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BLACK THERMAL CONTROL PAINT FOR GEOSTATIONARY SATELLITES

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ABSTRACT

A satellite with a passive thermal control system uses various thermal control materials to maintain temperatures during operation limits. Black paint is one of the thermal control materials which is used in geostationary satellites. The purpose of this paper is to study the applications of black paint used in geostationary satellites.

INTRODUCTION

The main aim of thermal control is to make sure that all the components are within their allowable temperature limits within a lifetime of the geostationary (GEO) satellite. All the equipments on the GEO satellite have to work from the beginning to end of the lifetime with the required performances. Depending on the design approach, passive and active methods are used for termal control of satellites. A passive thermal control system uses coatings and paints (black&white), multilayer insulation (MLI) and radiators to achieve the required thermal control [Anvari, et al. 2009]. Most of the GEO satellites use the passive thermal control because of the simplicity, cost, reliability, the limited mass, and power. In order to maintain the temperature of the equipments within the allowable temperature range, minimize the mass and power requirements, the thermal design is a key step to taken at the beginning of the program. Selection of surface properties and insulation are key design parameters at the beginning of the design phase of the GEO satellite. Therefore, the thermal design engineers select the passive and active thermal hardwares at the beginning of the program.

This study is intended to be broad review of black paint used in GEO satellites.

BLACK PAINTS

Materials for use in satellite design shall be a subject to a rigourous qualification and selection process [Hoły´nska, et.al, 2018]. The black coatings are one of materials used in the satellite and

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are applied on most of the internal surfaces of the satellite to improve their heat radiation chracteristics [Sharma, et.al, 1996]. Recently, the black coatings were studied in a heavy charging environment [Green, et. al, 2019]. A black coating with high solar absorptance and high thermal emittance is the best choice is such areas to avoid this large temperature gradient and maintain uniform on-orbit temperatures all the packages [Sharma, et. al, 1992]. Black paints used as passive thermal control elements in aerospace and aviation fields are polyurethane coatings that exhibit low outgassing characteristics, high thermal absortivity properties on surfaces they are used. Black coatings include in low outgassing, durable, and high thermal absorptivity. Although absorbtance and emittance values of black paints vary depending on the manufacturer, they generally have values between 0,85 < ε- emittance < 0,90 and 0,92 < α- solar absorbtance < 0,94. With advancing technology together, these values come to even better points. Black paint mainly used in satellites such as communication module (CM) panels, service module (SM) panels, batteries panels, waiveguide (WV), telecommand and receive equipments (TCR), etc. Aeroglaze A276, Aeroglaze Z306, Aeroglaze Z307 type are widely used in all satellites. Aeroglaze A276 and Aeroglaze Z306 are polyurethane-based paints that used in a variety of space applications for a variety of reasons. Aeroglaze Z306 is a flat black absorptive paint and Aeroglaze A276 is a white reflective paint . White paints, such as S 13GLO, are affected most strongly by UV radiation and charged particles, and their absorptance may rise from around 0.20 to 0.70 in just a few years [Gilmore, 2002]. Table 1 and Table 2 show white paints and black paints thermo-optical values. White paints have low absorbtance property and black paints have high absorptance property. Aeroglaze Z306 is previously known as Chemglaze Z306, the paint has been used for many years for painting the exterior of aircraft, as well as for space applications and thermal vacuum test chambers [Ash, 2008]. Black paint and other high-absorptance surfaces generally do not degrade much from space-environment exposure. Any change in black paint is more likely to be a slight reduction in absorptivity of a few percentage points from UV bleaching over time [Gilmore, 2002]. Black paint manufacturers are listed in Table 3.

Table 1: Properties of Common Black Paints [Gilmore, 2002]

Black Paints	α- Absorbtance (BOL)	ε- Emittance
Chemglaze Z306	0.92 to 0.98	0.89
3M Black Velvet	0.97	0.84

Table 2: Properties of Common White Paints [Gilmore, 2002]

White Paints	α- Absorbtance (BOL)	ε- Emittance
S13G-LO	0.20 to 0.25	0.85
Chemglaze A276	0.22 to 0.28	0.88

Table 3: Black Paint Manufacturers

Black Paints	Supplier/Manufacturers
Z306	Lord Corporation/Socomore
Z307	Lord Corporation/Socomore

Figure 1 shows a heat exchange. It can be seen from Figure 1 that emissivity value is generally stable. On the other hand, solar absorbtance value is sensitive to aging due to the UV-degrading effect of coating.

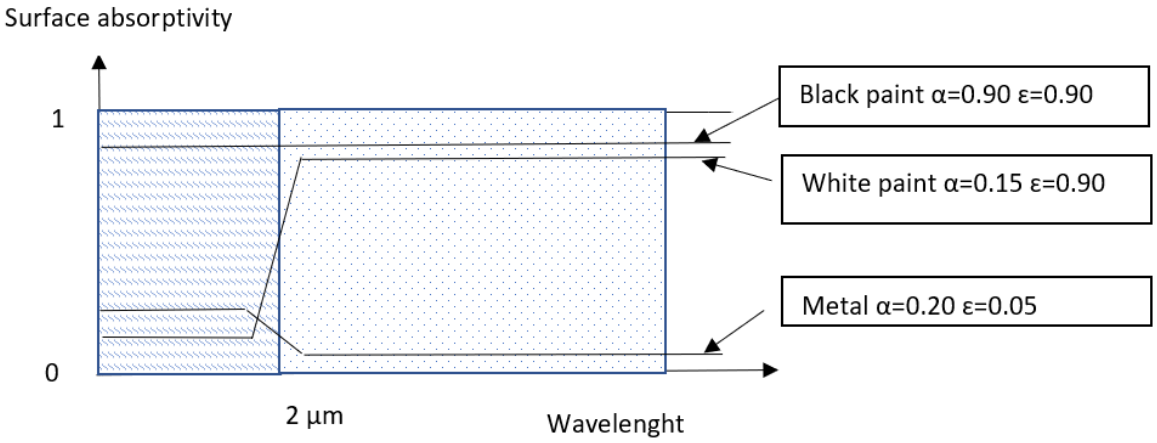

Figure 1: Heat exchange: absorptance

ANALYTICAL SOLUTIONS

The thermal control is to balance the thermal energy of the satellite to ensure all the equipments remain within their acceptable temperature limits during the worst hot and cold cases. External heat fluxes incident on each element of the satellite depend on position of satellite in orbit, satellite attitude in its current position, relative positions of the sun and earth (equinox(EQ), winter solstice(WS), summer solstice(SS)), eclipse time, and satellite geometry [Gilmore, 2002]. External and internal heat generation must be properly balanced with the excess heat radiated to space. An energy balance analysis between the space environment and the satellite can be used to determine whether or not the satellite has enough radiative area to maintain its temperature within acceptable limits for the hot case. In addition, it can be used to size survival heat power to maintain the temperature within acceptable limits for the cold case [Williams, et.al, 2006].

The steady-state temperatures uses a basic energy balance. The equilibrium temperature is obtained from condition $Q_{in}=Q_{out}$. The effects includes in the calculation are internal dissipation (Q_{id}), Solar radiation (Q_{Sun}), Albedo (Q_{albedo}), Earth radiation ($Q_{EarthIR}$) and radiation from the body to space.

The heat balance equation for node i coupled with nodes j though n is [Cherznik, 2004]

$$(Mc)_i \frac{dT_i}{dt} = Q_i^d + (\dot{Q}_{Sun} + \dot{Q}_{albedo} + \dot{Q}_{EarthIR})_i - \sum_j \Im_{ij} A_i^r (\sigma T_i^4 - \sigma T_{jr}^4) - \sum_j K_{ij}(T_i - T_{jk}) \quad (1)$$

The equilibrium temperature can be obtained by equating the heat rate inputs, where

$$\dot{Q}_{albedo} = a\alpha f_e A_s S \quad (2)$$

$$\dot{Q}_{EarthIR} = \alpha f_e q_e A_s \quad (3)$$

$$\dot{Q}_{Sun} = \alpha A_c S \quad (4)$$

$$f_e = \frac{1}{2}(1 - \cos\rho) \quad (5)$$

$$\rho = \sin^{-1}\left(\frac{R}{R+h}\right) \quad (6)$$

BLACK PAINT APPLICATION

Several types of paints were used in GEO satellites, depending on the desired thermal and optical requirements. In this study, the Aeroglaze Z306 application will be studied. During the black paint application, the following four steps are applied.

- Mixing
- Application
- Curing
- Cleanup

Before starting the black paint application,the surface (aluminum substrates) thoroughly is cleaned. After making sure that there is no dust, oil or grease, a primer is applied to increase the proper adhesion and performance of the coating.

Mixing

Before opening the lid, the black paint is mixed thoroughly for 5 minutes using a shaker. It is shaken until no settled material a is seen. After opening carefully, it is mixed the help of a clean black paint stick until a homogeneous mixture is obtained. The coating is diluted by volume to Zahn Cup #2 viscosity of 18-22 seconds using 15-20% Aeroglaze 9958 thinner. A Zahn cup is a viscosity measurement device widely used in the paint industry. Aeroglaze® 9958 thinner is used to reduce viscosities of Aeroglaze wash primers and Aeroglaze polyurethane coatings for spray applications [Socomore].

Application

Aeroglaze Z306 coating is best applied at 13-35°C (55-95°F) ambient conditions and with the aid of High Volume Low Pressure (HVLP) equipment or airless spray equipment, with substrate temperatures at least 2.8°C (5°F) above dew point. Aeroglaze Z306 is applied with a maximum of 25 dry micron or 100 wet micron (1 dry mil or 4 wet mil) per coat. Typical dry film thickness should be 38.1-50.8 micron (1.5-2.0 mil). When applying aeroglaze Z306, apply the gun right angles to surface, approximately 20.3-30.5 cm (8-12 in) with 50% overlap.

Curing

Aeroglaze Z306 coating, which is reacted with moisture in the air, cures. The curing rate depends on the relative humidity, the amount of air circulation required to remove solvent and the temperature.The coating will develop its ultimate properties within 7 days under the acceptable curing conditions. Lower temperature and humidity delay curing, while higher temperature ¾ and humidity causes bubbles. The coating is applied to a tack-free surface within 2-3 hours at 25°C (77°F) and 50% relative humidity. After the first application, Aeroglaze Z306 can be recoated within a minumum of 3 hours and 24 hours maximum. Recoating time depends on temperature and humidity. High temperature and humidity provide fast curing while low temperature and humidity slow curing. In high temperature and high humidity environment, it is recoat within 8 hours to prevent intercoat adhesion failure. In case the maximum recoating time is exceeded, the surface is roughened by sanding with fine sandpaper before recoating.

Cleanup

Aeroglaze 9958 thinner is used to clean the equipment. Lacquer thinners, water or solvents containing alcohols are not used. Figure 2-5 show an example of black painted surface. A lacquer thinner is a chemical solution that breaks or dissolves the chemical properties of varnishes and paints, lacquer, oils, grease, and other strong adhesive material.

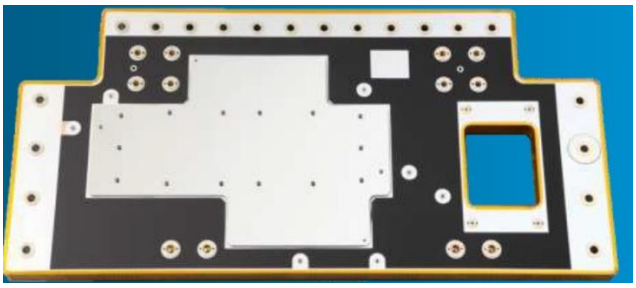

Figure 2: An example of black painted surface [APCO Technologies]

Figure 3: Picture of waiveguide components [C Tech]

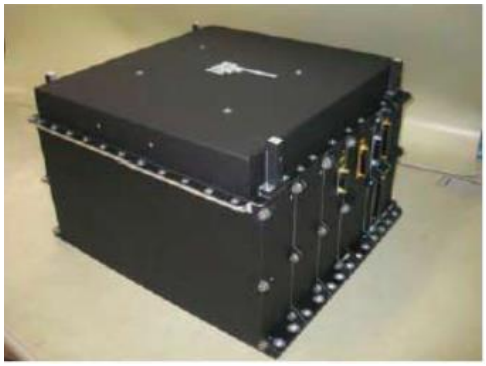

Figure 4: Picture of GEO PCU[Iwasa, et.al, 2013]

Figure 5: Picture of Solar array drive assembly SEPTA®31[RUAG Space]

CONCLUSION

The black paint is applied on most of the internal surfaces of satellite to improve their heat radiation characteristics. In this study, information about the application of black paint has been given by examining the literature written on satellites. In addition, the application of black paint have been explained.

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