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IN-PLANE THERMAL CONDUCTIVITY OF FLAT PLATES UTILIZING THE FOURIER HEAT CONDUCTION LAW

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1. SCOPE

This test method is used to determine the thermal conductivity of thermally conductive panel materials. It is specifically tailored to non-destructively evaluate materials exhibiting a thermal conductivity of at least 30 W/mK [watts/meter · Kelvin]. The upper limit can be as high as 1500 W/mK depending on sensor location and geometry.

This method evaluates the steady state one-dimensional heat transfer characteristics in terms of the differential temperature as a function of distance (dt/dx). This is accomplished by acquiring the necessary data from the face of the panel as heat flows from one end of the panel where heat is applied, to the other end of the panel where heat exits to the heat sink. This method is relatively inexpensive and is applicable to panel materials where the cross sectional area of heat flow remains constant. Thermal Conductivity is calculated using Fourier's Thermal Conduction Law.

2. SIGNIFICANCE AND USE

The goal is to satisfy the need for non-destructive thermal conductivity measurements that determine the overall thermal performance of the component rather than assessing only localized values. (This is a typical problem with many methods such as the 'Flash Diffusivity Method' which utilize small samples that are less than 1 cm^3.) Multiple simultaneous measurements allow data to be generated over a large area. This is particularly important for materials such as composites where the distribution of the conductive reinforcement may vary locally on the component. The non-destructive nature of this method is accomplished through the use of removable heaters and temperature sensors. Also, the use of a liquid immersion heat sink allows for various sized components to be immersed without any machining or coupon sizing. This is particularly important where expensive or end use hardware is being evaluated.

This method is particularly useful in evaluating materials that exhibit anisotropic properties. The method, which employs unidirectional heat transfer, allows for easy measurement of directional properties without the need for complex data reduction.

3. REFERENCED DOCUMENTS

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A. ASTM C 714-85 'Test Method for Thermal Diffusivity of Carbon and Graphite by a Thermal Pulse Method'
B. ASTM C 767-86 'Test Method for Thermal Conductivity of Carbon Refractories'
C. ASTM C 201 'Test Method for Thermal Conductivity of Refractories'
D. R.E. Taylor, "Thermophysical Property Determinations Using Direct Heating Methods," in *Survey of Measurement Techniques*, Vol.1, Plenum Press, NY, 1984.
E. F. Kohlrausch, "On Thermoelectricity, Heat and Electrical Conduction," Gottingen Nachr., Feb.7 1874.
F. ASTM E 1323-89 'Evaluating Laboratory Measurement Practices and the Statistical Analysis of the Resulting Data'

4. APPARATUS

The apparatus consists of the following:

A. Liquid Immersion Heat Sink
B. Liquid Chiller (5°C to 30°C cooling range)
C. Kapton laminated thermal-foil heaters
D. Platinum resistive element temperature sensors (RTD's)
E. Pressure sensitive film adhesive
F. Coated Fiberglass insulation (2 inch thick w/ < 0.1 W/mK)
G. Power supply (requirements: 60 Volts dc, Current @ 2 amps)
H. Instrumentation for measuring voltage and current
I. Signal Conditioning for RTD elements
J. Computer Data Acquisition System (optional)

The liquid immersion heat sink must be a closed loop system that is hooked to a chiller, which will allow near infinite 'sinking' of heat from the test coupon. See Figure 1 for a schematic view of the system. This system will act as a heat-exchanging device in which the coupon is clamped. A suitable liquid such as 50/50 ethylene glycol and water should be used for the recirculating coolant.

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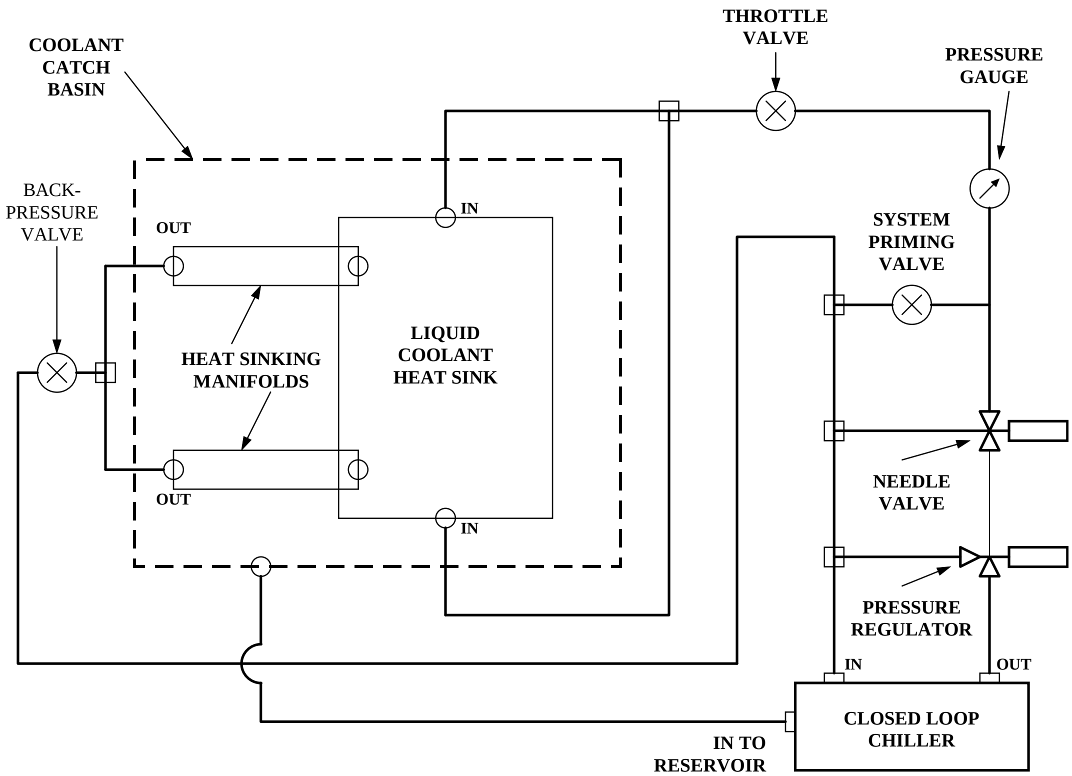
Figure 1

PLUMBING SCHEMATIC OF THE MII LIQUID IMMERSION HEAT SINK



The heat source should employ foil heaters with densely spaced elements. These should be able to tolerate at least 200°C. Aluminum backing may be necessary for anisotropic materials exhibiting poor heat spreading. This will insure uniform heat flow along the coupon surface.

Instrumentation should be capable of; 1) measuring voltage with a resolution of 1 mV, 2) measuring current with a resolution to 1mA, 3) measuring temperature with a resolution of 0.01 °C, and 4) ability to transfer data to a data acquisition system (optional).

5. TEST SAMPLE AND PREPARATION

The test sample should be in a rectangular or square configuration with all sides 90° relative to each other. The cross sectional area should not deviate more than 5% of the average area. All surfaces should be clean from dirt and oils. It is recommended that the minimum width be at least 1 inch, the minimum thickness at least 0.030 inch, and the minimum height (direction of heat flow) be at least 4

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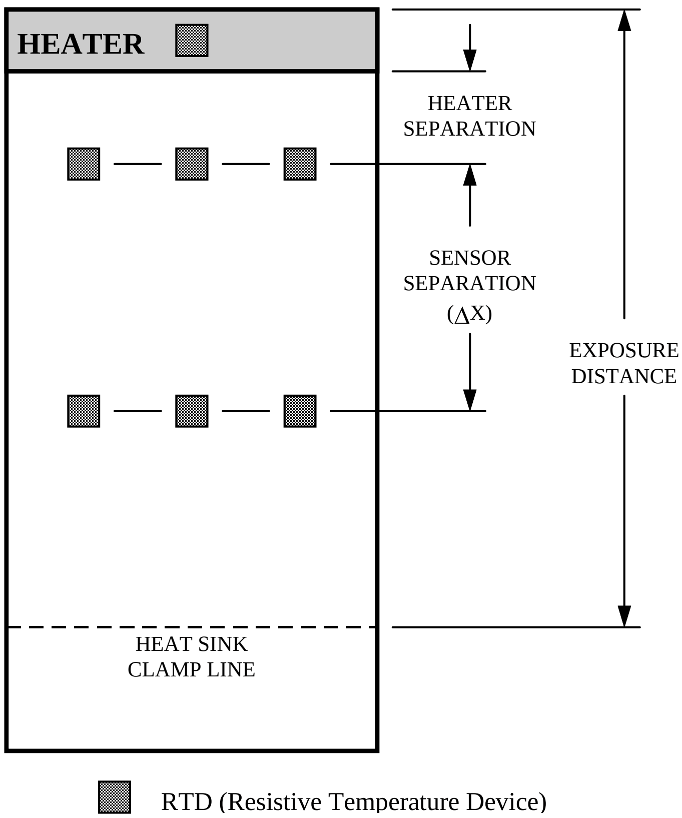
inches. Larger surface dimensions will typically yield additional temperature resolution in the measurement. Smaller surface areas should be analyzed for adequate resolution prior to testing.

Thermal foil heaters and RTD's are attached to the surface via a thermally conductive pressure sensitive adhesive. In cases where coupon thickness exceeds 0.200 inch thick, heating 'end-on' will be required in order to avoid temperature gradients through the thickness of the test coupon. A typical arrangement is shown in Figure 2.

Figure 2
THERMAL CONDUCTIVITY COUPON SENSOR LOCATION SCHEMATIC



The heating location should be at the top edge of the panel with heaters mounted on both faces of the test coupon. RTD's are mounted as two rows. The top row needs to be at a characterized distance from the heater such that the RTD's are measuring uniform heat flow. (RTD's too close to the heater may be influenced by heat input effects.) The bottom row needs to be a characterized distance from the

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top row such that the measured temperature gradients during the test exceed 1.50°C. Both rows of RTD's, as a set, should be place approximately half way between the heat source (heaters) and heat sink (clamp line). It is important to insure that there are no air bubbles or delaminations in the adhesive bond line.

All wiring should exit the coupon surface horizontally such that temperature gradients along the wire near the coupon are minimized. This will minimize thermal shorts.

7. CALCULATION

Calculation of thermal conductivity is performed in accordance to Fourier's Conduction Law. Rearranged and solving for Conductivity, the equation is as follows:

$$K = (Q/A) \cdot (\Delta X/\Delta T)$$

Where:

Q = Power in watts (Volts **X** Amps)
A = Cross sectional area (Width **X** Thickness = meters^2)
ΔX = Vertical distance between RTD temperature sensors
ΔT = Temperature differential between RTD's along the direction of thermal flow

Each RTD data point must be converted to a normalize value. This is performed by taking the differential in temperature between the initial (steady state) measurement at the heat sink temperature and the final (steady state) measurement at the heated (test) temperature. Once these values are determined, ΔT is calculated by taking the average normalized values of the upper row of RTD's, minus the average normalized values of the lower row or RTD's. This will yield the correct change in temperature.

8. REPORT

A. Report the Thermal Conductivity in SI units of Watts/meter · Kelvin (W/mK)
B. Report the average test temperature.
C. Report the ambient temperature.

9. PRECISION AND BIAS

Results must be correlated to a known standard of equivalent size tested with the same conditions, setup, and power parameters. The material should have a thermal conductivity as close a possible to the test coupon. Typical normalization of test results is usually a correction of 3% to 6%, which accounts for heat losses in the wiring and

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through the insulation. Heat losses in excess of 10% should be considered questionable and a detailed analysis should be performed prior to acceptance of data.

It is suggested that materials used as standards be of a homogeneous metallic material; however, composites and ceramics are also acceptable provided that they are reasonably uniform in their architecture.

Results from round robin testing between at least two different laboratories should be employed in establishing standard materials. Common techniques that are suggested for cross referencing purposes are the Kohlrausch Method used at the Purdue Thermal physical Properties Laboratory and the Laser Flash Diffusivity measurement used by Virginia Polytechnic Institute as well as many others. These measurements are widely accepted and are very useful for establishing properties on small, uniform, and well-understood samples.