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Thermophysical Properties of SUPER THERM Coating

A Report to Superior Products International II, Inc.

by

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INTRODUCTION

A gallon of SUPER THERM coating and a metal plate were submitted for thermophysical property testing from room temperature to 100°C. Specific heat (C_p) was measured using a differential scanning calorimeter (ASTM E1269) and the thermal diffusivity (α) was measured using the laser flash technique (ASTM E1461-92). Several different thicknesses of coating were tested. The bulk density (d) was calculated from sample geometries and mass. The thermal conductivity (λ) was calculated as a product of these quantities, i.e. $\lambda = \alpha C_p d$.

The conductivity/diffusivity of one layer in a multi-layer composite is determined from the temperature rise curve of layered samples. The half rise time values are measured in the same fashion as that for single layer experiments. The half time value is corrected for heat losses using the Cowan Correction procedure. It is necessary to measure the thermal diffusivity of all but one layer and the specific heats of all layers in separate experiments prior to the calculations of the conductivity/diffusivity of the unknown layer. The diffusivity and conductivity of the unknown layer are calculated simultaneously from the temperature rise curve of layered samples using computer programs called TWOLA or THRLA. The input parameters for these programs include the thicknesses, densities and specific heats of all layers.

Thermal diffusivity is determined using the laser flash diffusivity method. In the flash method, the front face of a small disc-shaped sample is subjected to a short laser burst and the resulting rear face temperature rise is recorded and analyzed. A highly developed apparatus exists at TPRL (Figure 1) and we have been involved in an extensive program to evaluate the technique and broaden its uses. The apparatus consists of a Korad K2 laser, a high vacuum system including a bell jar with windows for viewing the sample, a tantalum or stainless steel tube heater surrounding a sample holding assembly, a thermocouple or an i.r. detector, appropriate biasing circuits, amplifiers, A/D converters, crystal clocks and a microcomputer based digital data acquisition system capable of accurately taking data in the 40 microsecond and longer time domain. The computer controls the experiment, collects the data, calculates the results and compares the raw data with the theoretical model.

Specific heat is measured using a standard Perkin-Elmer Model DSC-2 Differential Scanning Calorimeter (Figure 2) with sapphire as the reference material. The standard and sample were subjected to the same heat flux as a blank and the differential powers required to heat the sample and standard at the same rate were determined using the digital data acquisition system. From the masses of the sapphire standard and sample, the differential power, and the known specific heat of sapphire, the specific heat of the sample is computed. The experimental data are visually displayed as the experiment progresses. All measured quantities are directly traceable to NBS standards.

RESULTS AND DISCUSSION

Table 1 lists the diffusivity sample's dimensions, masses and bulk density values. The average density for the metal plate and the paint were used in the conductivity calculations.

The specific heat results for the plate and the paint are listed in Table 2 and are plotted in Figure 3.

The thermal diffusivity results for the plate are shown in Figure 4 and are included in Table 3 along with the results for the paint, which are plotted in Figure 5.

The thermal diffusivity of a material should not depend on its thickness except when the thickness is very thin. The differences that are present are most likely due to uncertainties in the thickness. Errors in the thickness are squared in the thermal diffusivity determinations, so that the ~10% difference in diffusivity at 100°C would translate into a 3.3% difference in the thickness, i.e. using a value of 0.0154 cm in place of 0.0149 cm for the thickness (a difference of only 0.0005 cm) would bring the diffusivity values into agreement.

The thermal conductivity calculations of the metal plate are presented in Table 4 and the results are plotted in Figure 6. The calculations for the paint are given in Table 5 and shown in Figure 7.

We attempted the three layer case with the coating on both sides of the plate, but did not get reasonable results. We applied a thin SiC layer to the front surface in case the laser beam was penetrating the SUPER THERM coating. Since adding a SiC layer turned the problem into four layers and the programs are limited to three layers, we had to assume that the SiC had no effect on the experiment or combine one of the paint layers with the metal plate to make it effectively one layer. With either assumption, we could not get reasonable results. We concluded the high sensitivity to the thicknesses of the thin layers was preventing the calculation of the diffusivity/conductivity. If the layers were thicker the results should have been the same as those determined by the two layer case.

The thermal resistance (R_{total}) of a layered material being equal to the sum of the thermal resistance of each layer when there is no contact resistance, that is: $R_{total} = R_1 + R_2 + ... R_n$ with $R_n = P_n/\lambda_n$. P_n is the relative thickness of layer n, i.e $P_n = T_n/T_{total}$ and λ_n = thermal conductivity of layer n. So the thermal resistance of a material with any layer thicknesses can be calculated from the thicknesses and conductivities of the individual layers.

It should be noted that the conductivity of the paint is independent of the surface to which it is applied - that is, the conductivity of the paint is the same on a metal or a concrete surface.

TABLE 1

Sample Dimensions, Masses and Density Values

Sample (No.)	Thickness (cm)	Width (cm)	Length (cm)	Mass (gm)	Density (gms cm^{-3})
1	0.0844	1.2800	1.2862	1.07509	7.737
2	0.0843	1.2824	1.2858	1.07928	7.764
3	0.0844	1.2773	1.2826	1.07056	7.743
4	0.0841	1.2802	1.2814	1.06969	7.754
5	0.0844	1.2785	1.2824	1.07005	7.733
1+PAINT	0.0149	1.2800	1.2862	0.03819	1.556
2+PAINT	0.0397	1.2824	1.2858	0.11217	1.716
3+PAINT	0.0474	1.2773	1.2826	0.12874	1.657
4+PAINT F	0.0211	1.2802	1.2814	0.05740	1.661
4+PAINT FB	0.0411	1.2802	1.2814	0.10808	1.603

TABLE 2

Specific Heat Results

Temperature (C)	Specific Heat (W-s/gm-K) Paint	Specific Heat (W-s/gm-K) Plate
23.0	1.1861	0.4407
30.0	1.2110	0.4474
40.0	1.2400	0.4561
50.0	1.2661	0.4638
60.0	1.2870	0.4707
70.0	1.3111	0.4770
80.0	1.3305	0.4828
90.0	1.3540	0.4906
100.0	1.3695	0.4951

TABLE 3

Thermal Diffusivity Results

Temperature (C)	Plate ($cm^2\ sec^{-1}$)	t=0.0149 cm ($cm^2\ sec^{-1}$)	t=0.0397 cm ($cm^2\ sec^{-1}$)	t=0.0474 cm ($cm^2\ sec^{-1}$)
23.0	0.14800	0.00279	0.00324	0.00324
50.0	0.14700	0.00272	0.00303	0.00311
75.0	0.14200	0.00271	0.00287	0.00300
100.0	0.13800	0.00256	0.00274	0.00285

TABLE 4

Thermal Conductivity Calculations

Sample (No.)	Temp. (C)	Density (gm cm^{-3})	Specific Heat (W-s-$gm^{-1}K^{-1}$)	Diffusivity (cm^2 sec^{-1})	Conduct. (W-cm^{-1} K^{-1})	Conduct. (BTU *)	Temp (F)
Plate	23.0	7.746	0.4407	0.14800	0.50523	350.54	73.4
	50.0	7.746	0.4638	0.14700	0.52808	366.39	122.0
	75.0	7.746	0.4800	0.14200	0.52796	366.30	167.0
	100.0	7.746	0.4951	0.13800	0.52925	367.20	212.0

* (BTU in hr^{-1} ft^{-2} F^{-1})

TABLE 5

Thermal Conductivity Calculations

Sample	Temp.	Density	Specific Heat	Diffusivity	Conduct.	Conduct.	Temp
(No.)	(C)	(gm cm^{-3})	(W-s-gm^{-1}K^{-1})	(cm^{2} sec^{-1})	(W-cm^{-1} K^{-1})	(BTU *)	(F)
t=0.0149	23.0	1.639	1.1871	0.00279	0.00543	3.77	73.4
	50.0	1.639	1.2657	0.00272	0.00564	3.92	122.0
	75.0	1.639	1.3211	0.00271	0.00587	4.07	167.0
	100.0	1.639	1.3695	0.00256	0.00575	3.99	212.0
t=0.0397	23.0	1.639	1.1871	0.00324	0.00630	4.37	73.4
	50.0	1.639	1.2657	0.00303	0.00629	4.36	122.0
	75.0	1.639	1.3211	0.00287	0.00621	4.31	167.0
	100.0	1.639	1.3695	0.00274	0.00615	4.27	212.0
t=0.0474	23.0	1.639	1.1871	0.00324	0.00630	4.37	73.4
	50.0	1.639	1.2657	0.00311	0.00645	4.48	122.0
	75.0	1.639	1.3211	0.00300	0.00650	4.51	167.0
	100.0	1.639	1.3695	0.00285	0.00640	4.44	212.0

* (BTU in hr^{-1} ft^{-2} F^{-1})