Hukseflux
Thermal Sensors

Specimen requirements for thermal testing

Testing services at Hukseflux thermal properties laboratory

This document clarifies the requirements for specimens for thermal testing at Hukseflux.

Introduction

Hukseflux Thermal Sensors is well equipped to perform measurements for customers in its thermal properties laboratory. When offering specimens to Hukseflux for thermal testing purposes, usually for measurement of thermal conductivity or total thermal resistance, these have to fulfil certain requirements. Hukseflux cannot handle every material type and every test condition. To name a few common restrictions: the specimen size must match requirements imposed by our equipment, we must be able to safely handle the material and we must be able to work at the right reference conditions, for instance at a prescribed temperature or pressure. This document clarifies the specimen requirements for thermal testing at Hukseflux.

Procedure

To start with, we ask our customers to fill in the yellow-marked part of the thermal properties laboratory request form. Together with each customer, Hukseflux will **select a measurement method** and **estimate the measurement uncertainty**. Hukseflux will estimate uncertainty based on available specimen dimensions and the estimated order of magnitude of the thermal conductivity. In case of doubt, a free trial experiment may be considered. Together with the customer, Hukseflux will **optimise specimen dimensions**. In most cases, the customer will supply specimens.

No optimal specimen size available?

Working outside the rated measurement range is possible but will lead to higher measurement uncertainties than specified. Consult Hukseflux for an uncertainty evaluation.

1 Specimens for testing with THISYS and THASYS

1.1 General THASYS and THISYS

1.1.1 THYSIS and THASYS are the **preferred instruments for testing plastics and composites.** In some cases, the use of thermal needles may be an alternative. (see paragraph 3)

1.1.2 To reduce errors due to contact resistance, specimens in THASYS and THISYS are **usually submerged in a bath of glycerol**. The use of this fluid allows proper measurements with **non-porous or closed-cell specimens** only.

1.1.3 THAYS may be operated **in a dry condition, which allows us to work with porous materials,** typically with specimens of low thermal conductivity; in the order of < 0.1 W/m·K the uncertainty of the measurement will be higher than usual. Examples of specimens tested in a dry condition are foams, fabrics, leather and cloth. To be operated in a dry condition THASYS must be emptied and dried out at additional cost.

1.1.4 To determine contact resistances between materials, experiments can be done **in a dry condition** on dry specimens. To be operated in a dry condition THASYS must be emptied and dried out at additional cost.

1.1.5 The temperature dependence of thermal conductivity of most materials is low (usually in the order of < 0.05%/K) Most tests are therefore carried out **at room temperature** (15 to 25 °C) only. THASYS and THISYS rated operating **temperature range is from -30 to + 120 °C**. (NOTE: With THISYS, plugs on the heat sink must be opened for operation at high temperatures). Measurements at an extended temperature range are offered at additional cost as an option, typically in steps of 10 °C.

1.1.6 **Ideal specimen surface area** is 110 x 70 x 10^{-3} m; the **ideal thickness** for plastics / composites is in the range of (1 to 5) x 10^{-3} m, maximum thickness is 6 x 10^{-3} m.

1.1.7 The surfaces should be as **flat as possible** on both sides. Usually the **surface quality** and **thickness** of the specimen are not critical. Preferably, the specimens should have a **thickness uniformity** within 0.1 x 10^{-3} m or 2 % of the total thickness, whichever is largest. If this is not attainable, this will result in higher measurement uncertainty. A **surface roughness** of < 20 x 10^{-6} m is acceptable.

1.1.8 The specimen surfaces are not necessarily parallel, but for performance within specifications **parallelity** may have a maximum difference between the corners of 5 % of the average thickness.

1.2 Specifically for measurements with THASYS

1.2.1 THASYS measures in the direction perpendicular to the specimen (**through-plane measurement**). The influence of contact resistance is practically eliminated, which results in a very high measurement accuracy.

1.2.2 The **formal requirement or rated measurement range is: H/λ = (0.5 to 5) x 10^{-3} $m^2 \cdot K/W$**, with λ = specimen thermal conductivity in the through-plane direction. **Working outside the rated measurement range** is possible but will lead to higher measurement uncertainties than specified. Consult Hukseflux for an uncertainty evaluation.

1.2.3 In case the specimen's thermal resistance (thickness divided by thermal conductivity; H/λ) is less than 0.5 10^{-3} $m^2 \cdot K/W$, there is significant **loss of accuracy**; Hukseflux supplies a spreadsheet to calculate expected measurement accuracy as a function of thickness, thermal conductivity, temperature etc.

1.2.4 **Preferred specimen dimensions for THASYS** are: H by (70 by 110) x 10^{-3} m, with H = specimen thickness. Typical specimens are (1 to 5) x 10^{-3} m thick (specimens may be stacked to reach the nominal thickness) and in the thermal conductivity range up to 2 W/(m·K). Specimen dimensions may be reduced to (50 by 50) x 10^{-3} m if necessary. In that case a special **specimen holder** must be constructed, at additional cost, for accurate sensor positioning.

1.2.5 Measurements in **THASYS require at least two specimens for each material type**. Ideally, specimens have the same thicknesses but specimens of different thickness may also be accepted, provided they comply with the general requirements. A **specimen thickness** of 5 x 10^{-3} m is ideal, but for many materials it may be less depending on the thermal conductivity. (see 1.2.2)

1.2.6 THASYS can perform measurements on specimens down to 0.1 x 10^{-3} m thickness, but in that case specimens must be stacked (for example taking around 20 specimens to create 2 stacked specimens of 1 x 10^{-3} m each), ideally fulfilling the requirement of 1.2.2.

1.2.7 Working with THASYS the **pressure on the specimen** can be varied. A pressure cell is optional. The force is in the range from 0 to 400 N. For specimens of the ideal size (70 by 110) x 10^{-3} m) this means pressures up to 71000 N/m^2 or 0.71 bar, for (50 by 50) x 10^{-3} m specimens the maximum pressure is 160000 N/m^2 or 1.6 bar.

1.2.8 THASYS normally is filled with glycerol fluid. In case of the study of **thin porous materials** such as fabrics (which typically are also insulating), THASYS may be emptied, and a measurement can be performed without glycerol. To be operated in a dry condition THASYS must be emptied and dried out at additional cost. In such cases, calculation should prove that the remaining contact resistance is not significant.

1.2.9 **Low viscosity fluids** may be analysed using THASYS with "fluid test cells". In this case, the required specimen volume is **volume of 0.04 l** or 4 x 10^{-5} m^3 and the temperature range is from -30 to + 120 °C.

1.3 Specifically for measurements with THISYS

1.3.1 Measurements in **THISYS require only one specimen for each material type**

1.3.2 THISYS measures in the specimen plane (**in-plane measurement**). THISYS is used in case it is necessary to analyse the in-plane thermal conductivity (it is **assumed that there is no directional preference in-plane**), or in case the through-plane thermal resistance of isotropic specimens is too low for analysis with THASYS.

1.3.3 In THISYS the applied force on the specimen must be close to zero N/m^2 to avoid any damage of the measuring system. These internal heating foils cannot withstand significant pressure. Proper contact can be visually confirmed by pressing the first heat sink and the specimen to the second heat sink to the point where the second heat sink slightly moves.

1.3.4 **The formal requirement or rated measurement range is: $H \cdot \lambda$ = (1 to 5) x 10^{-3} W/K**, with λ = specimen thermal conductivity (2-axis average) in the in-plane direction and H the specimen thickness. This means that with THISYS both 5 x 10^{-3} m specimens made of glass and plastic and also thin metal foil specimens like 0.01 x 10^{-3} m thickness aluminium and 0.1 x 10^{-3} m thickness (stacked) stainless steel may be analysed. **Working outside the rated measurement range** is possible but will lead to higher measurement uncertainties than specified. Consult Hukseflux for an uncertainty evaluation.

2 Specimens for the Guarded Hot Plate

2.1 A guarded hot plate is the **preferred instrument for analysis of relatively thick insulation materials**.

2.2 Temperature range at Hukseflux is from 0 to 60 °C

2.3 **Preferred specimen dimensions** are: H by (300 by 300) x 10^{-3} m (may be stacked), with H = specimen thickness. Normal specimens are (20 to 80) x 10^{-3} m thick and in the thermal conductivity range up to 0.1 W/(m·K). Specimen **dimensions may be reduced** to (100 by 100) x 10^{-3} m if necessary.

2.4 Working outside the rated measurement range is possible but will lead to higher measurement uncertainties than specified. Consult Hukseflux for an uncertainty evaluation. As a rated measurement range is **H/λ > 0.2 (m^2·K) / W. The total measurement range H/λ = 0.2 to 8 m^2·K / W.**

2.5 **When not to apply the guarded hot plate**: A guarded hot plate measures the total thermal resistance of the specimen. When testing insulation materials, the differential temperature measurement across the specimen errors due to contact resistance (air layers and plastic) between specimen surface and the location of the temperature measurement are negligible. The higher the specimen thermal resistance, the lower the error due to the contact resistance. An estimate of the contact resistance is 1 x 10^{-3} m^2·K/W, so that a 30 x 10^{-3} m thick material of 0.015 W/(m·K) has a thermal resistance of 2 m^2·K/W, will have only 0.05 % error. For a solid plastic sheet of the same dimensions of thermal conductivity 0.2 W/(m·K), the error is in the 1 % range. For glass of same dimensions, the error is in the 4 % range. For a plastic sheet of 3 x 10^{-3} m thickness, the error is in the 10 % range, so that the THASYS system is preferable. For high conductivity plastics or glass, the Guarded Hot Plate is not the preferred measurement method.

3 Specimens for Thermal Needles

3.1 Thermal needles are the preferred tool for **measurement of any homogeneous isotropic material in which a needle can easily be inserted or in which a guiding tube can be cast in**. The use of needles is also possible with fluids with a viscosity higher than water (0.001 Pa·s).

3.2 Specimens for analysis with thermal needles are often **soft, granular or fluid** and are typically **supplied in moisture-proof containers.**

3.3 In some cases, solid specimens are prepared for analysis with thermal needles by **casting Guiding Tubes** into the material.

3.4 The rated measurement range of thermal needles is 0.1 to 6 W/m ·K. **Working outside the rated measurement range** is possible but will lead to higher measurement uncertainties than specified. Consult Hukseflux for an uncertainty evaluation.

3.5 **Ideal specimen requirement is a volume of 1 l** or 0.001 m^3 but smaller volumes are possible. The minimum allowable specimen volume depends on the thermal diffusivity of the specimen material type. In case it is not possible or too costly to provide ideal specimen dimensions, please estimate the thermal diffusivity and consult Hukseflux to find a compromise. In any case, **the volume should be larger than 0.128 l or 0.128 x 10^{-3} m^3** (needle type TP08)

3.7 The rated temperature range for measurements with thermal needle types TP02 and TP08 is -55 +180 °C. This may be extended to 250 °C relatively easily, and to higher ranges on request (both at additional cost).