DDE Annual Report

Title of Investigation:

Composite Coating For Passive Cryogenic Cooling

Principal Investigator:

Dr. Alan Kogut (Code 685)

In-house Members of the Team:

Dr. Edward Wollack (Code 685) and Lonny Kauder (Code 545)

Initiation Year:

FY 2004

Aggregate Amount of Funding Authorized in FY 2003 and Earlier Years:

$0

FY 2004 Authorized Funding :

$39,000

Actual or Expected Expenditure of FY 2004 Funding:

In-house: $16,000; Contracts: $23,000 (JMD Manufacturing, $7,000; Newark Electronics, $7,000; McMaster-Carr, $4,000; Custom Microwave, $3,000; and Penn Engineering, $2,000)

Status of Investigation at End of FY 2004:

Transitioned to other funding: Research and Technology Objectives and Plans (RTOP), NASA Astrophysics Research and Analysis

Expected Completion Date:

September 2006

Purpose of Investigation:

The purpose of this investigation is to develop a paint that could passively cool large surfaces to temperatures below 70 Kelvin (K). NASA's strategic plan anticipates large-aperture instruments operating at cryogenic temperatures. Passive cooling to deep space is a critical component of all such systems, either directly through passive cooling of the optical elements or indirectly through passive cooling of radiator panels that then reject heat from the warm stage of mechanical cryo-coolers.

Existing paints have significant problems with surface preparation, adhesion, and handling. These paints are fragile and flake easily under routine handling and thermal stress. Their emissivity—how well they emit or absorb heat—at long wavelengths is limited by their inability to form thick layers (a few hundred microns); this in turn, limits the cooling power at temperatures below 100 K. In this investigation, we planned to:

- Develop high-emissivity coatings suitable for passive cooling below 100 K.
- Characterize the optical, electrical, and mechanical properties of stainless steel-loaded epoxy composites to improve their ability to cool large apertures in space.
- Use stainless-steel powder suspended in commercially available epoxy adhesives.

FY 2004 Accomplishments:

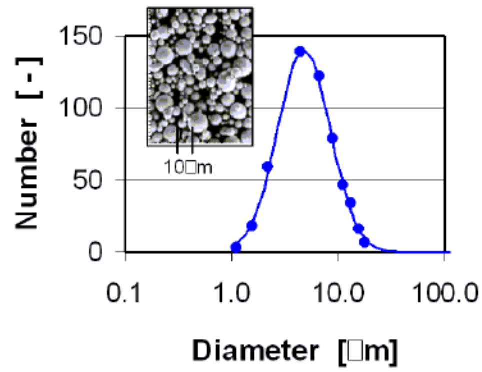

Figure 1. Measured size distribution for commercially available stainless steel powder. The grain size distribution peaks between 5 and 8 mm, well suited for emission at far-infrared wavelengths l > 30 mm.

We have measured the optical, mechanical, and thermal properties of stainless-steel-loaded epoxy to demonstrate that such a composite material is well suited for use as a high-emissivity paint for passive cooling. At temperatures below 200 K, emission occurs at far-infrared wavelengths. Commercially available far-infrared absorbers include iron-loaded epoxies, such as Emerson & Cumin Eccosorb CR-112. These materials have high emissivity, but do not adhere to metals well enough to form the thin layers needed for paints. Similar metal/epoxy composites can be formed using different base epoxies. Emerson & Cuming Stycast 2850 is an epoxy commonly used for cryogenic applications; it adheres well to metals even at temperatures near absolute zero. When mixed with a fine powder (10 micron grain size) of iron or stainless steel, it forms an emissive coating well suited for passively cooling large structures in space. Figure 1 shows the grain size distribution for commercially available stainless-steel powder. The grain diameter d < 10 mm is well suited for emission at far-infrared wavelengths.

We have tested absorptive composites using Stycast 2850 and either fine iron or stainless-steel powder. Since stainless steel is an amalgam, its conductivity tends to change very little from room temperature to cryogenic temperatures. Thus, room-temperature measurements correspond closely to the performance below 100 K. Figure 2 shows the measured dielectric properties of a Stycast/stainless steel composite as a function of the stainless-steel volume-filling factor. The emissivity of a thin coating is related to the dielectric properties as:

$$e = \frac{2\pi\eta \tan(\delta)}{\lambda}$$

where λ is the emitted wavelength, n is the index of refraction, and the loss tangent is given by the ratio of the real to imaginary parts of the dielectric constant, $\tan(\delta) = \varepsilon'/\varepsilon''$. The predicted emissivity is very high, e > 0.8 in the far infrared. Achieving such high emissivity requires a high metal loading, with volume fill factors of 20% or more. Simply loading the epoxy with metal powder produces a putty-like consistency, ill suited for paint-like applications. Diluting the epoxy with acetone alleviates this problem. Since acetone evaporates quickly compared with the curing time of the epoxy, even highly diluted mixtures can cure completely.

Stainless steel/Stycast composites also have very desirable mechanical properties. The coefficient of thermal expansion for a stainless steel/Stycast composite is very close to bare metal. In addition, in thin layers, the mixture remains pliable after curing and can deform slightly to take up the mechanical stress induced by any residual differential thermal contraction. Figure 3 shows an extreme example. We painted a 175-mm layer of stainless steel/Stycast composite onto a thin aluminum strip, which was then cured and dunked 10 times into liquid nitrogen for a worst-case thermal shock. After 10 cooling/warming cycles, the emissive coating showed no cracking or delamination even when bent.

Two papers describing the material properties of stainless steel/Stycast composite and its application as an absorber at far-infrared wavelengths are currently in preparation.

Planned Future Work:

We have obtained funding under NASA's Astrophysics Research and Analysis program to continue developing metal/epoxy composites as a high-emissivity paint. We will directly measure the emissivity at far-infrared wavelengths using a Fourier transform spectrometer to compare the measured emissivity to predictions based on the measured dielectric properties. We also plan to develop techniques and detailed procedures for applying thin layers over large areas.

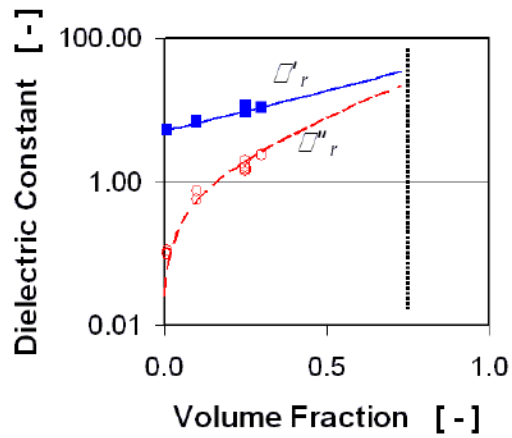

Figure 2. Measured dielectric constant as a function of stainless steel volume filling fraction. The squares and circles indicate the measured real and imaginary components of the relative dielectric constant, respectively. The lines show the modeled response at 30 GHz under the assumption that the particles are ~9 micron spheres with a bulk resistivity of ohm-cm. Volume filling fractions up to ~0.3 are achievable by dilution with acetone. The dotted vertical line shows the limit set by particle geometry and distribution.

Summary:

Adding a metal powder to a commercially available cryogenic epoxy produces a highly emissive coating suitable for passively cooling spacecraft components to temperatures below 100 K. The composite has markedly better mechanical and optical properties than the paints used to passively cool the Cosmic Background Explorer or the Wilkinson Microwave Anisotropy Probe. We can exploit the improved mechanical and optical properties of stainless steel/Stycast composites to improve the passive cooling of radiators or large optical systems in space. By controlling the thickness of the emissive layer, we should be able to passively cool below 50 K, bringing passive cooling techniques to the lower temperatures expected for future space missions in the far infrared. Our success criteria include achieving emissivity greater than 0.8 at wavelengths 30 < l < 1000 mm and developing a process to reapply paint in controlled thicknesses of up to 0.5 mm. Technical risks include: 1) acetone dilution may cause settling of stainless steel particles during cure, which would lower the emissivity of the composite layer and 2) accumulated thermal stress over a large (square-meter) surface area may lead to cracking or delamination of the emissive layer.

Figure 3. Stainless steel/ Stycast composites remain pliable in thin layers even after repeated immersions in liquid nitrogen. The high adhesion to metal surfaces is a very desirable property for emissive paints.