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ENVIRONMENTAL DURABILITY OF ELECTROPLATED BLACK CHROMIUM

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16. ABSTRACT

A study was undertaken to determine the durability of nickel-black chromium plated aluminum in an outdoor rural, industrial, and seacoast environment. Test panels were exposed to these environments for 60, 36, and 13 months, respectively. The results of this study showed that no significant optical degradation occurred from exposure to either of these environments, although a considerable amount of corrosion occurred on the panels exposed to the seacoast environment. The rural and industrial atmosphere produced only a slight amount of corrosion on test panels.

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INTRODUCTION

One major component of a device for collecting solar energy is the receiving surface or solar absorption panel. These panels are usually prepared from metals which are specially coated to increase their solar absorptance without significantly lowering their emissivity. Such optically selective surfaces are often expressed in terms of a solar absorptance/IR emittance ratio. Generally, the higher the ratio the greater the efficiency of the surface in terms of collecting solar energy. However, it is considered more beneficial to have coatings with very high solar absorptances (0.90 or higher) and moderately high emittances (0.1 to 0.2). To obtain such optical selectivity, extremely thin coatings are required which limit their ability to protect substrates from corrosive environments. Even though collector covers furnish substantial protection from such environments, this presents a problem in the coating of solar panels because the receiving surface must remain essentially free from corrosion for the absorption efficiency of the solar panel to remain high. Therefore, the absorber coating itself should have good resistance to moisture and other corrosive environments, as well as the ability to protect the substrate material.

Among several black absorber coatings that have shown good absorption characteristics (absorptances higher than 0.9 and emittances around 0.1) is electroplated black chromium. Results of laboratory accelerated corrosion tests [1] have also shown that its optical properties are not significantly affected by corrosive environments; and when plated over an intermediate coating, such as nickel, it protects substrate materials from corrosion. However, there appears to be no available data on the results of long-term natural environmental tests. Because of the difficulty of correlating laboratory test data with outdoor environments and because of the long life expectancy of solar collectors, a program was conducted to determine the long-term durability of electroplated black chromium in several different outdoor environments. This report presents the results of the study.

EXPERIMENTAL PROCEDURE

The test panels used in this program were 0.61 m by 0.91 m (2 ft by 3 ft) in size and in the form of flat sheets containing integral flow passages fabricated by the silk screen/hot roll process. The panels, constructed of 1100 aluminum, were manufactured by the Olin Brass Company and marketed under the trade name "Roll-Bond." The panel design was identical to absorber panels in solar collectors used in a solar residential heating and cooling system development program, conducted by NASA at the Marshall Space Flight Center (MSFC) [2]. A sketch of the panel design is shown in Figure 1. The aluminum panels were first plated with bright nickel to a thickness of approximately 0.0127 mm (0.0005 in.) to furnish better corrosion protection. The black chromium was then plated over the nickel (all the plating was done in a commercial facility) to a thickness sufficient to produce a high solar absorptance yet thin enough to maintain the low emittance (high infrared reflectance) of the bright nickel.

The durability of the nickel-black chromium electroplate was established for three different natural corrosive environments by exposing the panels outside at MSFC, on the coast at Kennedy Space Center (KSC), and at the American Cast Iron and Pipe Company (ACIPCO) in Birmingham, Alabama, these exposure sites representing a rural, a seacoast, and an industrial environment. The panels were exposed bare to represent a worst-case condition. The optical properties of test panels were determined by taking the average of at least three measurements made at different locations on each panel (generally in the middle and at each end). These determinations were made before, periodically during the exposure periods, and at the end of the test. Degradation in optical properties (decrease in solar absorptance and increase in emittance), as well as visual corrosion, were the criteria used for establishing the panel durability.

All optical measurements were made with a portable Gier Dunkle Solar and IR Reflectometer. The solar energy absorptances were determined by computing the difference between the solar energy reflectance and unity; the emittances were determined similarly by computing the differences between the IR reflectance and unity.

DISCUSSION AND RESULTS

Rural Environment

This exposure site, located at MSFC near Huntsville, Alabama, represents an environment that is low in, or essentially free from, the common pollution agents normally present in industrial or seacoast areas (such as hydrogen sulfide, sulfur dioxide, ammonia, nitrite, chlorides) that accelerate the corrosion of metals. The test rack and general area are shown in Figure 2.

Duplicate "Roll-Bond" panels plated with black chromium were exposed to this environment for a total of 60 months, positioned at a 45-degree angle facing south as shown in the figure. The results of the tests showed that the panels had excellent corrosion resistance to this environment. At the end of the test period, some minute specks surrounded by small areas of discoloration were present; but this condition had no significant effect on the optical properties. A representative test panel after 60 months exposure is shown in Figure 3. The optical properties (average of duplicate panels) before, during, and at the end of the test period are shown in Table 1. As shown in the table, no change in the solar energy absorptance had occurred at the end of the test; and the emittance had increased only slightly.

Seacoast Environment

This test site, located at Kennedy Space Center near Titusville, Florida, represents an environment which causes extremely high corrosivity because of the sea spray. Test specimens were exposed for a total of 13 months at two different locations in this area: (1) approximately 120 ft from the mean high tide line and (2) 1 mi inland. The panels were mounted at a 30-degree angle on racks that were facing the ocean in an easterly direction. A typical rack is shown in Figure 4.

At the end of the test period, the panels showed a considerable amount of corrosion; but the optical properties were not severely degraded. Corrosion in the form of small gray to white pits was observed on the panels located on the beach a few days after the initiation of the test. Similar pits were observed on the panels located 1 mi inland about 4 weeks after exposure. After 13 months, the panels at both sites were covered with numerous spots of white corrosion ranging from approximately

0.32 cm to 0.48 cm (0.13 in. to 0.19 in.) in size, but, as expected, were more numerous on those located on the beach. The black chrome and nickel coatings were lifted from the substrate in most of these corroded spots. Representative test panels are shown in Figure 5, and the optical properties (average of duplicate panels) are shown in Table 2. Table 2 shows that no significant change occurred in the solar energy absorptances, but the emittances showed a slight increase in the case of the panels located 1 mi inland and a moderate increase in the case of those on the beach site. Overall, the optical degradation was not considered severe. However, in view of the amount of corrosion present on the panels, severe degradation would be expected to occur soon.

Industrial Environment

This test site, located at ACIPCO in the northern section of Birmingham, Alabama, represents an area that is highly industralized. A test specimen, mounted on a rack designed to hold it at a 45-degree angle, was located on the top of a multi-story office building at ACIPCO where it remained exposed to this environment for a period of 36 months. Figure 6 shows the rack and panel at the test site facing a southerly direction at the initiation of the test.

The results of the test showed the black chromium had good resistance to this industrial environment. At the end of the test period, the solar energy absorptance showed a slightly favorable increase; but the emittance also increased slightly, indicating a degradation in this property. This small change, in either case, was not considered significant. The optical data are shown in Table 3. In appearance, the most significant change was the presence of numerous small brown spots scattered over the entire panel surface. This appeared to have resulted from the deposition of minute cinder particles onto the surface of the panel where they clung to the surface to form brown to red rust. These particles were apparently emitted from the ACIPCO metal furnaces. The brown spots covered the entire panel surface, but were very small, ranging from approximately 0.04 cm to 0.09 cm (0.02 in. to 0.03 in.) in diameter. The test panel, at the end of the exposure period, is shown in Figure 7.

CONCLUSIONS

Corrosion was most severe on the seacoast panels, even though they were exposed for a shorter period of time. The durability of the coating system in the rural and industrial environment was much greater than in the seacoast environment, as was expected. The aggressiveness of the environment in the ACIPCO and the northern Birmingham area was not as great as expected. The panels exposed to this environment were only slightly more corroded and optically degraded in 36 months than the panels exposed to the rural environment in 60 months. Considering the rate of degradation in the final 12 months of exposure, severe degradation in the ACIPCO environment for an additional 24 months would not be anticipated. Based upon the results of these tests and the conditions under which they were accomplished, it can be concluded that this coating system has exceptionally good optical durability in each of the environments.

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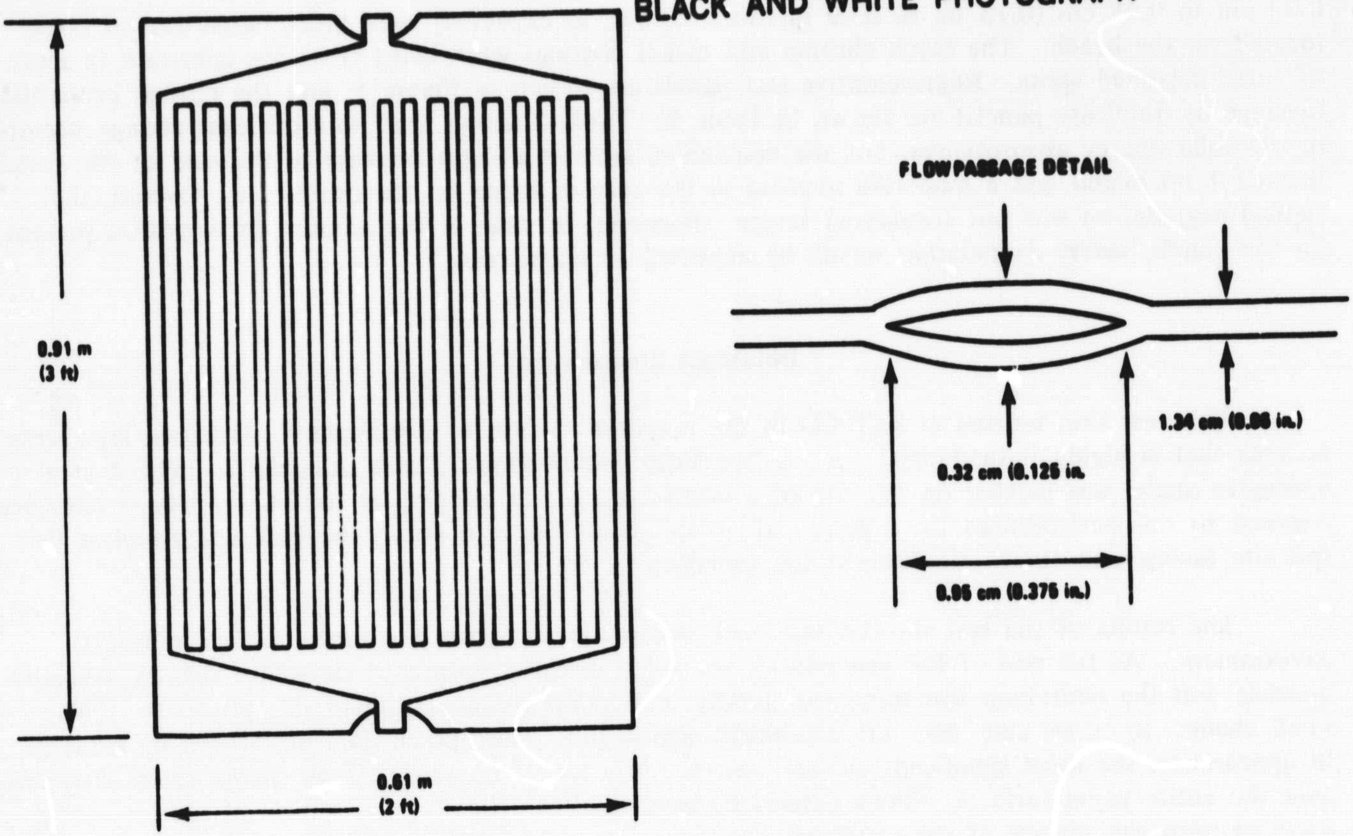

Figure 1. "Roll-Bond" panel design.

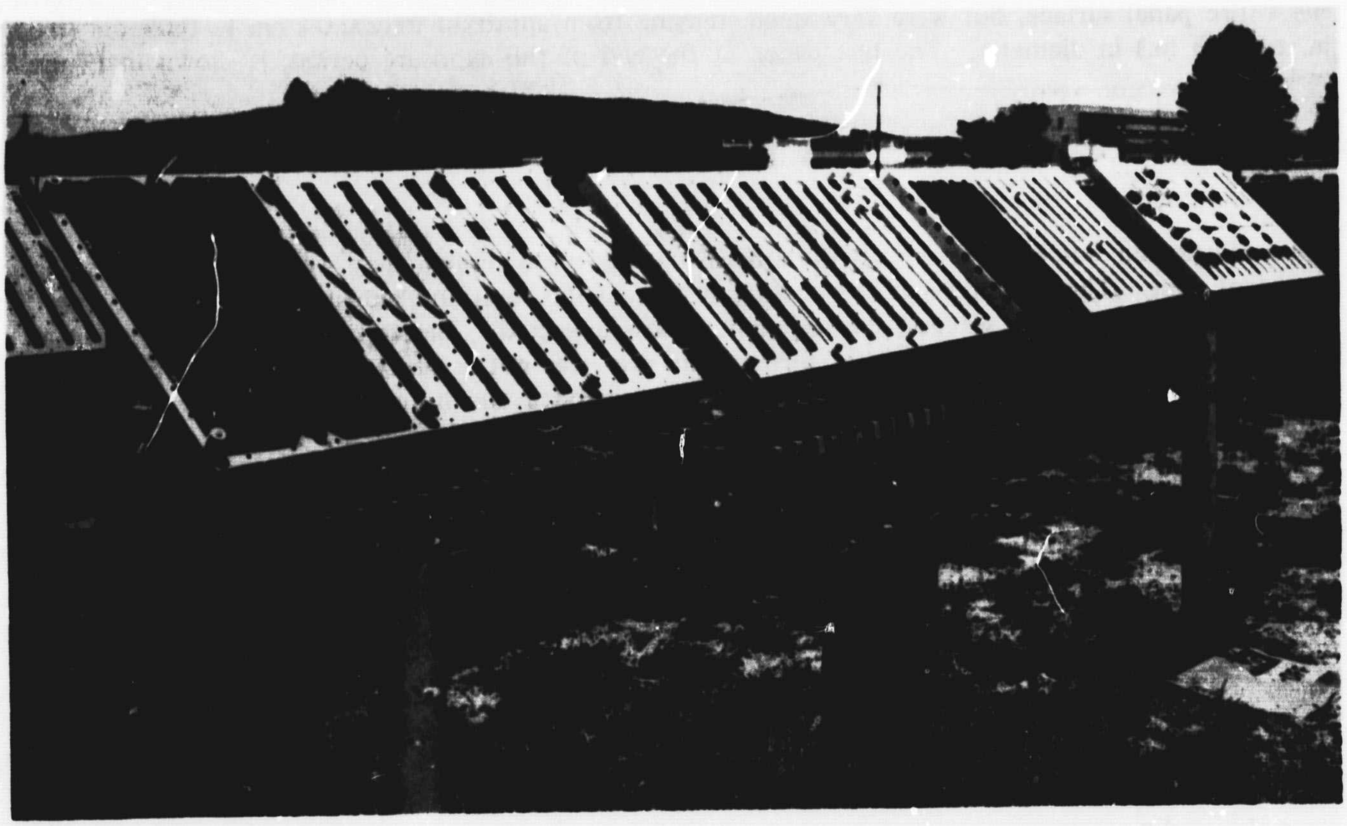

Figure 2. Atmospheric exposure test racks, located at MSFC.

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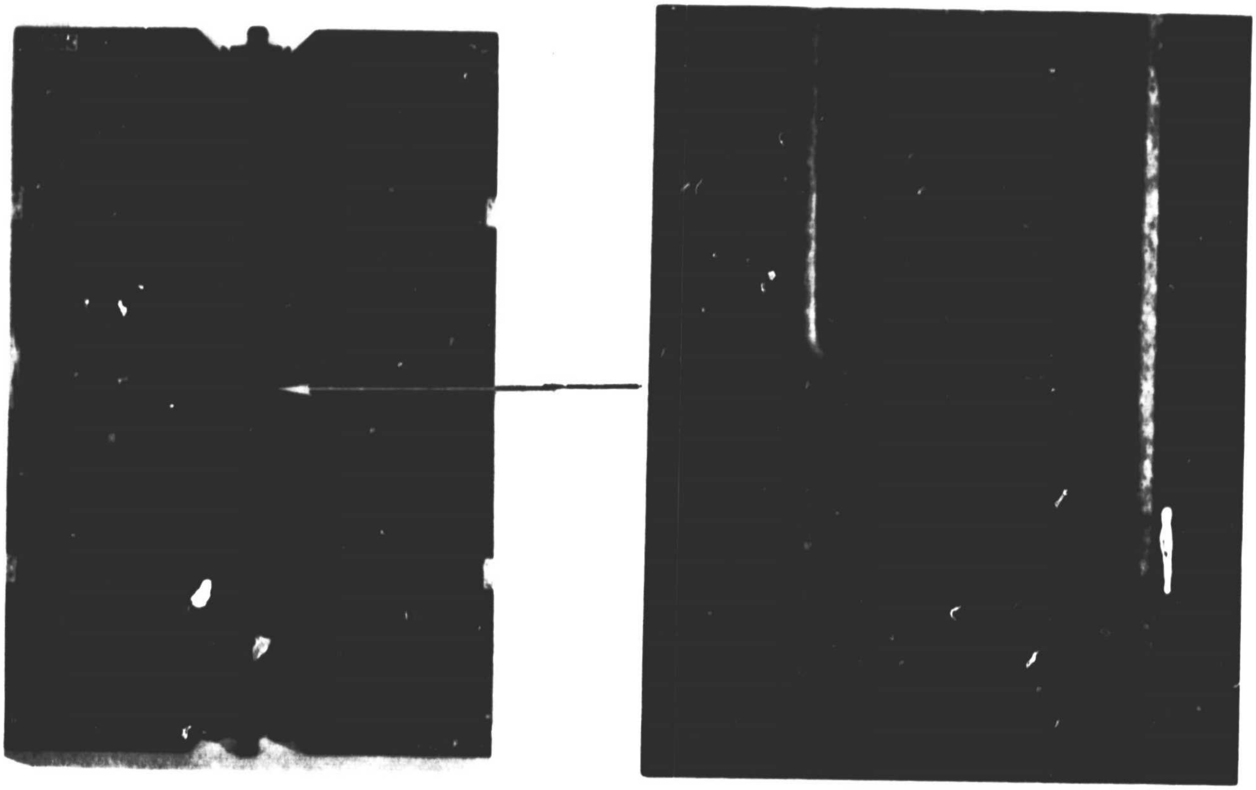
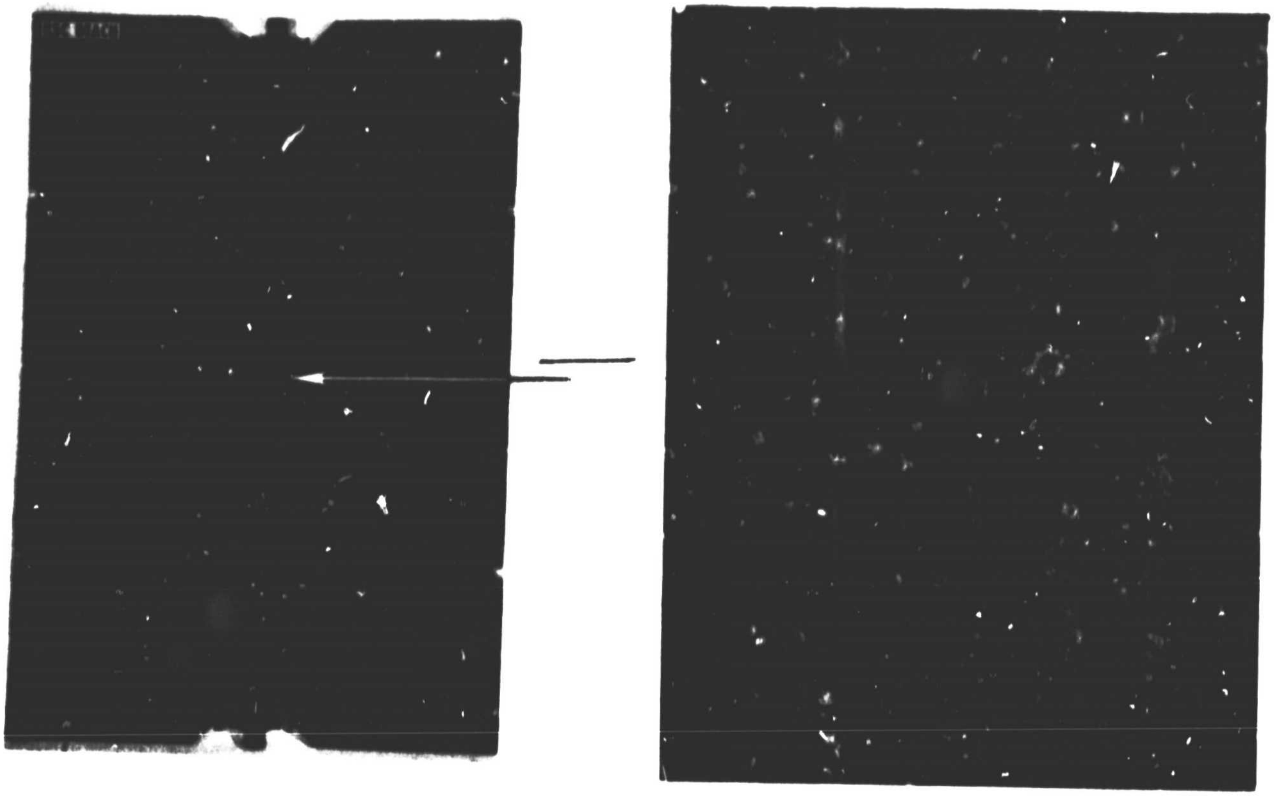
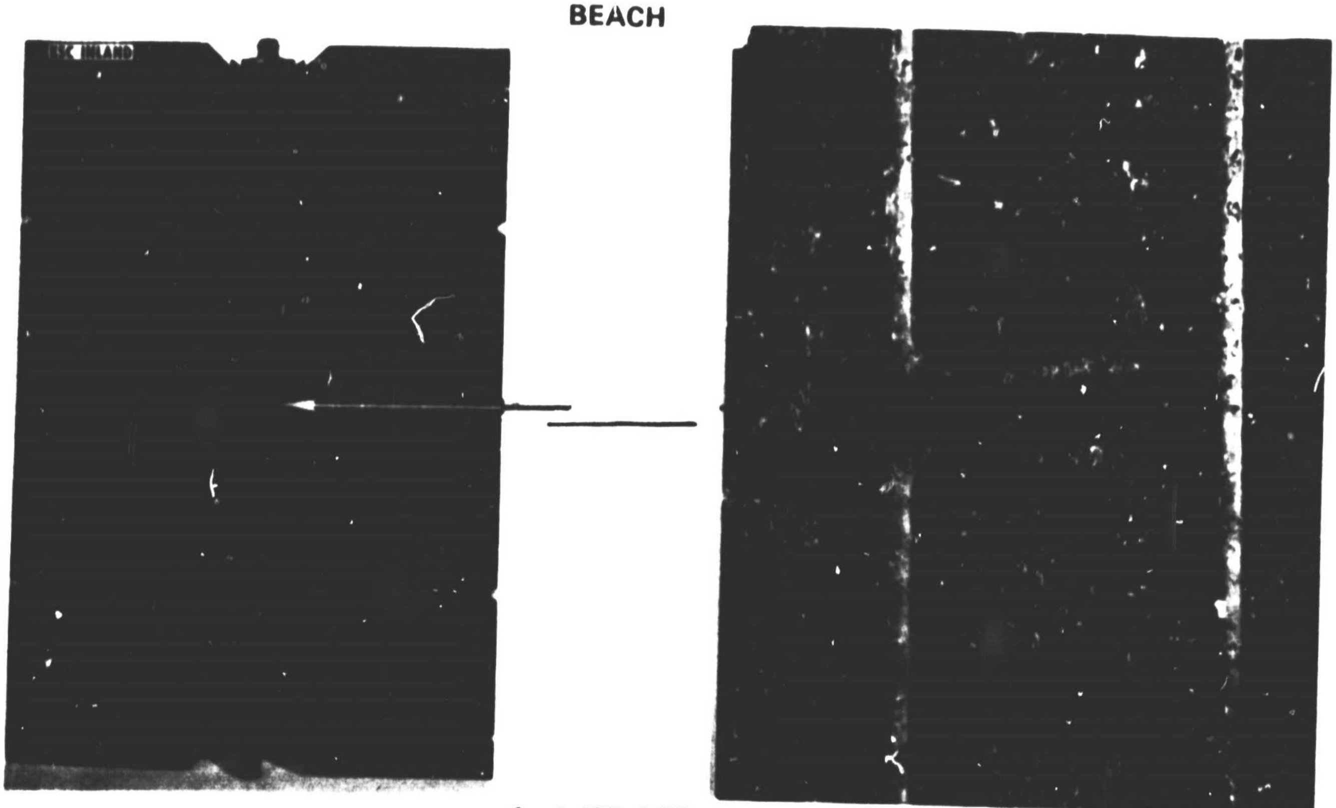


Figure 3. Nickel-Black chromium electroplated "Roll-Bond" panels after atmospheric exposure at MSFC, exposure time 60 months.

Figure 4. Atmospheric exposure racks located on the beach at KSC.



BEACH



1 mi. INLAND

Figure 5. Nickel-black chromium electroplated "Roll-Bond" panels after atmospheric exposure at KSC, exposure time 13 months.

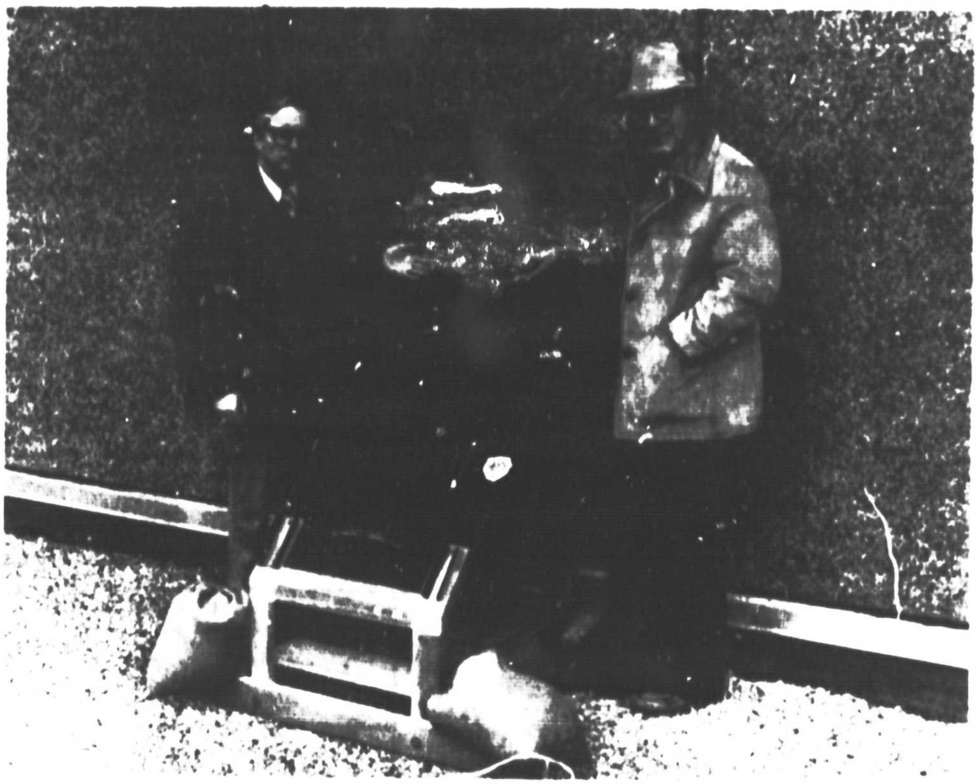


Figure 6. Atmospheric exposure site, located at the top of an office building at ACIPCO in Birmingham, Alabama.

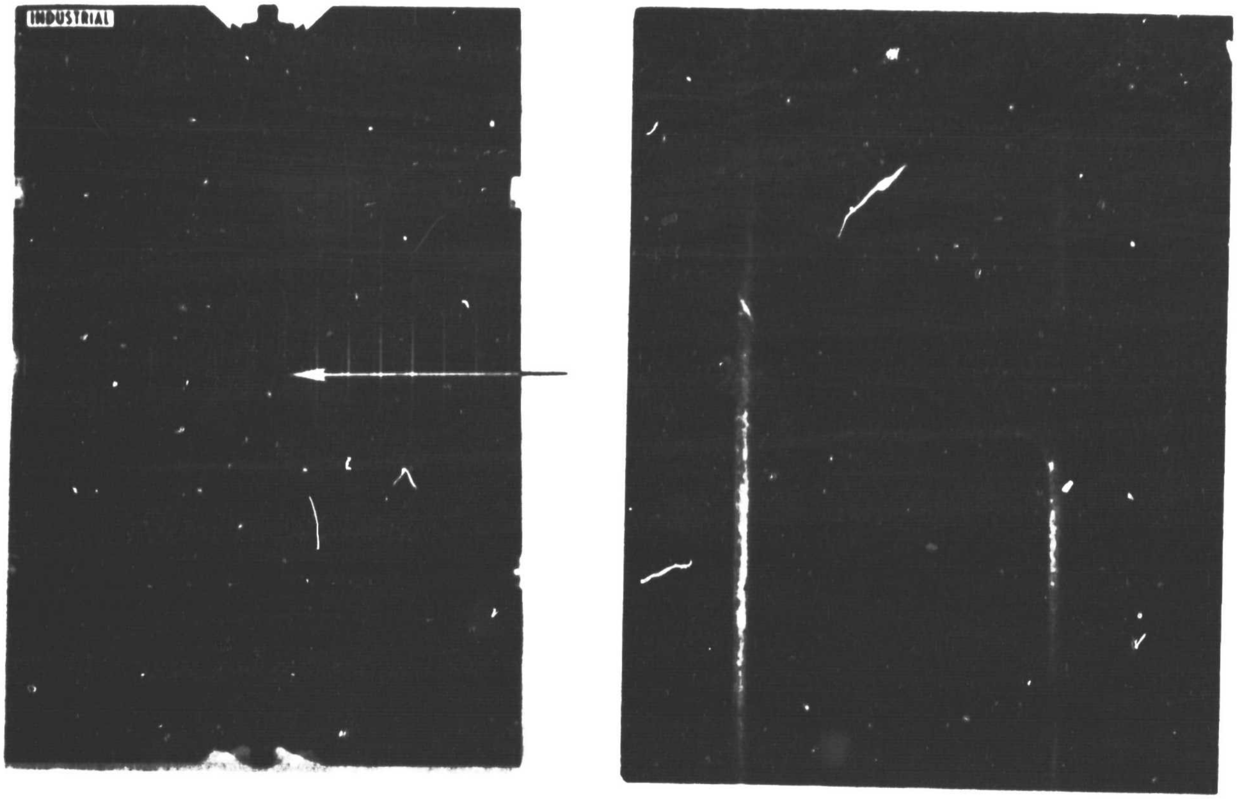


Figure 7. Nickel-black chromium electroplated "Roll-Bond" panels after atmospheric exposure at ACIPCO in Birmingham, Alabama, exposure time 36 months.

TABLE 1. EFFECT OF RURAL OUTDOOR ENVIRONMENT ON THE SOLAR ENERGY ABSORPTION CHARACTERISTICS OF BLACK CHROMIUM

Optical Properties	Before Exposure	Exposure Time – Months							
		3	9	21	29	38	47	55	60
Absorptance	0.96	0.96	0.94	0.96	0.94	0.94	0.94	0.96	0.96
Emittance	0.08	0.08	0.08	0.08	0.10	0.09	0.11	0.10	0.10

TABLE 2. EFFECT OF SEACOAST ENVIRONMENT ON THE SOLAR ENERGY ABSORPTION CHARACTERISTICS OF BLACK CHROMIUM

Optical Properties		Before Exposure	Exposure Time Months	
			1	13
Beach	Absorptance	0.94	0.96	0.93
	Emittance	0.11	0.12	0.28
1 mi. Inland	Absorptance	0.95	0.97	0.94
	Emittance	0.09	0.08	0.13

TABLE 3. EFFECT OF AN INDUSTRIAL ENVIRONMENT ON THE SOLAR ENERGY ABSORPTION CHARACTERISTICS OF BLACK CHROMIUM

Optical Properties	Before Exposure	Exposure Time – Months				
		2	9.5	13.6	26.5	36
Absorptance	0.93	0.94	0.89	0.92	0.93	0.96
Emittance	0.09	0.10	0.13	0.12	0.17	0.14

REFERENCES

1. Lowery, James R.: Solar Energy Absorption Characteristics and the Effects of Heat on the Optical Properties of Several Coatings. George C. Marshall Space Flight Center, NASA TM-82414, April 1981.

2. George C. Marshall Space Flight Center, "The Development of a Solar-Powered Residential Heating and Cooling System," May 10, 1974.