Defense Systems Information Analysis Center

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Means to Determine Heat Capacities of Multilayer Insulation Materials

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Defense Systems Information Analysis Center (DSIAC) received a concerning specific heats of multilayer insulation (MLI) materials used in space adhesives. The inquirer was looking for the specific heats of MLI materials and space adhesives over a temperature range of -150°C to 250°C (123 K to 523 K). In particular, the inquirer was asking for efficient and cost-effective ways to determine the specific heat of various materials. Materials in question were samples of Sheldahl indium tin oxide-coated silvered fluorinated ethylene propylene, with a layer of Polyonics aluminum tape. DSIAC contacted a subcontractor, Texas Research Institute Austin, Inc. (TRI-Austin), for subject matter expert (SME) input. The following report was completed by a TRI-Austin SME. Other SMEs provided input, including those at Johns Hopkins University, NASA, and AVID R&D, LLC. Options for obtaining specific heat such as Water Bath, Rule of Mixtures, and Differential Scanning Calorimetry (DSC) are described with an assessment of the options and a final recommendation of using DSC.

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A chief service of the DoD IACs is free technical inquiry (TI) research, limited to 4 research hours per inquiry. This TI response report summarizes the research findings of one such inquiry jointly conducted by DSIAC.

ABSTRACT

Defense Systems Information Analysis Center (DSIAC) received a concerning specific heats of multilayer insulation (MLI) materials used in space adhesives. The inquirer was looking for the specific heats of MLI materials and space adhesives over a temperature range of -150°C to 250°C (123 K to 523 K). In particular, the inquirer was asking for efficient and cost-effective ways to determine the specific heat of various materials. Materials in question were samples of Sheldahl indium tin oxide-coated silvered fluorinated ethylene propylene, with a layer of Polyonics aluminum tape. DSIAC contacted a subcontractor, Texas Research Institute Austin, Inc. (TRI-Austin), for subject matter expert (SME) input. The following report was completed by a TRI-Austin SME. Other SMEs provided input, including those at Johns Hopkins University, NASA, and AVID R&D, LLC. Options for obtaining specific heat such as Water Bath, Rule of Mixtures, and Differential Scanning Calorimetry (DSC) are described with an assessment of the options and a final recommendation of using DSC.

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1.0 TI Request

1.1 INQUIRY

What are means to efficiently and cost effectively determine the heat capacities of small amounts of material?

1.2 DESCRIPTION

The inquirer requested a review of the available means to efficiently and cost effectively determine the heat capacity of small amounts of materials used as part of multilayer insulation (MLI) materials.

2.0 TI Response

The Defense Systems Information Analysis Center (DSIAC) received support from subject matter experts (SMEs) at Johns Hopkins University, National Aeronautics and Space Administration (NASA), AVID R&D, LLC, and Texas Research Institute Austin (TRI Austin). DSIAC and Georgia Tech Research Institute (GTRI) completed literature searches on the Defense Technical Information Center (DTIC) Research and Engineering (R&E) Gateway and other scientific and technical information (STI) sources to find articles relevant to the inquiry.

2.1 HEAT CAPACITY

Heat capacity (also known as specific heat or specific heat capacity) is defined as the amount of energy necessary to increase the temperature of a material by a single degree (J/kg·K). It can be nonconstant depending on the environment the material is in. (Typically, as the environmental temperature increases, the amount of energy needed to further increase a unit of material by a single degree increases.) Heat capacity is usually defined as the specific heat at constant pressure (c_p) or specific heat at constant volume (c_v), depending on how the unit of material is confined; the value of c_v is usually less than c_p. This difference is particularly notable in gases where specific heat values at c_p are 33−66% greater than those at c_v [1].

2.2 MLI MATERIAL

The MLI material of interest was Sheldahl indium tin oxide (ITO)-coated silvered fluorinated ethylene propylene (FEP) (2-mil [0.002-in.] thick). Some of the samples also had Polyonics aluminum tape with a pressure-sensitive adhesive (2-mil [0.002-in.] thick) on the back.

SMEs at Johns Hopkins University stated that the ITO-coated silvered FEP consists of the materials listed in Table 1 [2].

Table 1: Contents of the ITO-coated silvered FEP [2].

Material	Specific Heat J/(kg·K)	Thickness
FEP (ASTM D-3368)	1,172	2 mil
Silver	240	1,500 Å
Inconel	429	275 Å
Conductive Acrylic 3M™9703 Adhesive	Unknown	2 mil

Note that the properties listed in Table 1 are not temperature/pressure dependent and that the Inconel is assumed to be Inconel 625. For the aluminum (Al) tape with the pressure-sensitive adhesive, material properties for the Al are fairly easy to identify in existing literature, but without further information, the properties of the adhesive are impossible to determine.

2.3 OPTIONS TO DETERMINE SPECIFIC HEAT

There are several options available to determine temperature-dependent specific-heat properties of a material depending on what it is required for and the specifics of the temperature range.

1. Water Bath. With this method, a known mass of the material is placed into either an ice-water or boiling-water bath for 5−10 minutes. Once the material has reached thermal equilibrium with the bath, a known amount of the bath is measured out to determine its temperature. Next, the hot or cold material is placed quickly into the water, and the resulting temperature change is measured. From this method, the specific heat can be calculated from the energy change measured (water has a known specific heat) and the mass of the material used. This method is a rudimentary way to determine a specific-heat value over a temperature range from 273−373 K (encompassing the freezing and boiling points of water).

To achieve the full temperature range desired by the inquirer (-150°C to 250°C), a cold source, such as a liquid nitrogen bath, can be used to measure the specific heat at -150°C. An acetone and dry ice bath at thermal equilibrium can be used to measure the material specific heat at -75°C. Finally, results from using boiling water to determine the specific heat at 100°C should be close enough to 175°C to assume linearity between the previous temperatures and determine the specific heat at this higher temperature.

This experiment provides the most accurate temperature-dependent properties possible for a relatively easy and quick way of testing. The caveat with this experiment is that it does not necessarily provide the most accurate results and also may require time/funding to develop the test setup.

2. Rule of Mixtures. With this method, if the constituents of an unknown alloy or compound can be determined (such as by using energy-dispersive X-ray spectroscopy [EDS]), such as the contents of an Al alloy, then the Rule of Mixtures can be used to determine the specific heat. The Rule of Mixtures can be defined as:

$$c_{p,overall} = x_1 c_{p1} + x_2 c_{p2} + \ldots + x_y c_{py} \ ,$$

where c_p is the specific heat; 1, 2, and *y* denote the species; and *x* denotes the individual species fraction. This method provides a reasonable, first-order approximation of the bulk specific heat of a material. However, the main limitation is that using this method assumes total insolubility, or that each constituent solely occupies its own phase. In reality there will be some (or total) solubility, or there will also be intermetallic phases that have different thermophysical properties than their constituents. The next step is to determine what phases may be present (by looking at phase diagrams, etc.) and their material properties. In addition, it is unknown how appropriate this method would be for the different polymers of the MLI.

3. Differential Scanning Calorimetry (DSC). DSC is a thermoanalytical technique in which the difference in the amount of heat required to increase the temperature of a sample and reference is measured as a function of temperature. Both the sample and reference are maintained at nearly the same temperature throughout the experiment. Generally, the temperature program for a DSC analysis is designed such that the sample holder temperature increases linearly as a function of time. The reference sample should have a well-defined heat capacity over the range of temperatures to be scanned [3].

2.4 RECOMMENDATIONS

Based on the options available, the DSC option is recommended. There are numerous machines available from laboratory service firms that conform to ASTM and ISO 9000 standards that offer the precision that the inquirer is seeking. Using a water bath is problematic as it will take time and labor to setup and operate and may not provide the degree of precision required. The Rule of Mixtures method makes many assumptions and would require the use of equipment that may not be available. Sending samples out for the DSC would provide the most accurate results for the least cost and time and DSC can address the temperature range required. An example of expected results is shown in the paper “Heat Capacities of Technetium Metal and Technetium-Ruthenium Alloy” [4].

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