Thermal Conductivity Evaluation Report - TPS

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		Report Type	Final
Contact	Graeme Sargent	**Rev.**	3.0[1]

Test Details and Example Setup

Sample(s) Submitted: 4
Sample(s) Tested: 1 (Zenova IR 5mm)
Test Method(s): TPS
Accessory(s): N/A
Sensor Size(s): 6mm
Temperature Condition(s): Ambient
Atmospheric Condition(s): Ambient

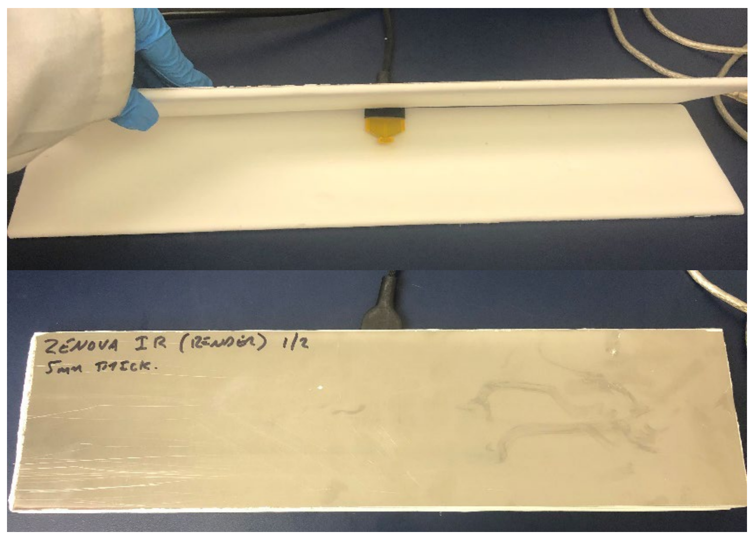

Figure 1. Example Test Setup

Procedure

Details on the operation of the Trident, the test method, and the analysis of results are provided in **Appendix 1**. Zenova IR 5mm brick sample was tested using the 6mm TPS sensor with the Bulk testing utility. Both specimens of the sample were found to be of valid testing thickness. Sample was tested using the Polymers calibration (0.01W power and 2 second test time). Sample was used to sandwich the sensor (**Figure 1**) and a weight was placed on top to ensure good contact between sample and sensor. 5 measurements were taken to test for repeatability in different areas of the sample.

[1] This revision specifies sample tested- 5mm IR sample and removes thin film testing completed on another material.

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Detailed Results

Table 1. Thermal Conductivity Results

Test #	Thermal Conductivity (W/mK)	Average Thermal Conductivity (W/mK)	RSD (%)	Thermal Diffusivity (m^2/s)	Average Thermal Diffusivity (m^2/s)	RSD (%)
1	0.0672	0.0728	4.6	2.07E-06	2.23E-06	9.3
2	0.0729			2.55E-06		
3	0.0733			2.17E-06		
4	0.0760			2.04E-06		
5	0.0744			2.31E-06		

Discussion

1 sample provided by Zenova Group was tested using the TPS (Transient Plane Source) method. Thermal conductivity was found to be relatively consistent in different locations of the sample (4.6% RSD). Care was taken to ensure penetration depth of heat pulse stayed below 5mm (thickness of sample) to ensure valid analysis.

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Appendix 1: C-Therm Trident Thermal Conductivity Analyzer

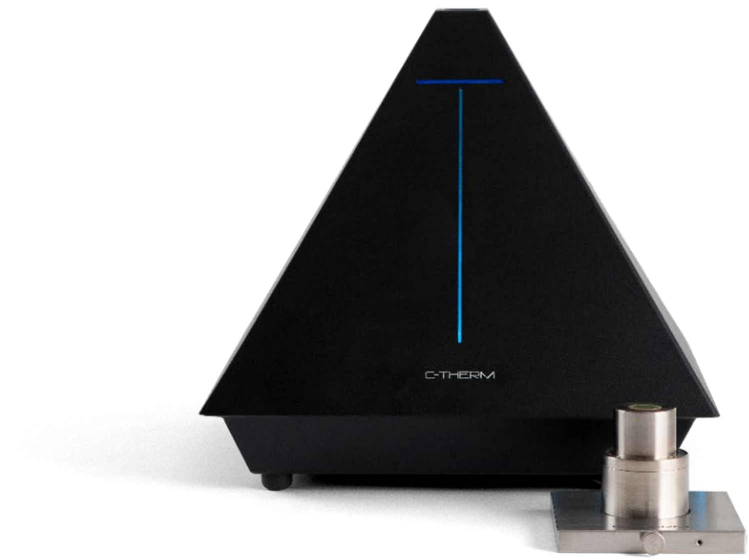

Figure A1. C-Therm's Trident Controller & MTPS Sensor

The C-Therm Trident is a modular system that uses different sensor configurations to accommodate a wide range of sample types. When operated with a Transient Plane Source (TPS) sensor, it is an integrated solution for thermal conductivity and thermal diffusivity measurement and operates in compliance with ISO Standard 22007-2.

The TPS sensor is a double-sided, interfacial heat reflectance device that applies a constant current heat source to the sample. The interfacial sensor heats the sample by approximately 1-3°C during the testing. The sample's thermal properties define the dissipation of the heat, and causes a distinct temperature rise at the sensor interface. The temperature behavior of the sensor is recorded with time. Following a test, the raw data are fitted to the model appropriate to the sample with thermal conductivity, thermal diffusivity and a time correction factor as fitting constants. Thermal conductivity and diffusivity are measured directly in an absolute manner, without the use of comparative method calibrations.

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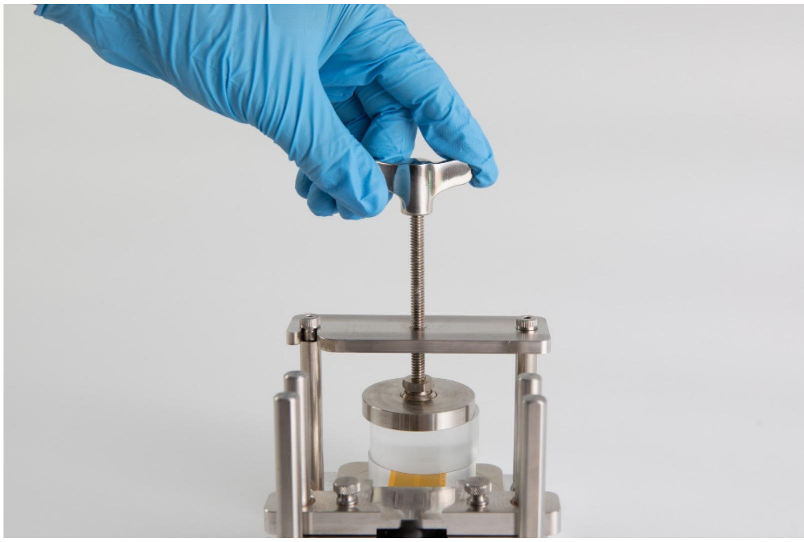

Figure A2. TPS Sample Clamp

For solid bulk and anisotropic style samples: Two identical sample specimen halves are sandwiched around the sensor surface and clamped into position using the TPS testing clamp shown in **Figure A2.**

Figure A3. Operation of the Powders Test Cell

For powder samples: The powder test cell is prepared by filling the test chamber to the first fill line shown in the powder test cell in **Figure A3**. The TPS sensor is mounted into the housing of the powder test cell as shown in **Figure A3**. The powder is then placed into the cell over the sensor surface until the cell is full of the sample material. To ensure uniform testing, a small mass is placed on top of the powder test cell.

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Figure A4. Reverse operation of the clamp assembly.

For large samples: The Trident TPS clamp may be operated in reverse testing mode as shown in **Figure A4** to test samples under elevated pressures or which produce hazardous off-gasses. In this case, an TPS sensor is mounted into the clamp but the cross-bar is reversed. The sample is placed behind the clamp and mounted around the sensor as normal. For light samples where contact may be a challenge, a weight may be employed to ensure adequate pressure.

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Appendix 2: Reference Material Test Results

The accuracy of Trident measurements under specific test conditions can be determined by measuring a reference material under the same conditions. Reference materials have precisely known and externally certified thermal conductivity values. A comparison of the measured thermal conductivity of the reference material against its known thermal conductivity value allows the accuracy and bias of the measurement to be quantitatively determined for a given set of test conditions. These accuracy and bias figures are applicable to the results for test sample measurements under these test conditions and must lie within specified limits.

An accuracy check is always performed on a Trident prior to its use in any analytical measurements. This check requires that the measured value of the thermal conductivity of the standard reference material is within 5% of the known and certified thermal conductivity of the reference material.

The results for the reference accuracy check for the measurements carried out in this study are listed in the tables below.

Table A1 – Reference Material Test

Reference Material & Calibration	Measured Thermal Conductivity (W/mK)	Reference Thermal Conductivity Value (W/mK)	Bias (%)	Result (Pass/Fail)
Stainless Steel	15.870	15.361	3.3	Pass

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Appendix 3: Test Services Provided by TAL

Transient-Based Thermal Conductivity

TAL specializes in transient-based thermal conductivity analysis. The Modified Transient Plane Source (MTPS), Transient Plane Source (TPS) and Transient Line Source (TLS) offer 3 different, yet complimentary methods of analysis which covers a wide range of material types. The MTPS also provides a measure of thermal effusivity, while the TPS also measure thermal diffusivity and volumetric heat capacity, allowing for a complete material thermal property profile.

Figure A5. C-Therm's Trident Controller with all 3 sensor types (MTPS, TPS and TLS)

Steady State Thermal Conductivity

TAL also offers steady state thermal analysis using C-Therm's ASTM C518 compliant Heat Flow Meter (HFM). Steady state thermal analysis requires a much longer test time compared to transient-based methods, however the accuracy of this type of measurement is unrivaled. Using measurement plates containing high-precision Peltier elements, the heat flux through the sample is quantified along with its thickness to provide a high-quality measurement of thermal conductivity.

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Figure A6. C-Therm's Heat Flow Meter (ASTM C518 Compliant)

Thermal Effusivity (ASTM D7984)

C-Therm's Tx Touch Experience Platform utilizes the MTPS sensor and is the only method that conforms to ASTM D7984 to quantify the "warm feel" and "cool touch" of fabrics. Adopted as the global standard for characterizing thermal performance of textiles, ASTM D7984 is used by the world's top textile groups to develop and produce the highest quality materials in today's market.

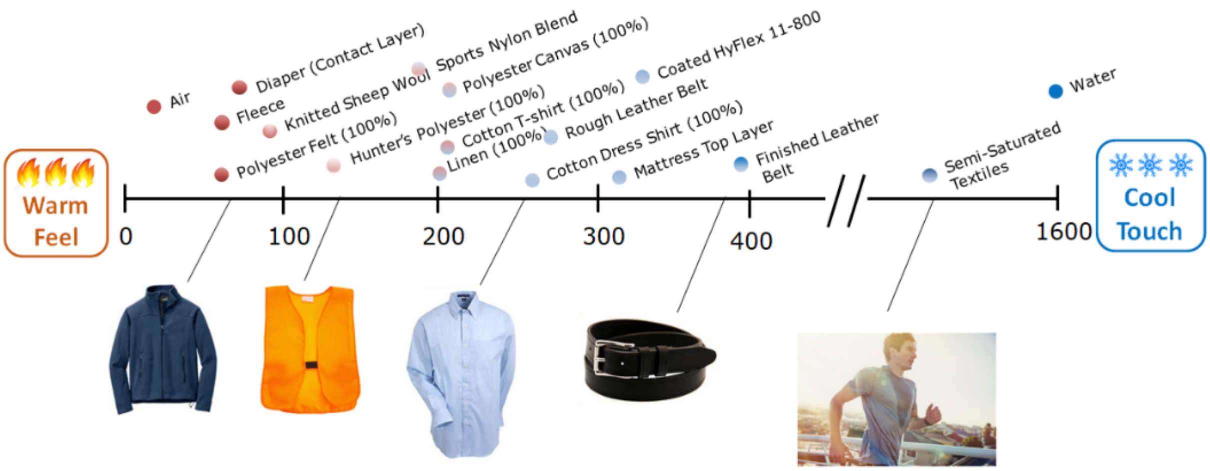

Figure A7. C-Therm's Warm Feel – Cool Touch Product Performance Index

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Thermal Diffusivity

TAL offers thermal diffusivity analysis using a broad range of methods. C-Therm's TPS is a reliable method that conforms to ISO-22007, however TAL also offers diffusivity analysis using various flash-based instruments. For testing using a flash instrument samples are placed into a sample tray and a high-energy beam is allowed to impinge on one side of the sample while the heat generated by this interaction is measured by an infrared detector on the other side of the sample. The signal received by the detector is then used to determine thermal diffusivity. TAL offers flash-based analysis in accordance with ASTM E1461.

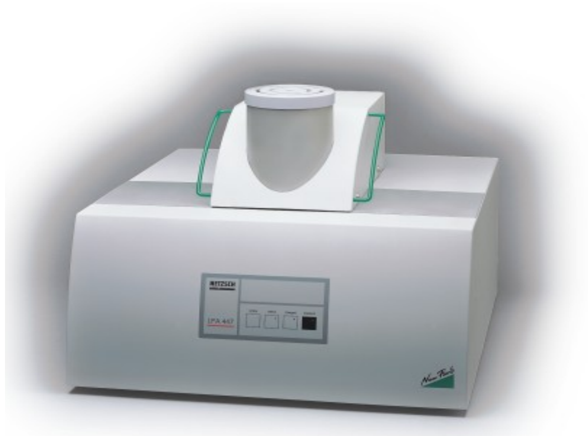

Figure A8. Netzsch LFA 447 Flash Analyzer

Thermal Expansion

TAL utilizes the Rigaku TMA8311 to provide thermal expansion analysis from -70°C to 1500°C. Multiple attachments are available for this instrument depending on sample type/thermal event of interest. For the measurement of CTE, both single rod type and differential rod type are offered. For the measurement of softening temperature, a differential penetration rod is used. Thermal expansion analysis is typically performed in accordance to ASTM E831.

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Figure A9. Rigaku TMA8311

Calorimetry

TAL offers various calorimetric-based analysis such as DSC, TGA, DTA and STA using a range of Setaram products. The Labsys Evo DSC, DSC 131 and Micro DSC VII are all available for testing at TAL and cover a range of sample types and temperatures.

Figure A10. Setaram Labsys Evo DSC/TGA/DTA