Designation: E2683 – 09

Standard Test Method for Measuring Heat Flux Using Flush-Mounted Insert Temperature-Gradient Gages[1]

This standard is issued under the fixed designation E2683; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method describes the measurement of the net heat flux normal to a surface using gages inserted flush with the surface. The geometry is the same as heat-flux gages covered by Test Method E511, but the measurement principle is different. The gages covered by this standard all use a measurement of the temperature gradient normal to the surface to determine the heat that is exchanged to or from the surface. Although in a majority of cases the net heat flux is to the surface, the gages operate by the same principles for heat transfer in either direction.

1.2 This general test method is quite broad in its field of application, size and construction. Two different gage types that are commercially available are described in detail in later sections as examples. A summary of common heat-flux gages is given by Diller (**1**).[2] Applications include both radiation and convection heat transfer. The gages used for aerospace applications are generally small (0.155 to 1.27 cm diameter), have a fast time response (10 µs to 1 s), and are used to measure heat flux levels in the range 0.1 to 10 000 kW/m^2. Industrial applications are sometimes satisfied with physically larger gages.

1.3 The values stated in SI units are to be regarded as the standard. The values stated in parentheses are provided for information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standard:*[3]

E511 Test Method for Measuring Heat Flux Using a Copper-Constantan Circular Foil, Heat-Flux Transducer

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *heat flux*—the heat transfer per unit area, q, with units of W/m^2(Btu/ft^2-s). Heat transfer (or alternatively heat transfer rate) is the rate of thermal energy movement across a system boundary with units of watts (Btu/s). This usage is consistent with most heat transfer books.

3.1.2 *heat transfer coefficient, (h)*—an important parameter in convective flows with units of W/m^2-K (Btu/ft^2-s-F). This is defined in terms of the heat flux q as

$$h = \frac{q}{\Delta T} \tag{1}$$

where ΔT is a prescribed temperature difference between the surface and the fluid. The resulting value of h is intended to be only a function of the fluid flow and geometry, not the temperature difference. If the surface temperature is non-uniform or if there is more than a single fluid free stream temperature, the proper definition of ΔT may be difficult to specify (**2**). It is always important to clearly define ΔT when calculating the heat transfer coefficient.

3.1.3 *surface emissivity, (ε)*— the ratio of the emitted thermal radiation from a surface to that of a blackbody at the same temperature. Surfaces are assumed to be gray bodies where the emissivity is equal to the absorptivity.

4. Summary of Test Method

4.1 A schematic of the sensing technique is illustrated in Fig. 1. Temperature difference is measured across a thermal-resistance layer of thickness, δ. This is the heat flux sensing

[1] This test method is under the jurisdiction of ASTM Committee E21 on Space Simulation and Applications of Space Technology and is the direct responsibility of Subcommittee E21.08 on Thermal Protection.

Current edition approved June 15, 2009. Published August 2009. DOI: 10.1520/E2683-09.

[2] The boldface numbers in parentheses refer to the list of references at the end of this test method.

[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

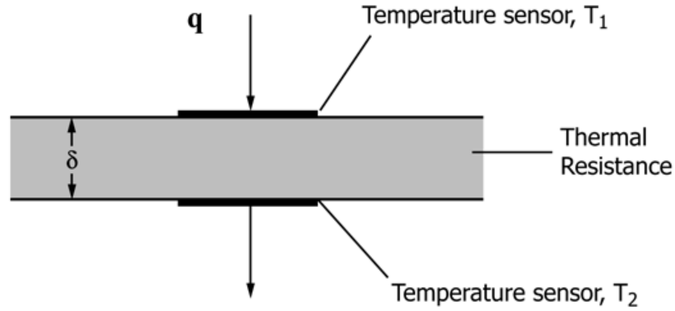

FIG. 1 Layered Heat-Flux Gage

mechanism of this method following Fourier's law. The measured heat flux is in the same direction as the temperature difference and is proportional to the temperature gradient through the thermal-resistance layer (TRL). The resistance layer is characterized by its thickness, δ, thermal conductivity, *k*, and thermal diffusivity, α. The properties are generally a weak function of temperature.

$$q = \frac{k}{\delta}(T_1 - T_2) \tag{2}$$

From this point the different gages may vary in how the temperature difference $T_1 - T_2$ is measured, the thickness of the thermal-resistance layer used, and how the sensing element is mounted in the gage. These three aspects of each different type of gage are discussed along with the implications for measurements. In all of the cases considered in this standard the gage housing is a circular cylinder that is inserted into a hole in the material of the test object flush with the surface.

4.2 Gages using this test method generally use differential thermocouple pairs that give an output that is directly proportional to the required temperature difference. The differential thermocouple pairs are put in series to form a differential thermopile to increase the sensitivity to heat flux.

$$S = \frac{E}{q} = \frac{N\sigma_T\delta}{k} \tag{3}$$

Here *N* represents the number of thermocouple pairs forming the differential thermopile and σ_T is the effective temperature sensitivity (Seebeck coefficient) of the two thermocouple materials.

5. Significance and Use

5.1 The purpose of this test method is to measure the net heat flux to or from a surface location. For measurement of the radiant energy component the emissivity or absorptivity of the surface coating of the gage is required. When measuring the convective energy component the potential physical and thermal disruptions of the surface must be minimized and characterized. Requisite is to consider how the presence of the gage alters the surface heat flux. The desired quantity is usually the heat flux at the surface location without the presence of the gage.

5.1.1 Temperature limitations are determined by the gage material properties, the method of mounting the sensing element, and how the lead wires are attached. The range of heat flux that can be measured and the time response are limited by the gage design and construction details. Measurements of a fraction of 1 kW/m^2 to above 10 MW/m^2 are easily obtained with current gages. With thin film sensors a time response of less than 10 μs is possible, while thicker sensors may have response times on the order of 1 s. It is important to choose the gage style and characteristics to match the range and time response of the required application.

5.1.2 When differential thermocouple sensors are operated as specified for one-dimensional heat flux and within the corresponding time response limitations, the voltage output is directly proportional to the heat flux. The sensitivity, however, may be a function of the gage temperature.

5.2 The measured heat flux is based on one-dimensional analysis with a uniform heat flux over the surface of the gage. Measurements of convective heat flux are particularly sensitive to disturbances of the temperature of the surface. Because the heat-transfer coefficient is also affected by any non-uniformities in the surface temperature, the effect of a small temperature change with location is further amplified as explained by Moffat et al. (**2**) and Diller (**3**). Moreover, the smaller the gage surface area, the larger is the effect on the heat transfer coefficient of any surface temperature non-uniformity. Therefore, surface temperature disruptions caused by the gage should be kept much smaller than the surface to environment temperature difference driving the heat flux. This necessitates a good thermal path between the sensor and the surface into which it is mounted. If the gage is not water cooled, a good thermal pathway to the system's heat sink is important. The gage should have an effective thermal conductivity as great or greater than the surrounding material. It should also have good physical contact insured by a tight fit in the hole and a method to tighten the gage into the surface. An example method used to tighten the gage to the surface material is illustrated in Fig. 2. The gage housing has a flange and a separate tightening nut tapped into the surface material.

5.2.1 If the gage is water cooled, the thermal pathway to the plate is less important. The heat transfer to the gage enters the water as the heat sink instead of the surrounding plate. Consequently, the thermal resistance between the gage and plate may even be increased to discourage heat transfer from the plate to the cooling water. Unfortunately, this may also increase the thermal mismatch between the gage and surrounding surface.

5.2.2 Fig. 2 shows a heat flux gage mounted into a plate with the surface temperature of the gage of T_s and the surface temperature of the surrounding plate of *Tp*. As previously discussed, a difference in temperature between the gage and plate may also increase the local heat transfer coefficient over