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# THE SEARCH FOR MATERIALS TO MITIGATE SPACECRAFT CHARGING

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## Introduction

As spacecraft orbit the earth, they encounter a variety of particles and radiation. Charged particles are common enough that a spacecraft can collect substantial charges on its surfaces. If these charges are not bled off, they can accumulate until electrostatic discharges occur between a charged surface and some lower-potential location on the craft. Electrostatic discharge (ESD) is the suspected culprit in a number of spacecraft failures, according to *Spacecraft Environment Interactions: Protecting Against the Effects of Spacecraft Charging,* (NASA Reference Publication 1354). Silverized Teflon film has become the standard heat-reflecting outer layer of spacecraft because of its flexibility, chemical inertness, and low volatiles content. However, as spacecraft are designed to operate in orbits with greater probability of accumulating enough ions and electrons to create ESD, the Teflon-based thermal control blankets are becoming a liability. Unless stringent (and sometimes burdensome) shielding measures are taken, ESD can upset delicate electronic systems by upsetting or destroying components, interfering with radio signals, garbling internal instructions, and so on. As orbits become higher and more eccentric, as electronics become more sensitive, and as fault-free operation becomes more crucial, it is becoming necessary to find a replacement for silver/Teflon that has comparable strength, flexibility and chemical inertness, as well as a much lower potential for ESD. This is a report of the steps taken toward the goal of selecting a replacement for silver/Teflon during the Summer of 1995. It is a condensation of a much larger report available on request from the author. Three tasks were undertaken. Task 1 was to specify desirable properties for thermal control blankets. The second task was to collect data on materials properties from the literature and organize into a a spacecraft could be effectively grounded, then the floating ground potential could increase to very large levels, without ESD, and so without ESD-induced electromagnetic interference (EMI). The best way to avoid ESD in a charging environment appears to be to increase the conductivity of the TCB to a level which will allow charges to be bled off to ground as voltage levels well below the ESD threshold.

Table 1 summarizes some material property requirements for the "ideal" thermal control blanket material, compared with two of the most popular materials. The ideal TCB material will be conductive, tough, lightweight, stable to UV, radiation and oxidation, will not flake, outgas or volatilize, and will allow designers to specify the alpha/epsilon ratio to suit the needs of any given mission. The first step toward finding such a material is to gather data on existing materials, and looking for significant correlations.

Table 1: Summary of desirable material properties.

| **Property** | **Teflon + silver** | **Kapton+Z93 white paint** | **Ideal Material** |
|---|---|---|---|
| ESD potential | very great | tolerable | very slight |
| Resistivity ohm-cm | $10^{16}$ | Kapton = $10^{14}$<br>Z93 < $10^{2}$ | < $10^{8}$ |
| alpha/epsilon | 0.08/0.80 = 0.10 | 0.19/0.90 = 0.21 | 0.0/1.0, no change over lifetime |
| UV stability | stable | N/A | stable |
| Radiation Stability | not recommended | preferred | preferred |
| Atomic oxygen stability | not recommended | N/A | preferred |
| Contamination potential | slight | very great<br>(paint chips) | slight to none |

## Task 2

The database, MATDAT was compiled to give NASA engineers a compact reference for the material properties that affect choices for spacecraft applications. Special emphasis was given to polymeric materials and thermal control coatings. Other materials were chosen for inclusion because they were already used in spacecraft, or because they were under consideration for spacecraft. In all, 43 properties for 118 materials were collected. The database contains 1056 entries, which gives an overall completion of approximately 21% so the database is far from complete. The literature is fragmentary when it comes to the properties of polymers of greatest interest to spacecraft designers, namely absorptivity and emissivity of light energy, ability to withstand vacuum, radiation and atomic oxygen bombardment, and electrical properties such as resistivity and dielectric constant. Properties which depend on surface treatment, such as emissivity, are particularly hard to find in the literature. Data on atomic oxygen and radiation tolerance are largely lacking. Filling in all the empty spaces in the database is probably neither possible nor desirable. Further effort should concentrate on those values of most importance to the task at hand, which is designing space worthy craft. Each entry contains a material name, a property name, a property type, units and numerical value, then a reference. At the far right of the table are columns containing values in consistent SI units, to make graphing and comparisons easier. Extensive analysis of the data has already been done, and the results are discussed in the full report, available from the author or the author's colleagues, on request.

Note: Some properties are given more than once, from different sources. This serves to show the range of values reported in the literature. This should also be a warning that these numbers should be used with caution. They are good enough to be used for screening purposes, or to debate trade-offs, but any particular material should be tested *in the form in which it is going to be used*, before precise calculations can be made or relied upon.

**Task 3**

During the analysis of the data being collected in MATDAT, it was noticed that values given for the resistivity for polyethylene were lower than any other polymer, except 'conductive' and 'anti-stat' grades. Therefore, samples of UV stabilized film grade low density polyethylene (LDPE) film were obtained from Eastman Chemical Co. in Longview, Texas. The samples were tested for absorptivity and emissivity at the MSFC materials testing lab, and results are contained in Table 2, below. The film samples were 3 mil thick. The absorptivity of the film was measured without a mirrored back surface. The high density polyethylene sample was included for comparison. The small value of the standard deviation on all four sets shows that the tests have good repeatability. It also appears that there is little reason, based on absorptivity or emissivity to choose one of these grades over another. The absorptivity of the HDPE is only slightly better than the two grades of LDPE, and its emissivity is essentially the same.

Compared to silverized Teflon, these polyethylene samples have about double the absorptivity, and about one third of the emissivity. This does not indicate that these samples are immediate replacements for silver/Teflon, but it is worth pointing out that these PE samples were run-of-the-mill film with no special effort made to obtain clarity, and no silver backing applied. Given that the clarity of PE film is highly dependent on the rate of cooling during the film drawing process, clearer film is probably attainable. Therefore there appears to be room for improvement in the absorptivity of these PE films. As it is, the absorbtivity of the PE films is about equal to the absorptivity of white thermal control paints, like Z93, at the beginning of their lives.

The values for the emissivity are another story. The emissivity of the gold/PE is only 36% of that of 5 mil thick silver/Teflon, and only 45% of that of 2 mil thick silver/Teflon. Since emissivity is so strongly dependent on surface properties, it would be worth investigating PE films of varying surface roughness. Unless the emissivity of PE films can be brought up to at least 0.7, their advantageous electrical properties will not offset their thermal disadvantage in comparison with silver/Teflon.

Table 2: Thermal properties of polyethylene samples.

| Material | absorptivity | emissivity | alpha/epsilon |
|---|---|---|---|
| $MgF_2$ Mirror | 0.088 | N/A | |
| High density PE | 0.156 | 0.293 | 0.53 |
| PE1-3 A | 0.169 | 0.294 | |
| PE1-3 B | 0.173 | 0.295 | |
| PE1-3 C | 0.174 | 0.293 | |
| PE1-3 AVG. | 0.172 ± 0.0026 | 0.294 ± 0.0010 | 0.59 |
| PE2-3 A | 0.176 | 0.294 | |
| PE2-3 B | 0.176 | 0.294 | |
| PE2-3 C | 0.177 | 0.296 | |
| PE2-3 AVG. | 0.176 ± 0.0006 | 0.295 ± 0.0012 | 0.60 |
| Silver/Teflon, 2 mil | 0.08 | 0.66 | 0.12 |
| Silver/Teflon, 5 mil | 0.08 | 0.82 | 0.10 |

## Conclusions.

As part of this project, a database of material properties for materials important to spacecraft was established. In all 43 properties of 118 materials were surveyed. As of the date of this report, the database is approximately 21% filled. It will not be advisable to attempt to complete the 43 by 118 matrix of property values versus materials. Instead, it is desired to use the data gathered heretofore to decide where to concentrate further data-gathering efforts. The three properties of greatest interest for identifying candidates to replace Teflon as a thermal control blanket material are the electrical resistivity, the solar absorptivity, and the emissivity. As discussed above, several other properties, including the dielectric constant and the dielectric strength seem to be of little importance to the choice of candidate materials.

Polyethylene samples were obtained from Eastman Chemical Co. in Longview Texas. Polyethylene resin seemed attractive from the literature value of $10^7$ to $10^9$ ohms-cm for resistivity. The samples have been undergoing testing at the MSFC materials testing lab, and preliminary results indicate that the thermal properties are not as good as those of silver/Teflon, but that further testing seems warranted.

Several gaps in the published literature of material properties were found in the course of this study. For example, electrical resistivity values are lacking for many of the thermal control paints commonly used in space, and for which the thermal properties (absorptivity and emissivity) are well documented. In general, the resistivity of polymeric materials has been published, without any data on the thermal properties.

Conductive grades of several polymers have been coming into commercial production for applications in the computer and electronics industries. These polymers deserve scrutiny as candidate materials, as they have resistivities as low as $10^3$ ohms-cm. However, all of these polymers are untried in an orbital environment, and extensive testing will need to be done. In particular, there is no data on atomic oxygen and UV stability of these resins. As some anti-static additives work by absorbing water to the surface of the polymer, it is expected that these additives should be avoided as candidate materials, because the vacuum of space will deplete the surface-bound water, and diminish the surface conductivity. It may not be common knowledge among polymer manufacturers which additives work in this manner, and so a screening test may have to be devised. This would probably consist of performing the standard test for resistivity in a vacuum environment.

**Recommendations.**

Electrical resistivity, solar absorptivity and emissivity seem to be the properties most valuable in screening candidate materials for thermal control blanket applications in charging environments. Values of all these properties for any single material were not available in the literature.

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Therefore, there is a need for the values to be generated experimentally for a variety of candidate materials.

During the course of this study, the author became aware of the commercial availability of polymer resins which have very low resistivities; on the order of $10^3$ ohms-cm. These polymers should be investigated as candidates for thermal control blanket applications. Anticipated problems are UV stability, atomic oxygen stability, and retention of low resitivity in a vacuum environment.

Testing on the polyethylene film samples obtained from Eastman Chemical Co. should continue. Of particular interest is their behavior in a simulated space environment. Preliminary results indicate that thermal properties are not as good as silver/Teflon, and methods to improve them should be investigated.

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