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by

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EVALUATION OF ELECTROCONDUCTIVITY OF TWO SURFACE PAINTS FOR SPACECRAFT

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Abstract

This article briefly discusses the manufacturing process for two surface paints (used on spacecraft): No. 956 gray paint, and No. 956 green paint. Experimental studies were conducted on both paints at room temperatures in variations of electroconductivity in space environments: in a simulated space vacuum, under electron radiation and under solar radiation. From the experimental results, the states of both surface paints used in orbit can be predicted. In addition, the possibility of using such paints in high orbit is accepted.

Subject terms: organic paints, electroconductive coating, technical factor, artificial satellite, research.

I. Foreword

As is well known, one of the important problems in space science and technology is to sufficiently acknowledge and evaluate the charge state on spacecraft surface, and to solve the problem in real situation. On the one hand, the material constituents on a spacecraft surface are quite complex in order to satisfy requirements of optics, remote sensing, heat control, communication and adiabatic protection of energy; thus, these constituents have widely diverse difference in electrical properties. Secondly, the space environment can be considered as an environment with charged particles. In the intermediate layer between 100 and 200 kilometers of altitude, there are NO^+, O_2^+ and N_2^+ ions. In the thermal ionosphere between 200 and 1000 kilometers of altitude, there are O^+, N^+ and H^+ ions [1]. Further, higher in a synchronous orbit, there are large amounts of charged particles from solar wind. In this environment, high accumulation of electrical charges may occur on the spacecraft surface. Therefore, studies of electrical properties and variations in materials on spacecraft surfaces are one of important problems attracting consistent attention from astronautical researchers.

This article will discuss No. 956 gray paint and green paint; when these paints are used on a spacecraft surface, a paint type coating with spectrum selectivity on scattering kind optical surface will appear. Both paints were investigated in a simulated space thermal vacuum environment. Flight tests were also conducted, thus producing a certain understanding on heat control properties of both paints. Remaining to be done are evaluation studies of the experiments of electrical charge on spacecraft surfaces in the space electronic environment. Therefore, the authors made evaluation studies on electroconductivity in simulated space environments with exposure to electron radiation and solar radiation on both coating layers in order to have more understanding on such paints, and , more importantly, to explore their potential applications. In the authors' view, there is promise for prospective new applications of both paints in the near future. As both paints use identical adhesive with only little difference in other constituents, a brief discussion is made of common properties of both paints in the following section.

II. Preparation of Samples for a Coating

The adhesive used for No. 956 gray paint and No. 956 green paint is an organic silicon resin which is in a category of organic coatings. The main bond of organic silicon resin is composed of $-\overset{|}{\underset{|}{Si}}-O-\overset{|}{\underset{|}{Si}}-O-$. Since the bonding energy of Si--O bond is high, such a bond exerts very high resistance to heat. The lateral bond contains organic genes therefore such resin has the properties of conventional high polymer compounds. Properties of organic silicon resin are mainly determined by R/Si and P_h/R values (R indicates methyl; P_h indicates phenyl). The R/Si value of resin used for preparation of the coating is generally between 1.4 and 1.7. If P_h/R=0, this is pure methyl organic silicon resin, which leads to a coating with high hardness and low mixed flow property of pigment. By introducing phenyl, toughness and adhesiveness can be raised. Pigment added into the paint also is important to stability of the coating. High quality pigment not only has the capability of absorbing ultraviolet light, but also is resistant to photolysis. Zinc oxide, chromium oxide and high pigment carbon black are used as raw materials for coating the sample. Fig. 1 shows the preparation process. This paint is of a thermosetting type. After solidification, the coating can be washed clean. Care should be taken in the preparation process that water and other impurities do not get into the paint. It is best to prepare the paint just before its application because separation occurs in paint during storage. Once separation occurs, sufficient stirring and mixing are required before application.

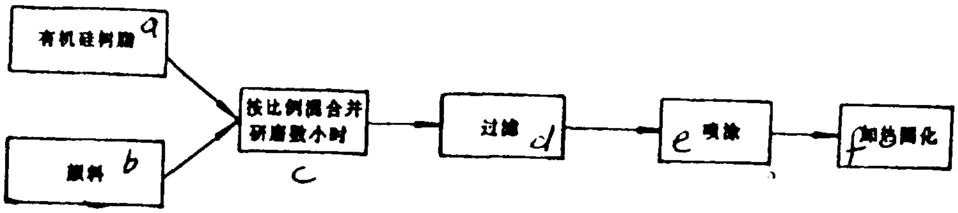

Fig. 1 Flow chart for preparation process of coating

Key: a - organic silicon resin b - pigment
c - mixing proportionally and grinding for several hours d - filtering
e - spraying of paint f - solidification with heating

In both heat control coatings, α_s=0.60 to 0.80; ε_H is approximately 0.86. To obtain α_s/ε_H at a certain value, the thickness of the heat control coating is the main factor. In most coatings, with increasing thickness, both α_s and ε_H also increase. When thickness increases to a certain value, α_s and ε_H approach some other value. Therefore a more ideal α_s/ε_H can be obtained from the value of control thickness. Too thick a coating not only is not helpful to selection of α_s/ε_H, but also leads to heavier weight and lowering of adhesive force with the base material. Thickness of the coating is measured by using a nonmagnetic thickness gauge.

III. Response to Space Environment by the Electroconductivity Property of the coating

The authors observed the response of electroconductivity properties of No. 956 gray paint and green paint to the simulated space vacuum environment, solar radiation environment and the environment exposing them to electron irradiation. The observation method is shown in the literature [2] and [3]. Measurements were made on the site of operation.

1. Electroconductivity Response on the coating surface to a

vacuum environment

Fig. 2 presents the response rule of electroresistivity ρ on the coating surface of No. 956 gray paint and green paint to a variation of vacuum. As indicated by the measurements, the value of coating with No. 956 green paint consistently remains constant (at 1.3 x $10^{11}\Omega\cdot$cm) from atmospheric pressure to high vacuum environmental conditions. However, the ρ value of No. 956 green paint is about 3 x $10^{10}\Omega\cdot$cm in the atmosphere; the value gradually increases as pressure intensity in the vacuum chamber is lowered during experiments. After the system enters a high vacuum environment, the ρ value maintains steady, about 8 x $10^{11}\Omega\cdot$cm. For both paints, in a high vacuum environment their ρ values reach a magnitude of $10^{11}\Omega\cdot$ cm, not too much difference between both values. Possibly with different compounding formulas, materials (previously adhered) are deposited on the surface, thus leading to gradual increase of the value of surface electroconductivity; finally the value for green paint approaches the electroconductivity of gray paint.

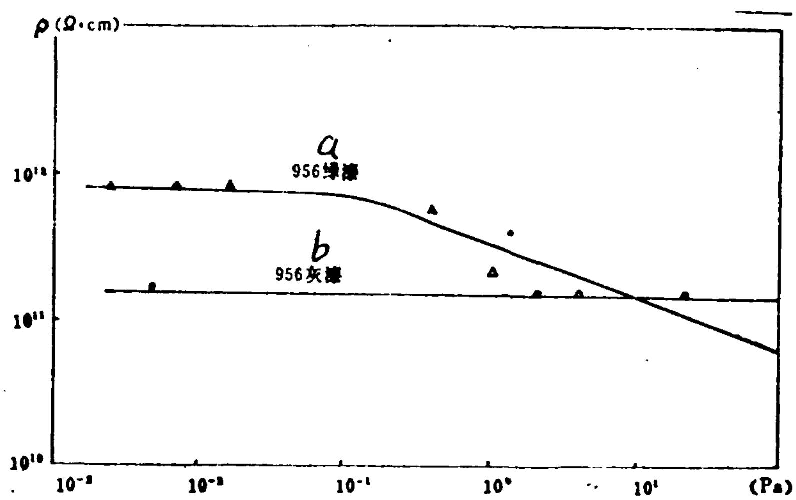

Fig. 2 Response of Surface Electroconductivity of coating to vacuum environment

Key: a - No. 956 green paint b - No. 956 gray paint

2. Response of the coating surface electroconductivity to electron radiation

Fig. 3 and 4 present, respectively, the variation rule for surface electroconductivity σ of No. 956 gray paint and No. 956 green paint in a simulated space environment exposed to electron radiation. Energy values of an electron beam in a radiation environment are 5, 10, 15, 17 and 20 kilovolts. At each stationary beam energy, density of beam current is changed to gradually increase from 0. In the experiment, the maximum density of beam current approaches 3 nanoamperes per square centimeter and above. Such density of beam current corresponds to incident flux density observed on a spacecraft flying in a magnetic layer exposed to electron radiation.

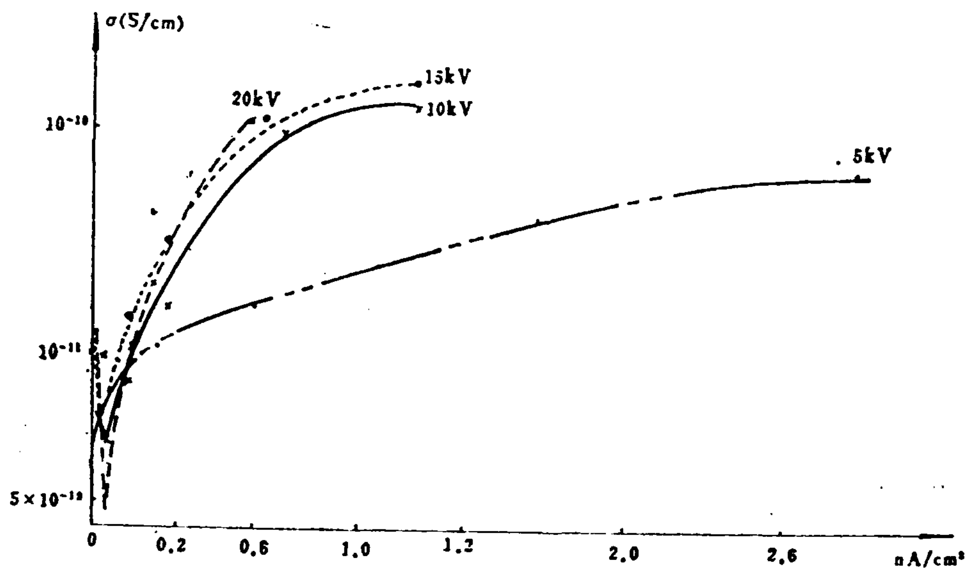

Fig. 3 Response of surface electroconductivity of No. 956 gray paint to electron radiation

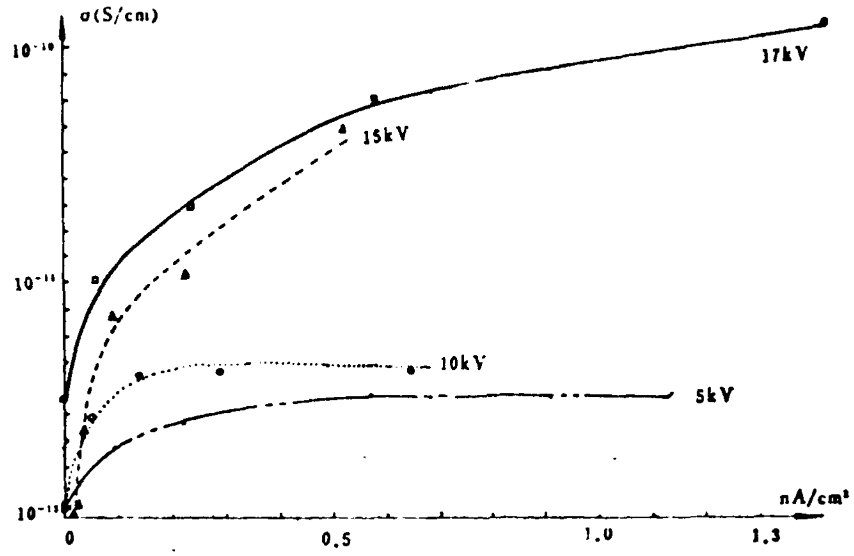

Fig. 4 Response of surface electroconductivity of No. 956 green paint to electron radiation

As revealed in experiments, both coatings are of a cavity type material because the two electroconductivity σ values follow the same process of first decreasing before abruptly rising at the beginning of electron radiation. On the sample surface to the left of the point of abrupt change, positive polarity is exhibited. However, to the right of the point of abrupt change, polarity is negative on the sample surface, exhibiting electron accumulation. At the same time, σ begins to increase with increasing density of beam current. However, in both cases the value at the point of abrupt change is extremely low, approximately less than 0.05 nanoampere per square centimeter. This is more than one order of magnitude lower than the actual incident flux density occurring in space exposed to electron radiation. It is apparent that once electron radiation occurs, both coatings change from cavity conductivity type to electron conductivity type; in addition, with increasing density of beam current, the value σ rises exponentially.

In addition, both coating layers exhibit an apparent response relationship between σ and energy of beam current. In both cases, σ increases with rising energy of incident electrons, showing that electrons with higher energy make a greater contribution to surface el ectroconductivity of the coating. In other words, electrons with higher energy tend to excite the bound electrons in deeper layers to take part in electroconductivity; thus, the rising amplitude of σ is about two orders of magnitude. In addition, the experimental results indicate that the point of abrupt change for No. 956 green paint is not as apparent as for gray paint; for green paint, the value of the abrupt change point is much smaller than 0.05 nanoampere per square centimeter, and the process of abrupt change is relatively short.

3. Response of coating surface electroconductivity to solar radiation

When both coatings are irradiated with sunlight in a container with simulated environment, the researchers discovered that the surface electroconductivity σ value rises exponentially. Value σ of gray paint jumps from a magnitude of 10^{-12} to a magnitude of 10^{-10} in only about 20 seconds. Stabilization is quickly established thereafter (Fig. 5). The phenomenon indicates that basic equilibrium has been achieved at the instant between light and carriers excited by heat. With continual light irradiation, increase of the σ value has no apparent function. In Fig. 6, having a greater irradiation memory effect, the green paint is apparently different from gray paint. The specimen was first irradiated with electrons and then placed into a simulated chamber for 14 hours before the experiment with light irradiation. During this period, the electroconductivity of the sample was unable to recover from the value of post-electron radiation (17 kilovolts in energy) of 6.9 x 10^9 ($\Omega\cdot$cm) to the value of pre-6electron radiation of 8.1 x 10^{11} ($\Omega\cdot$cm), only recovering about one order of magnitude to 4.1

$\times 10^{10}\ \Omega \cdot cm$. Hence, this was used as the initial value for experimentation of light irradiation. As revealed in experiments, the value σ of green paint rises exponentially with response to light irradiation; however, the rise is still slower than that of gray paint. After irradiation for 20 seconds, the σ value still tends to increase moderately. After irradiation for 90 seconds, the value σ has reached 6×10^{-10} s/cm. Like the memory effect of electron radiation, this sample also exhibits the memory effect of light irradiation.

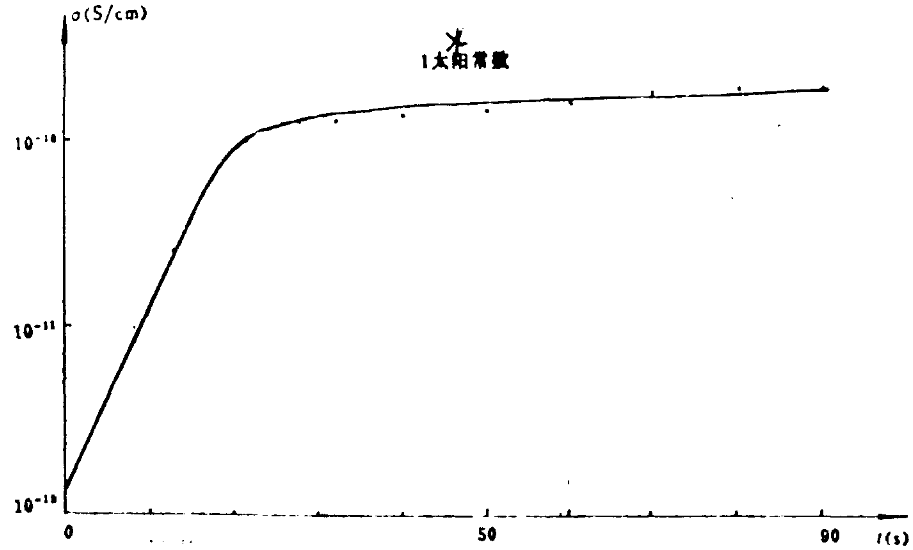

Fig. 5 Response of surface electroconductivity of No. 956 gray paint to sunlight radiation

Key: * - 1 solar constant

IV. Discussion

The following results were obtained on two heat controlled coatings for No. 956 gray paint and green paint after experimental evaluation and a study of electroconductivity properties in a simulated space environment exposing the samples to electron radiation.

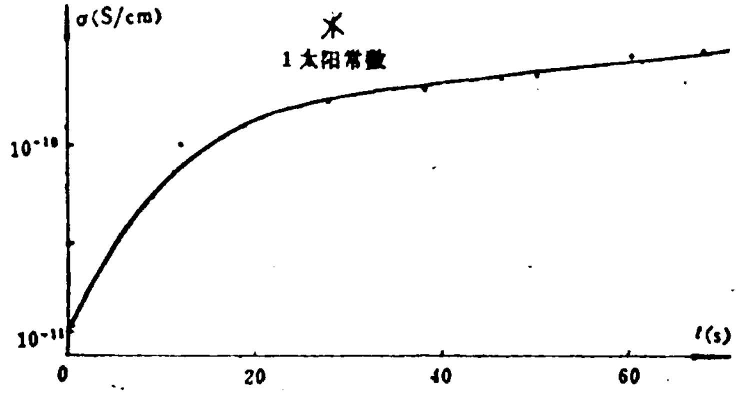

Fig. 6 Response of surface electroconductivity of No. 956 green paint to sunlight radiation

Key: * - 1 solar constant

1) In both heat control coatings with scattering type optical surface, surface electroconductivity of green paint is lower than that of gray paint in the atmosphere. In a space vacuum environment, however, conductivity of gray paint is lower than that of green paint.

2) Although both coatings are of cavity conductive regime, during exposure to electron radiation in space, both coatings quickly change to an electron conductive regime, thus greatly beneficial to improvement of surface conductivity.

3) Value σ of both coatings exhibits a positive response to solar radiation.

4) Compared to gray paint, green paint has a stronger memory effect to radiation. This is more beneficial for eliminating excessive accumulation of electrical charges on the surface.

5) Both types of coating reveal that excessive electrical charging is unlikely to occur in a space environment exposed to

electron radiation because the radiation induces quite high electroconductivity so that the electroconductivity σ is only lower by about one order of magnitude than that of the NASA norm. The potential difference caused by such a surface electrical charge is about a magnitude of 10 volts. Therefore both coatings are adaptable for application on low orbit spacecraft; undoubtedly, with their electrical properties, both coatings are also adaptable to application on surfaces of high orbit spacecraft.

The article was received for publication on 18 October.

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