ThermTest Inc
ThermoPhysical Measurements & Instrumentation

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CLIENT	Advanced Coating Solutions	**DATE**	July 25, 2014
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SUBJECT:

Reporting of the results for the measurement of **Axial (through-plane)** and **Radial (in plane) Thermal Conductivity (W/m·K)** and **Axial (through-plane)** and **Radial (in plane) Thermal Diffusivity (mm^2/s)** of an insulation coating sample, received from Advanced Coating Solutions. Thermal properties were determined at 100°C as per project requirements.

The ThermTest TPS 2500 S Thermal Constants Analyzer was the instrument used for all thermal conductivity measurements. **The TPS 2500 S meets the ISO Standard ISO/DIS 22007-2.2**.

EXPERIMENTAL:

There were two stock sample pieces received for the measurement of thermal properties. The stock sample was identified as **.75 mm Double Sided Coat**.

Directional thermal properties were measured using the **TPS Anisotropic Analysis Method**. In making anisotropic measurements with the TPS system, the following assumptions are made:

- The main directions in the material to be measured are orthogonal and can be described in terms of x-, y- and z-axes.
- The properties along the radial direction (x- and y-axes) are identical and the properties along the axial direction (z-axis) are different.

Sample size limitations are important with anisotropic measurements and must be taken into consideration when analyzing results.

When measurements are made, the TPS sensor is placed between two sample pieces, each with plane surfaces facing the sensor. The solution to the thermal conductivity equation assumes the sensor is in an infinite medium, so the measurement and analysis of data must account for the available sample size and limitations in both the axial and radial directions of the sample.

The nominal thickness of the stock samples was 0.90 mm. To measure this material with only 1 sample layer on each side of the TPS sensor would be difficult with only 0.90 mm of penetration depth for the heat that dissipates from the TPS sensor into the sample. For this reason, 12 sample pieces with nominal dimensions of 40 mm by 40 mm by 0.90 were cut from the stock samples. Then 6 sample layers were positioned on each side of the TPS sensor. This afforded a penetration depth in the radial direction of the sample of slightly more than 5 mm. Light clamping pressure was applied to the sample/sensor assembly for the measurements.

In addition, it is vital to orient the sample pieces and the TPS sensor correctly according to the main directions in the material being measured. The TPS sensor is positioned so that it is perpendicular to the axial direction (z-axis) and parallel with the radial direction (the plane formed by the x- and y-axes).

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With only one measuring position of the TPS sensor possible; **Volumetric Heat Capacity (MJ/m³·K)** is a required input to resolve thermal properties in two directions by the Anisotropic Analysis Method.

Specific Heat Capacity (and for our purposes Volumetric Heat Capacity) was measured for the coating sample using the Specific Heat Analysis Method. The **TPS Specific Heat Analysis Method** is used to determine the specific heat capacity of isotropic or anisotropic materials with a thermal conductivity typically greater than 0.2 W/m·K.

From the specific heat measurement, the results given are heat capacity (**J/K**) and with input of sample mass (**kg**) and density (**kg/m³**) prior to measurement, you will also have results expressed in terms of specific heat capacity (**J/kg·K**) and volumetric heat capacity (**MJ/m³·K**).

RESULTS:

For thermal property measurements at 100°C, the experimental setup was placed in a CascadeTEK Model TFO-1 forced air lab oven. The chamber temperature was set and monitored with the onboard Watlow "ramp & soak controller". For both the specific heat and anisotropic measurements of the coating sample, once at measurement temperature the tolerance on the chamber temperature was monitored to be within ± 2°C for 30 consecutive minutes. This was followed by the tolerance for sample temperature at the sample interface being checked to be within ± 1°C for 30 consecutive minutes. This was to confirm the test chamber and sample were isothermal prior to measurements.

Bulk thermal conductivity was also measured at 100°C. This additional testing was done to highlight the difference between a bulk average result for thermal conductivity of a material known to have directional properties and the actual directional properties found by the anisotropic method.

The idea would be that the bulk thermal conductivity would be a weighted average of the thermal conductivity in the two sample planes and would be at value that would fall somewhere between the measured axial thermal conductivity and radial thermal conductivity.

Multiple measurements were done to confirm reproducibility; the results are found in the following tables.

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Table 1. .75 mm Double Sided Coat - Specific Heat Results at 100°C

Temperature (°C)	Heat Capacity (J/K)	Specific Heat Capacity (J/kg·K)	Volumetric Heat Capacity ($MJ/m^3·K$)
100	1.078	1182.2	0.6387
	1.074	1178.1	0.6365
	1.074	1177.5	0.6362
Mean	1.075	1179.3	0.6371
Standard Deviation	0.002	2.1	0.0011
RSD (%)	0.2	0.18	0.18

Notes: Measurements were made using the TPS Specific Heat Method. A test time of 40 seconds and output of power to the TPS sensor of 0.1 Watts was determined to be optimal measurement parameters. For all measurements, data using points 100 to 200 was reported.

Table 2. .75 mm Double Sided Coat - Directional Thermal Properties at 100°C

Temperature (°C)	Axial Thermal Conductivity (W/m·K)	Axial Thermal Diffusivity (mm^2/s)	Radial Thermal Conductivity (W/m·K)	Radial Thermal Diffusivity (mm^2/s)
100	0.1180	0.1852	0.1772	0.2781
	0.1179	0.1850	0.1766	0.2773
	0.1179	0.1851	0.1776	0.2788
	0.1171	0.1838	0.1805	0.2833
	0.1170	0.1837	0.1810	0.2841
	0.1177	0.1847	0.1796	0.2819
Mean	0.1176	0.1846	0.1788	0.2806
Standard Deviation	0.0004	0.0006	0.0017	0.0026
RSD (%)	0.3	0.3	0.94	0.94

Notes: Measurements were made using the TPS Anisotropic Analysis Method and TPS sensor #5501 (6.403 mm radius) with Kapton® insulation. A test time of 40 seconds and output of power to the TPS sensor of 0.025 Watts was determined to be optimal measurement parameters.

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Table 3. .75 mm Double Sided Coat - Bulk Thermal Conductivity at 100°C

Temperature (°C)	Bulk Thermal Conductivity (W/m·K)
100	0.1456
	0.1448
	0.1455
	0.1444
	0.1448
	0.1455
Mean	0.1451
Standard Deviation	0.0005
RSD (%)	0.3

Notes: Measurements were made using the TPS Anisotropic Analysis Method and TPS sensor #5501 (6.403 mm radius) with Kapton® insulation. A test time of 40 seconds and output of power to the TPS sensor of 0.025 Watts was determined to be optimal measurement parameters.

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