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SURFACE VEHICLE INFORMATION REPORT

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Thermal Transport Properties Germane to Friction Materials and Brakes

1. Scope

This SAE Information report defines the thermal transport properties important in the assessment of heat management capability of brake lining, shoe, disc and drum materials. The report discusses thermal diffusivity, specific heat capacity, thermal conductivity and thermal expansion. Measurement techniques for the appropriate ASTM standards are identified. The thermal transport properties discussed are material sample properties, not the properties of entire components such as pad assemblies.

2. References

2.1 Applicable Publications

The following publications form a part of this information report to the extent specified herein. Unless otherwise specified, the latest issue of SAE and ASTM publications shall apply.

2.1.1 SAE Publications

None.

2.1.2 ASTM International Publications

Available for purchase from: ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, Pennsylvania, USA 19428-2959. www.astm.org.

ASTM E 1461—Standard Test Method for Thermal Diffusivity of Solids by the Flash Method
ASTM C 1114—Steady-State Thermal Transmission Properties by Means of the Thin-Heater Apparatus
ASTM E 1225—Thermal Conductivity of Solids by Means of the Guarded-Comparative-Longitudinal Heat Flow Technique
ASTM E 1269—Determining Specific Heat Capacity by Differential Scanning Calorimetry
ASTM E 228—Linear Thermal Expansion of Solid Materials With a Vitreous Silica Dilatometer

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2.2 Related Publications

The following publications are for information purposes only and are not a required part of this document.

2.2.1 SAE Publications

SAE J160—Swell, Growth and Dimensional Stability of Brake Linings

2.2.2 Other Publications

JIS D4416—Test procedure of thermal expansion for brake linings and pads of automobiles
ISO 6313—Effects of heat on dimensions and form of disc brake pads

3. Definitions

3.1 Symbols Used

α	Thermal diffusivity
λ	Thermal conductivity
C_p	Heat capacity per unit mass at constant pressure
CTE	Coefficient of thermal expansion
D	Specimen thickness
t	Time
ΔQ	Heat energy
M	Specimen mass
ΔT	Temperature rise
H	Rate of heat transfer across the area A
A	Sample area
$\frac{dT}{dx}$	Temperature gradient
ρ	Sample density
L_o	Sample original length

3.2 Summary of Thermal Transport Materials Properties

Thermal properties of disc, drum and friction materials are typically required to assess the heat management of brake components. These properties are often used to perform computer-aided design of brakes and computer simulations or modeling of brake performance. This document defines several standard thermal transport material properties: thermal diffusivity, specific heat capacity, thermal conductivity and thermal expansion, and describes the techniques used to measure them. Table 1 is included below listing the equipment used to measure the material properties and the applicable ASTM International standards.

TABLE 1—SUMMARY TABLE OF THERMAL TRANSPORT PROPERTIES

Property	Symbol	Typical Units	Typical Measurement Equipment/Technique	Measurement Standards
Thermal diffusivity	α	cm^2/sec mm^2/sec	Laser Flash, Transient Plane Source	ASTM E 1461 ASTM C 1114
Thermal conductivity	λ	W /mK cal /cm s K	Calculation, Longitudinal Heat Flow	ASTM E 1225
Specific heat	C_p	cal /g °C J /g °C	Differential scanning calorimetry (DSC)	ASTM E 1269
Coefficient of thermal expansion	CTE	mm/mm/°C	Dilatometer	ASTM E 228

It should be noted that the transport properties discussed in this information report are material properties, and not the component properties measured by SAE J160, ISO 6313 and JIS 4416.

4. Thermal Diffusivity, α

Thermal diffusivity is a measure of how fast heat flows through a material. It is the rate of change of temperature during a transient heat flow event. The greater the thermal diffusivity value, the faster the rate of temperature propagation or heat flow through a material. Thermal diffusivity is a useful descriptor for brake materials. It is easy to measure and can be used to calculate thermal conductivity. It should be noted that thermal diffusivity is temperature dependent, typically decreasing as temperature increases.

The laser flash technique is one method used to measure thermal diffusivity. A small material sample of known thickness is subjected to an intense, short burst of energy from a laser or xenon flash lamp. The temperature rise at the rear surface of the sample is measured, and thermal diffusivity is computed from the temperature rise versus time data. The diffusivity, α, is typically calculated at the time that it took the rear surface of the sample to achieve 1/2 of its maximum temperature rise with the equation

$$\alpha = \frac{0.1388 D^2}{t_{0.5}} \qquad \text{(Eq.1)}$$

where D is the specimen thickness and $t_{0.5}$ is the half rise time of the rear surface temperature. The laser flash technique requires that a small sample (e.g. a 10 mm diameter, 3 mm thick disc) be cut from the material to be measured. Thermal diffusivity can be measured at room and elevated temperatures with this technique.

The transient plane source (or hot disc) method allows nondestructive measurement of the thermal diffusivity, thermal conductivity and specific heat simultaneously. This new technique relies on a thin sensor that consists of an electrically conducting pattern in the shape of a double spiral; the sensor is used as both a heat source and as a dynamic temperature sensor. It can be performed on brake linings without cutting small samples; the thin sensor can be placed between two whole, identical pads to do the measurements. Room temperature values are easy to measure with this technique, however for elevated temperature numbers, the linings must be held at temperature by an external heater, oven or hot plate.

Another recent development in nondestructive thermal diffusivity measurement techniques is pulsed video thermography. There is no industry standard for this technique yet.

5. Specific Heat, C_p

Heat capacity is defined as the ratio of the amount of heat energy (ΔQ) supplied to a body to its corresponding temperature rise (ΔT). The heat capacity per unit mass of the body at constant pressure is known as the specific heat, or

$$C_p = \frac{\Delta Q}{m \Delta T} \qquad \text{(Eq.2)}$$

Specific heat is the amount of energy per unit mass required to create a unit temperature rise. Hence, the greater the value of the specific heat, the better the material's performance as a 'heat sink.' Specific heat is temperature dependent; its value will be different depending upon the temperature interval over which it is measured.

Specific heat is typically measured with a Differential Scanning Calorimeter (DSC); the DSC measures the thermal response of a material specimen as compared with a standard (such as sapphire) when the two are heated uniformly at a constant rate. Data is typically recorded from 100 °C up to the user-specified maximum temperature. This measurement also reveals if any phase changes occur in the material over the temperature range applied. It should be noted that if phase transitions occur during the DSC test, subsequent testing on the same sample of material would yield different results. Specific heat values can be used in conjunction with thermal diffusivity values to calculate thermal conductivity. (Discussed below.)

One issue with measuring the specific heat of friction materials is that the typical sample volumes used for DSC are very small, e.g. 0.5 to 20 mm^3. Individual material samples may not be representative of friction materials with large size ingredients or coarsely mixed ingredients. Suggested approaches for addressing this problem are: 1) measure specific heat on numerous material samples, and make those samples as large as the equipment allows, or 2) grind a representative piece of the friction material into a fine powder and lightly compact into pellets to be measured via DSC.

6. Thermal Conductivity, λ

Thermal conductivity, the steady state measure of heat flow or how fast heat moves through a material, is a commonly quoted assessment of a material's thermal transport ability. Thermal conductivity (λ) is defined as the rate of steady state heat flow through a unit thickness of material induced by a unit temperature rise, or roughly

$$\lambda = \frac{H}{A\frac{dT}{dx}} \qquad \text{(Eq. 3)}$$

where H is the rate of heat transfer across the area A, and dT/dx is the temperature gradient. A material with a high value of λ is a good thermal conductor. Thermal conductivity is a function of temperature, typically increasing as temperature increases.

The simplest way to determine thermal conductivity is to measure α, ρ and C_p and calculate it from the following equation:

$$\lambda = \alpha \rho C_p \qquad \text{(Eq. 4)}$$

where α is the thermal diffusivity, ρ is the sample density and C_p is the specific heat capacity at constant pressure.

Thermal conductivity can also be measured directly via the transient plane source technique mentioned above, or equipment such as a Longitudinal Bar Cryostat. A bar-shaped test specimen is mounted to a temperature-controlled heat sink, and a small heater is applied to the opposite end of the specimen to produce a temperature gradient. Thermal conductivity is calculated from the temperature gradient (measured with thermocouples), the cross-sectional area of the specimen and the heater power dissipation. The disadvantage to this measurement technique is that relatively large bar samples of material are required; hence it is difficult to apply to friction materials.

7. Thermal Expansion (Coefficient Thermal Expansion, CTE)

Thermal expansion is defined as the change in length per unit length of a material resulting from a temperature change of one degree. The coefficient of thermal expansion is described in different ways:

1. Coefficient of linear expansion ($\Delta L/L_o$) is simply the change in length, ΔL, divided by the sample's original length at some reference or starting temperature, L_o.
2. The mean coefficient of expansion is the average coefficient from the temperature range (ΔT) evaluated, $\Delta L/L_o\Delta T$. When using this value, the temperature range over which it applies must be specified.
3. The instantaneous coefficient of linear thermal expansion is the expansion coefficient at any temperature T; it is the slope of the observed change in length versus the temperature curve at a particular instantaneous temperature.