THERMAL TRANSMISSION PROPERTIES MEASUREMENTS

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Scope

Infinita Lab Inc. measured the thermal conductivity and related properties of Foam test specimens. The measurements were performed with a technique based on ASTM D5470-17(2024) using Infinita Lab Inc. procedure 5.4_8.6 Rev1 “Thermal Conductivity (k) Test Procedure D5470”. The contracted test service has been performed in accordance with the ISO/IEC 17025-2017. Results are provided in Table 5.

Sample Description

Elven Technologies provided the samples listed in Table 1.

Sample ID	Sample Description	Nominal Sample Dimensions			
		Length [X] (mm)	Width [Y] (mm)	OD (mm)	Thickness [Z] (mm)
1	Foam			33	5
2	Foam			33	5
3	Foam			33	5
4	Foam			33	5
5	Foam			33	5
6	Foam			33	5
7	Foam			33	5
8	Foam	310	310		6
9	Foam	310	310		6
10	Foam	310	310		6
11	Foam	310	310		6
12	Foam	310	310		6

Table 1: Samples received

Testing

Sample Check-In

The samples were inspected for damage. No damage was observed (see Figure 1). Prior to measurement, the samples were labeled and stored in a secure environment.

Figure 1: Sample material as received.

Testing

Specimen Preparation

The specimens were extracted using a razor knife. Specimen dimensions are provided in Table 2.

Specimen ID	Sample ID	Sample Description	Specimen		
			Length (mm)	Width (mm)	Thickness (mm)
17427-1	1	Foam	25.4	25.4	5.5
17427-2	2	Foam	25.4	25.4	5.5

Table 2: Specimen details.

Testing

Specimen Conditioning

The specimens were tested as received.

Test Procedure

The specimens were tested in the thickness direction. Test setup and operational parameters are given in Table 3. Meter bars matched for thermal resistance with the specimen and fitted with thermocouples, were used for the heat flux measurements. Copper adaptor plates ≈6.3 mm thick with areas to match the meter bars on one side and matching area on the specimen side, were placed between the meter bars and specimen to act as heat spreaders and as a point to measure the surface temperatures of the specimen (see Figure 2 for a picture of the specimen as loaded into the test apparatus). The thermocouples were placed in the appropriate holes in the copper adaptors and meter bars for temperature measurements, wrapped once around the meter bar (MB) or copper plate on an isotherm and secured with tape. A small quantity of thermal grease was applied to the tip of each thermocouple to improve thermal grounding to the meter bars. An appropriate thermal interface material was used at all interfaces in the test stack. A compressive force was maintained on the test stack while testing to minimize contact resistance. The test stack was enclosed in fiberglass insulation (λ = 0.038 W/(m·K)), surrounded by an Infrared (IR)- reflective, low-emissivity aluminum shield, an actively heated guard, and a final radiation shield for minimizing lateral heat losses. The test apparatus was ramped to the desired temperatures and held for sufficient time to reach steady state.

Testing

Specimen Conditioning

The specimens were tested as received.

Test Parameters	Value
Test Environment	Vacuum < 13.3 Pa (< 100 mTorr)
Test Temperature Points	23 °C, 60 °C
Meter Bars	Vespel SP1
ΔT Heat Source to Heat Sink	60 °C
Applied Pressure	0.021 MPa, 0.345 MPa, and 0.689 MPa (13.3 N, 222.4 N, and 444.8 N force applied over specimen area)
Thermal Interface Material	Silicone-based Thermal Grease, except on the specimen surfaces.
Thermocouple Type	36 ga, K-type

Table 3: Test setup conditions.

Testing

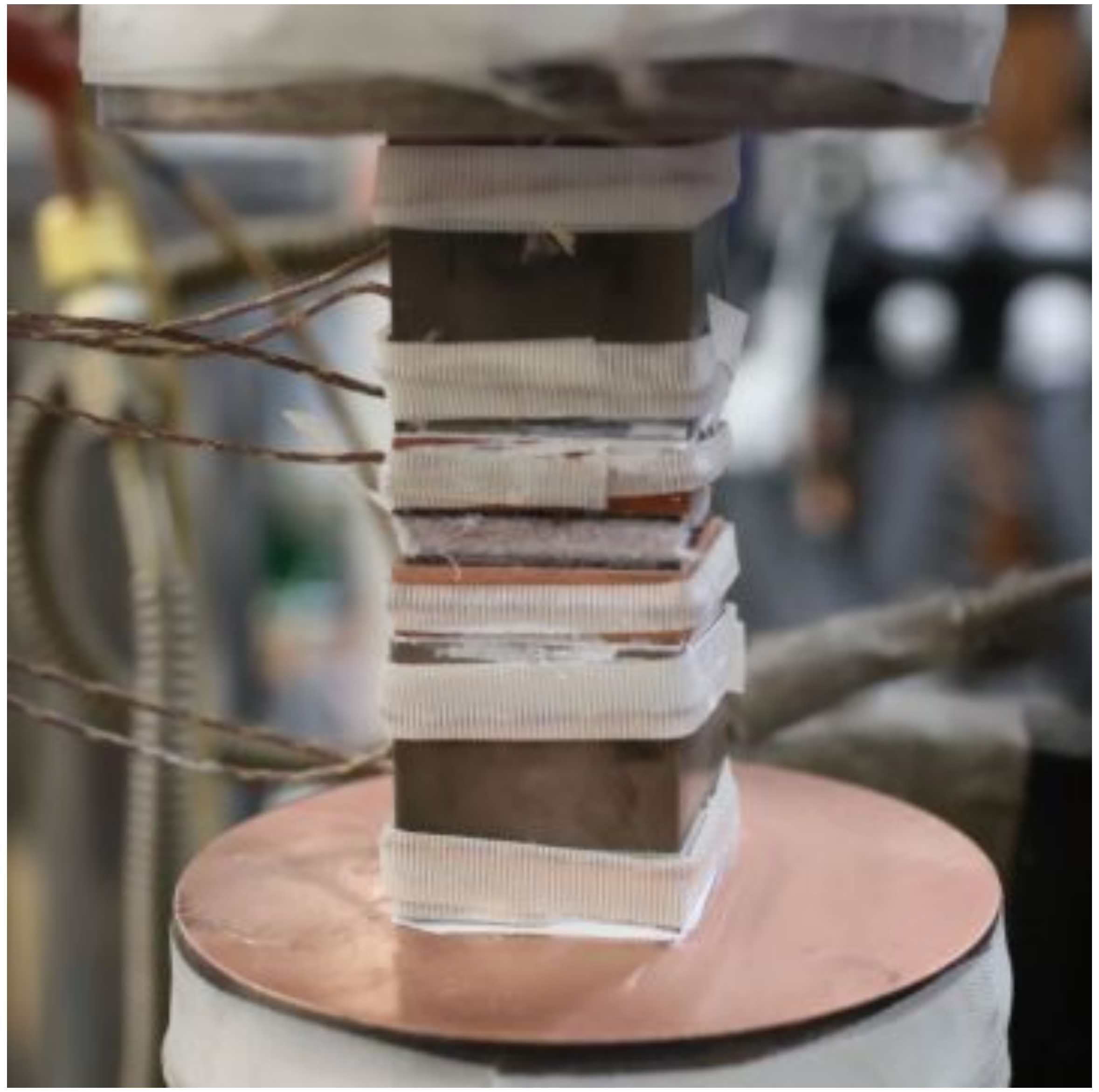

Figure 2: Specimen as loaded into the test apparatus.

Thermal property data for Vespel® SP1 was obtained from the data published in the 27th and 29th International Thermal Conductivity Conference proceedings (ITCC 27, 2003 and ITCC 29, 2007). With the Vespel® SP1 reference material in place of the specimen, a test was run under similar conditions to ensure the accuracy of the test setup.

Test Results

Data Processing

After the specimen had stabilized at each desired temperature, sufficient data were collected and analyzed to ensure that no significant temperature drift occurred during logging. The temperature of each specimen and meter bar thermocouple was averaged over this time. The analysis is based on the solution of Fourier's First Law for one-dimensional heat conduction:

$$\lambda = -\frac{Q}{A}\frac{L}{\Delta T}$$

where

- λ is the thermal conductivity (W/(m·K)),
- Q is the heat flow in the metered section (W),
- A is the cross-sectional area (m^2),
- L is the specimen length (m), and
- ΔT is the temperature difference across the specimen (°C).

Test Results

Measurement Uncertainty

The combined standard uncertainty in the measurement, u_c, was calculated using the following RSS method:

$$u_c = \left[\left(\frac{\partial\lambda}{\partial x_1}u_1\right)^2 + \left(\frac{\partial\lambda}{\partial x_2}u_2\right)^2 + \cdots + \left(\frac{\partial\lambda}{\partial x_n}u_n\right)^2\right]^{1/2} \qquad (2)$$

where

x_i is the measurement input with i = 1...n,
u_i is the estimated uncertainty in each measurement input, x_i, and
$\partial\lambda/\partial x_i$ is the weighted contribution of each input, x_i.

Test Results

The estimated uncertainty inputs of each measurement are listed in Table 4:

Quantity	Symbol	Estimated Uncertainty	Unit
Thermal conductivity (RM/SRM or MB)	λ	5 % of reading	(W/(m·K))
Cross-sectional area	A	1 %	(m2)
Specimen length	L	0.127 × 10-3	(m)
Temperature difference	ΔT	0.25	(°C)

Table 4: Estimated uncertainties.

The estimated uncertainties of the thermal conductivity measurements are provided in Table 5.

Test Results

Thermal Conductivity Results

The results are presented in Table 5. The thermal impedance is expressed in ($m^2 \cdot K/W$) and the thermal conductivity is expressed in ($W/(m \cdot K)$). This test was conducted on specimen of single thickness and, as per the contract, were not layered to make different thicknesses. The apparent thermal conductivity was calculated directly from the specimen ΔT (not extrapolated from the meter bars) and the average heat flow through the meter bars, which is considered to be the heat flow through the specimen in accordance with the standard.

Prior to testing, the sample material was tested by heating it to 600 °C from 23 °C and found to be dimensionally unstable. A range of loads from 13 N to 445 N was also applied and it was found that the material was unable to recover fully from the loads, leaving it thinner than it was originally. To account for these changes, a specimen was tested at a single temperature and the load varied so that a new thickness (the specimen gage length, Lo, listed in Table 5) could be measured after each test.

The test on the Vespel® SP1 reference material returned results that were within 2.2 % of accepted values over the range of test temperatures.

Test Results

Infinita lab Specimen ID	Specimen Lo (mm)	Average Specimen Temperature (°C)	Apparent Thermal Conductivity (W/(m·K))	Thermal Resistance (m2·K/W)	Estimated Uncertainty (%)	Date Tested
1	5.5	22.2	0.019	0.286	7.1	1-Dec-25
	3.57	22.2	0.021	0.173	6.5	
	3.11	21.7	0.03	0.102	6.3	
2	5.5	59.1	0.023	0.244	6.7	3-Dec-25
	3.57	59	0.023	0.156	6.4	
	3.11	58.8	0.029	0.106	6.4	

Table 5: Thermal Conductivity Results.

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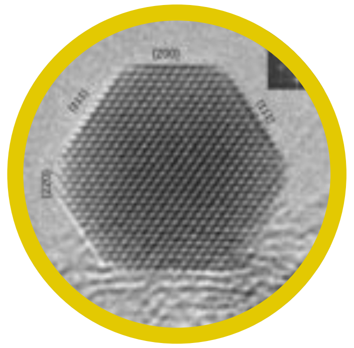
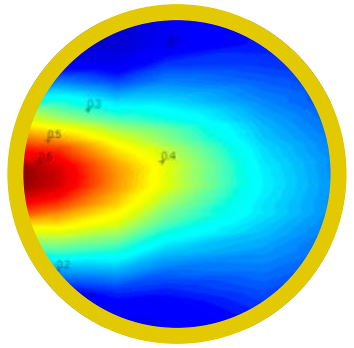


Materials Characterization



Thermal Testing

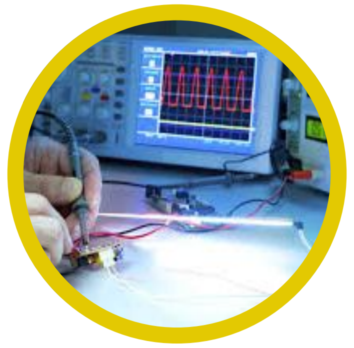
Chemical Testing

Mechanical Testing

Optical Testing

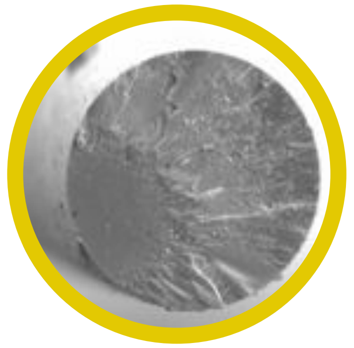
Environmental Testing

Biomechanical Testing



Electrical Testing

Semiconductor Testing



Failure Analysis