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VARIATION OF SOLAR-SELECTIVE PROPERTIES
OF BLACK CHROME WITH PLATING TIME

by Glen E. McDonald and Henry B. Curtis
Lewis Research Center
Cleveland, Ohio 44135
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Glen E. McDonald

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Henry B. Curtis

Lewis Research Center

ABSTRACT

The spectral reflectance properties of a commercially prepared black chrome over dull nickel, both plated on steel, for various plating times of the black chrome were measured. The plating current was 180 amperes per square foot.

The following values of absorptance α integrated over the solar spectrum, and of infrared emittance ϵ integrated over black-body radiation at 250°F were obtained for the plating times τ . (See Table 1.)

The heat absorbed over the solar spectrum for insolation of 250 Btu/hr-ft², and the heat lost by radiation at a plate temperature of 250°F in radiation equilibrium with a 100°F body were each calculated for the various combinations of α and ϵ given above. The results indicate that plating between one and two minutes produces the optimum combination of highest heat absorbed and lowest heat lost by radiation.

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INTRODUCTION

The NASA-Lewis Research Center is conducting research on solar collectors as part of the national program to develop new energy sources. It is essential that flat-plate nonconcentrating solar collectors have both the maximum possible absorptance across the solar spectrum and the minimum possible emittance in the infrared in order to ensure maximum efficiency at high collector-plate temperatures (ref. 1).

Other essential requirements of a practical solar-selective coating, in addition to the requirement for maximum efficiency, are ease and availability of application, low cost, and long-term durability under solar radiation. It has been previously determined at the NASA-Lewis Research Center that a widely available, commercial, decorative electroplated finish of the acetic-acid type of black chrome has desirable solar-selective properties of high absorptance in the visible and low emittance in the infrared portions of the spectrum (ref. 2). It was also shown that improved solar-selective properties of black chrome could be obtained by underplating the black chrome with dull nickel (ref. 3).

The plating time was investigated that would produce the optimum solar-selective properties for black chrome plated over dull nickel on steel. The black-chrome plating compound used is available as a proprietary mixture from the Harshaw Chemical Company. Visible and infrared spectral reflectance were measured to determine the performance of the solar-selective coating.

This paper describes the method of producing the black chrome and the results of the measurements of spectral reflectance.

DESCRIPTION OF SPECTRAL MEASUREMENTS

All measurements reported are hemispherical diffuse reflectance.

The spectral reflectance from 0.35 to 2.1 microns of the black chrome was measured with a Cary-14 spectrophotometer with a spherical diffuse reflectance attachment. A MgO surface prepared at the NASA-Lewis Research Center was used as a standard.

The spectral reflectance from 3.0 to 18.0 microns was measured with a Willy 318-A spectrophotometer which uses a spherical diffuse reflectance attachment. The Willy 318-A is a Fourier transform type of spectrophotometer. Evaporated gold film was used as a standard. Evaporated aluminum on glass was used as a secondary standard.

DESCRIPTION OF BLACK CHROME PREPARATION

In this investigation black chrome was plated over dull nickel on 4x6-inch steel test panels.

The steel panels used for the measurements were 1020 cold-rolled steel polished on one surface to a roughness of less than 1/2 micro-inch RMS; the panels are regularly furnished by Apollo Steel as standard test coupons for the electroplating industry. There was no significance for solar collector application in use of these panels; their use resulted only from ready availability as a base for tests of electroplating conditions.

The panels were first plated with approximately 0.0005 inch of dull nickel since it had been previously determined that more desirable solar selective properties are obtained with undercoating of dull nickel (ref. 2) than with bright nickel (ref. 1). Next the dull nickel was over-plated with black chrome for varying lengths of time to produce a variation among panels in thickness of black chrome. The result was a dull, matte, nonspecular finish covered over with a deposit of black chrome which varied from barely visible coverage at the lower plating times to a velvet black coat at the longer times.

The panels were plated in the following sequence:

(1) Cleaned by electrolytic alkaline chelating cleaner at 190°F and 70 to 80 amps/ft². Two cycles, interspersed with acid, were used.

(2) Dull nickel was plated from Harshaw Chemical Company NUSAT at 40 amps/ft² for 15 minutes to deposit approximately 0.0005 inch of nickel.

(3) Black chrome plated from Harshaw Chemical Company CHROM-ONYX at 24 volts and 200 amps/ft² for varying periods of time.

(4) Water rinsed.

(5) Alcohol rinsed.

(6) Air dried.

The panels were wrapped in tissue and stored until spectral measurements were completed.

TEST RESULTS

For the plating times of 15 seconds to 10 minutes, the general appearance of the panels varied from an almost purely dull-nickel appearance at 15 seconds to a velvet black at 10 minutes. Only a very faint deposit of black chrome could be observed on the 15-second panel by visual observation.

The results of the spectral measurements of reflectance of black chrome as a function of plating time are shown in figure 1. It is evident that both the visible and the infrared reflectances decrease with increasing plating time. The corresponding values of the visible absorptance α integrated over solar air mass-2 spectrum, and of the infrared emittance ϵ as integrated over a 250°F black-body emitter are shown in Table I and are plotted in figure 2. With increasing plating time, and consequently increasing black-chrome thickness, there is first a rapid increase in visible absorptance without a significant increase in infrared emittance until a nearly maximum value of absorptance is reached, after which the emittance rapidly increases with no appreciable increase in absorptance. Indeed, as plating is continued, there is even a slight decrease in absorptance across the solar spectrum.

The optimum plating time is determined by the radiative energy balance of the collector plate. Since the absorptance in the solar spectrum and the infrared emittance both increase with plating time, but at different rates, the "optimum" plating time occurs when

$$\frac{dQ_{\text{abs}}}{dQ_{\text{rad}}} \approx 1$$

where Q_{abs} is the heat absorbed by the collector plate from solar radiation and Q_{rad} is the heat radiated by the collector plate in the infrared.

$$\text{At values of } \frac{dQ_{\text{abs}}}{dQ_{\text{rad}}} < 1, \text{ plating time has}$$

produced coating conditions such that increases in energy lost by changes in radiation are greater than increases in energy gained by changes in absorption.

The relationship for solar energy absorbed is

$$Q_{\text{abs}} = \alpha H$$

where α is the absorptance across the solar spectrum and H is the total solar irradiance on the collector plate.

The heat lost by infrared radiation is

$$Q_{\text{rad}} = \sigma (T_{\text{plate}}^4 - T_x^4) \frac{1}{1/\epsilon_{\text{plate}} + 1/\epsilon_x - 1}$$

where ϵ is the infrared emittance as integrated over the black-body

spectrum, and x denotes the body with which the plate is in infrared radiative equilibrium. The exact magnitudes of Q_{rad} and $\frac{dQ_{\text{abs}}}{dQ_{\text{rad}}}$ are dependent on the assigned values of T_x and ϵ_x .

Q_{abs} and Q_{rad} have been calculated for assigned values of:

$$H = 250 \text{ Btu/hr-ft}^2$$

$$T_{\text{plate}} = 710^\circ\text{R} \text{ (250}^\circ\text{F)}$$

$$T_x = 560^\circ\text{F} \text{ (100}^\circ\text{F)}$$

$$\epsilon_x = 0.9$$

The relation between Q_{abs} and Q_{rad} is plotted in figure 3. The optimum plating time is approximately one minute at 180 A/ft².

SUMMARY OF RESULTS

Measurements of the spectral reflectance over the range from 0.35 to 18 microns of black chrome plated at times varying from 15 seconds to 10 minutes, all at 180 amps/ft², and calculation of the balance between heat absorbed over the solar spectrum and heat radiated over the infrared for a plate temperature of 250°F, indicates that the optimum plating time for this current density is between one and two minutes. Lesser plating times would produce low thermal performance of a solar collector due to low absorptance of the plate. Greater plating times would produce low thermal performance of a solar collector due to high heat loss resulting from high plate emittance.

REFERENCES

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Table 1

SOLAR SPECTRUM ABSORPTANCE AND 250°F
BLACK BODY EMITTANCE OF BLACK CHROME
AT VARIOUS PLATING TIMES

	PLATING TIME					
	15 SEC	30 SEC	1 MIN	2 MIN	4 MIN	10 MIN
ABSORPTANCE, α	0.64	0.87	0.96	0.96	0.95	0.94
EMITTANCE, ϵ	.04	.06	.10	.12	.17	.34

REFLECTANCE OF BLACK CHROME VS PLATING TIME

180 A/FT²

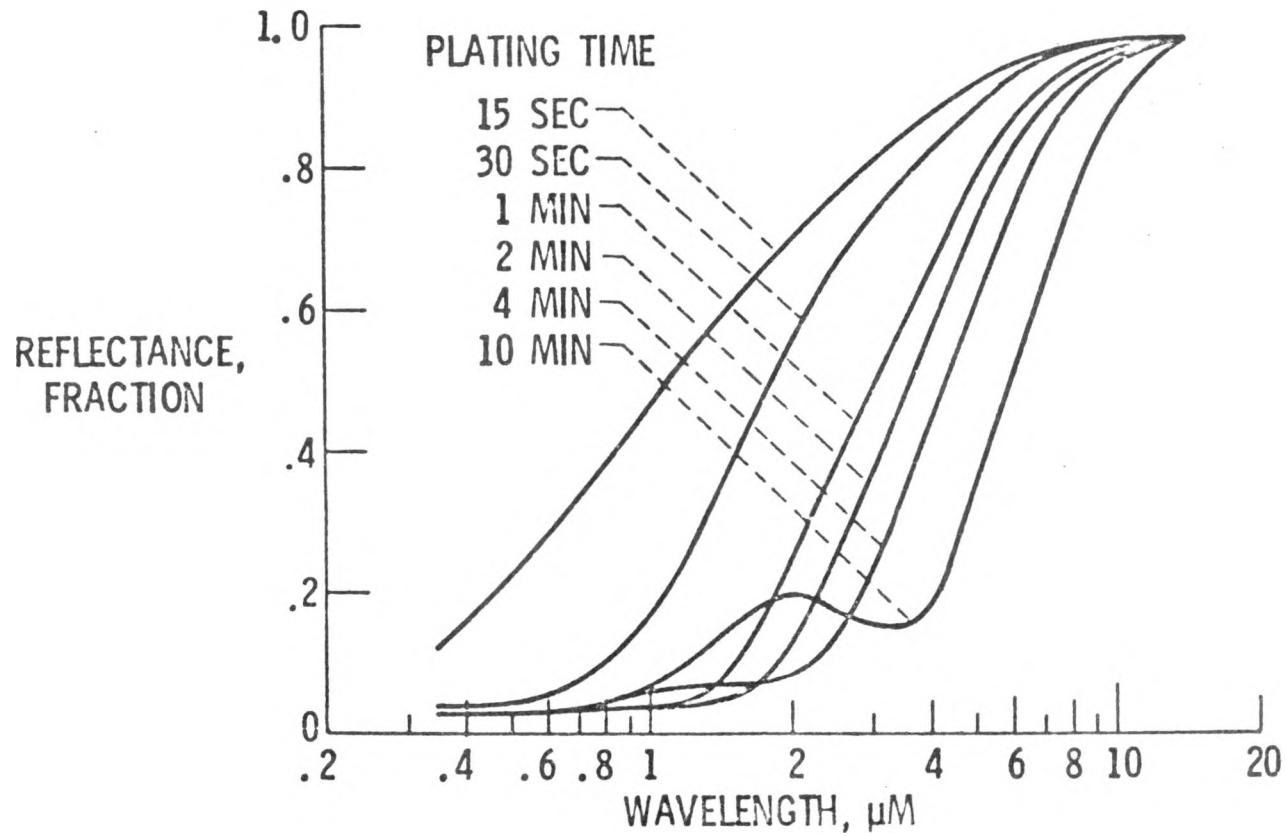


Fig. 1

SOLAR SPECTRUM ABSORPTANCE, α
VS. INFRA-RED EMITTANCE,

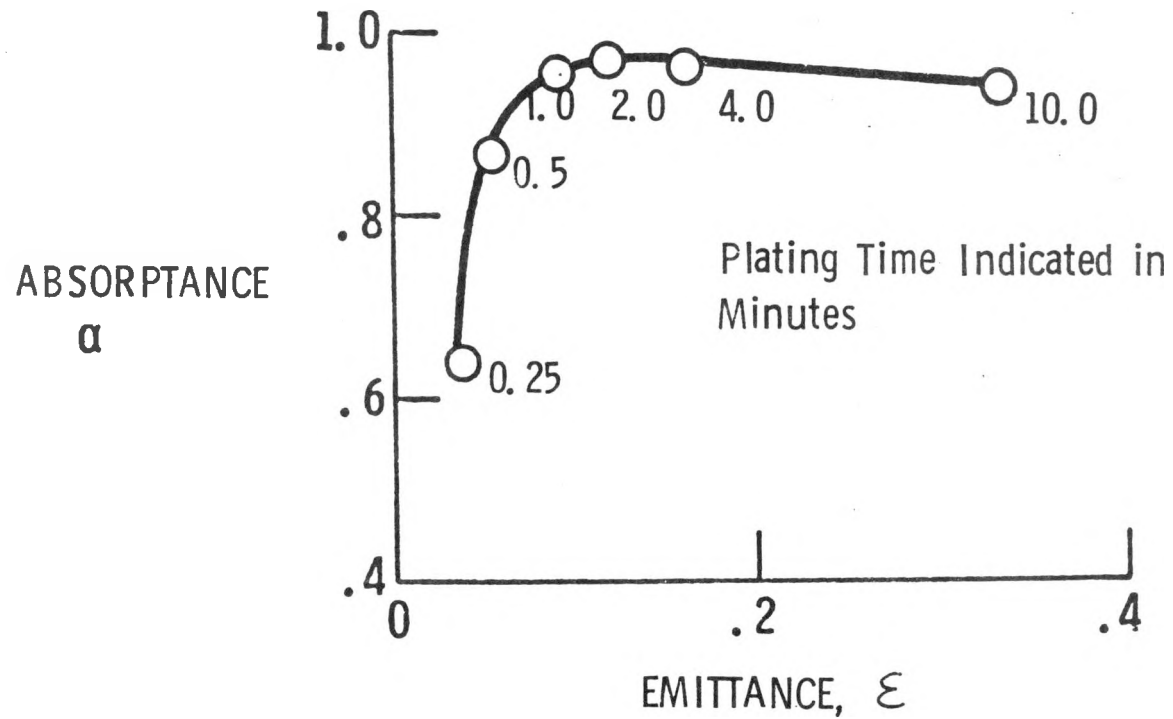


Figure 2

Q ABSORBED VS Q RADIATED FOR BLACK CHROME PLATED AT VARIOUS TIMES

FOR SOLAR INSOLATION OF 250 BTU/HR-FT² &
COVER GLASS TEMP OF 100° F & GLASS EMITTANCE OF 0.9

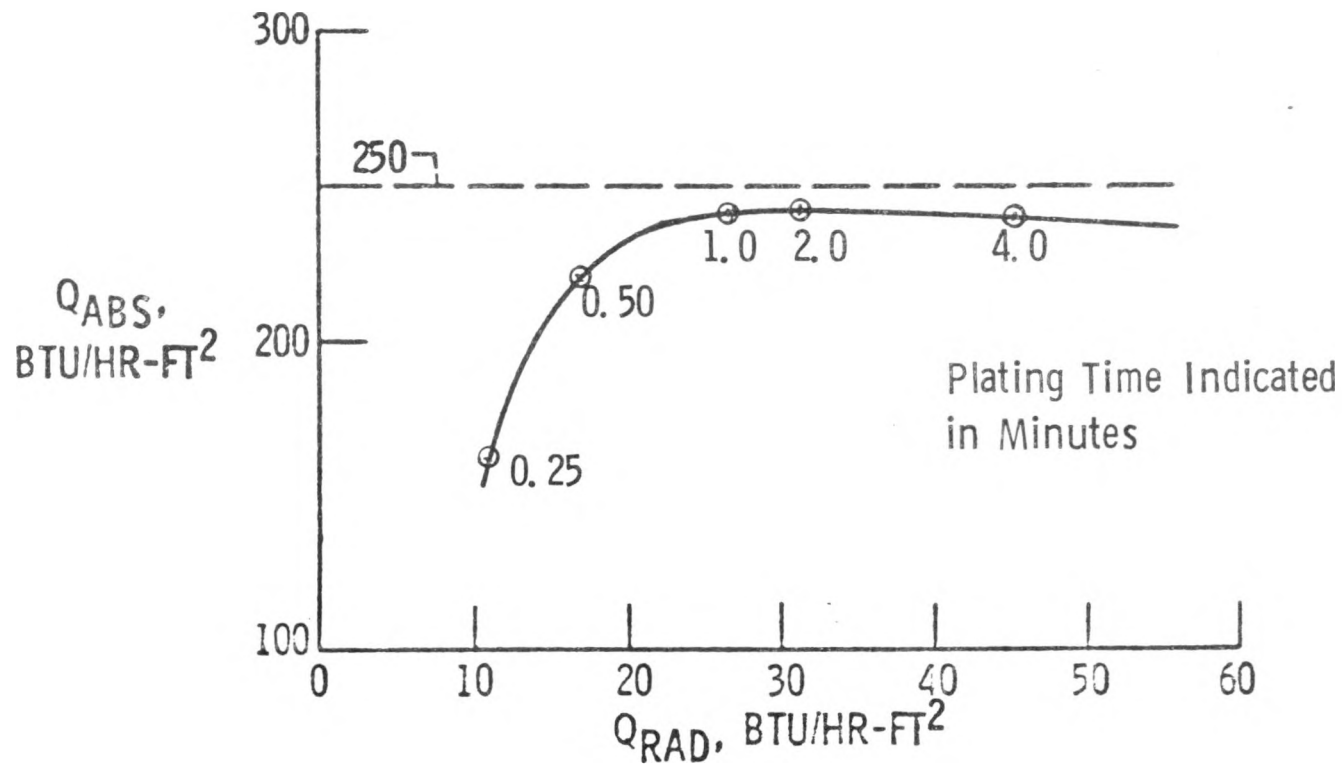


Fig. 3