samples was prepared by spray and the other by brush. Coatings were applied so that thick coatings resulted and the substrate could not show-through. Solar absorptance and total emittance were measured and the data recorded in Table 9.

The results indicate that large aluminum flake (#2468) offers the best optical properties in coatings by spray and brush application techniques. The spray applied paint coatings with 30% large flake were the best obtained. There appears to be a difference in optical performance between the urethane and silicone systems. One explanation for this is a possible chemical side reaction between the urethane isocyanate component and a fatty acid (stearic acid) which is coated on the surface of aluminum flake by Alcoa.

To eliminate this protective fatty acid layer, a quantity of the flakes was washed in chloroform (CHCl_3). The aluminum flakes were then incorporated into the solar paint, applied and measured as before. From Table 10, it is evident that emittance values are higher after washing. This may have come about from the washing procedure, after removing the protective fatty acid layer, the aluminum is subject to corrosion. This corrosion would reduce the reflection (proportional to emittance) of the aluminum flakes, therefore, resulting in

TABLE 9

OPTICAL PROPERTIES OF 30PVC F-6331/SILICONE AND 30PVC F-6331/URETHANE
COATINGS WITH ALUMINUM FLAKE SPRAY AND BRUSH APPLIED

TYPE	ALUMINUM FLAKE ¹	% BY WT	SILICONE				URETHANE			
	RELATIVE SIZE		SPRAY		BRUSH		SPRAY		BRUSH	
			α _S	ε	α _S	ε	α _S	ε	α _S	ε
6205	Small	10	.90	.65	.90	.60	.67	.53	.79	.47
		15	.85	.60	.88	.56	.56	.47	.77	.47
		20	.78	.54	.85	.53	.47	.44	.73	.52
		25	.67	.49	.77	.49	.43	.42	.71	.52
		30	.58	.45	.73	.47	.39	.40	.63	.54
6230	Medium	10	.84	.54	.91	.65	.49	.40	.79	.48
		15	.75	.48	.90	.59	.32	.30	.79	.50
		20	.64	.42	.89	.59	.31	.30	.79	.49
		25	.54	.36	.89	.56	.29	.29	.77	.52
		30	.43	.32	.83	.50	.33	.31	.76	.49
6231	Medium	10	.88	.60	.89	.54	.60	.49	.80	.48
		15	.84	.54	.87	.55	.43	.39	.80	.60
		20	.79	.51	.89	.59	.36	.35	.75	.49
		25	.68	.44	.85	.49	.31	.31	.74	.48
		30	.66	.42	.85	.53	.29	.30	.74	.46
6091	Large	10	.88	.61	.89	.50	.60	.44	.78	.45
		15	.84	.54	.89	.59	.46	.37	.78	.45
		20	.73	.45	--	--	.36	.31	.78	.41
		25	.65	.41	.85	.51	.30	.30	.76	.41
		30	.57	.35	.85	.51	.28	.28	.74	.43
2468	Extra Large	10	.93	.57	.91	.55	.87	.52	.83	.47
		15	.92	.52	.91	.55	.79	.35	.81	.44
		20	.92	.44	.90	.45	.81	.36	.81	.41
		25	.91	.39	.90	.48	.78	.31	.80	.42
		30	.90	.31	.90	.48	.76	.31	.80	.44

¹ Aluminum Company of America, Pittsburgh, PA.

TABLE 10.. OPTICAL PROPERTIES OF 30 PVC F-6331/URETHANE
USING UNWASHED AND WASHED (FATTY ACID FREE)
ALUMINUM FLAKE

Particle Size	Aluminum Flake ¹		Optical Properties			
	Type	% Alum Flake	Unwashed		Washed	
			α_s	ϵ	α_s	ϵ
Large	2468	10	.87	.52	.88	.58
		20	.81	.36	.82	.40
		30	.76	.31	.74	.36
Medium	7468	10	.86	.51	.88	.59
		20	.82	.45	.82	.52
		30	.81	.45	.82	.50
Small	6233	10	.84	.56	.73	.53
		20	.72	.46	.64	.48
		30	.71	.46	.42	.40

¹ Aluminum Company of America, Pittsburgh, PA.

higher emittance values.

THICKNESS-INSENSITIVE COATING SOLUTION SCALE-UP

A scale-up to a 1000g batch was successfully performed. Optical properties of $\alpha_s = 0.90$ and $\epsilon = 0.35$ were achieved. Samples were exposed to abrasion environments using the Gardner Straight Line Washability and Abrasion Machine. After 1750 cycles of abrasion, optical properties of $\alpha_s = 0.83$ and $\epsilon = 0.38$ were achieved. It was noted during the scale-up that optical properties were improved after a few days of paint storage, from $\alpha_s = 0.90$, $\epsilon = 0.43$ to $\alpha_s = 0.90$, $\epsilon = 0.35$. This phenomenon will be further investigated in an attempt to improve optical properties.

ABRASION RESISTANCE

Optical properties of various types of thickness-insensitive paint coatings were measured before and after abrasion exposure. All coatings tested were formulated at 30 percent solids, spray applied and consist of 30 PVC. A series of coatings were made with 15 and 30 percent aluminum flake, type 2468 and different binders; silicone, acrylic and urethane. These coatings were then compared after exposure to abrasion. It can be seen from Table 11 that the system that employs the silicone and acrylic binders with 15 percent aluminum flake gives the best abrasion results. It should be noted that all coatings do give good abrasion resistance.

A comparison was made between coatings containing different types of aluminum flakes. Alcoa flakes 2468, 7468 and 6233 used in coatings, range from large to small respectively. Aluminum flakes were incorporated into 30 PVC F-6331/urethane paint coating. No significant abrasion changes were apparent from different size flakes as can be seen from Table 11.

TABLE 11. OPTICAL PROPERTIES OF SPRAY APPLIED SOLAR SELECTIVE THICKNESS-INSENSITIVE PAINT COATINGS BEFORE AND AFTER 1750 CYCLES OF ABRASION¹

30% Solids Coating	Alum. Flake Type	Percent Alum.	Before		After	
			α_s	ϵ	α_s	ϵ
30 PVC F-6331/SR-125	2468	15	.92	.59	.87	.59
		30	.90	.41	.80	.43
30 PVC F-6331/Acrylic	2468	15	.93	.64	.91	.64
		30	.92	.55	.88	.58
30 PVC F-6331/Urethane	2468	15	.79	.35	.71	.37
		30	.76	.31	.69	.33
30 PVC F-6331/Urethane	7468	15	.85	.48	.80	.48
		30	.81	.45	.79	.44
30 PVC F-6331/Urethane	6233	15	.75	.49	.70	.50
		30	.71	.46	.68	.47

1 Garden Straight Line Washability and Abrasion Machine

SECTION IV

FUTURE PLANS

Plans for the next four months are as follows:

THICKNESS SENSITIVE SELECTIVE PAINTS

In the development of large scale production, optimization of the optical properties of paint coatings on aluminum foil will continue. A pressure sensitive adhesive will be developed for the back of the aluminum foil. The effects of pinholes in the adhesive on the corrosion resistance of the foil-steel interface will be investigated.

THICKNESS INSENSITIVE SELECTIVE PAINTS

Optimization of the coating optical properties will continue.

REFERENCES

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2. R.J.H. Lin and P.B. Zimmer, "Selective Paint and Black Chrome Development," Semi-annual Report for DOE under Contract No. EM-78-C-04-4287, December 1978.