Thermal Conductivity Measurements of Concrete Using the Heat Flow Meter (HFM) and Guarded Hot Plate (GHP) Methods

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1   HFM 436/3 *Lambda*

2   GHP 456 T*itan®*

Introduction

The thermal performance of rigid and higher thermal conductivity (lower thermal resistance) building materials such as lumber, gypsum board, concrete, stone and other masonry products can be measured using the HFM and GHP instruments (figure 1 and 2). These methods are standardized test techniques and the application (insulating and building materials) is strongly connected with e.g., the following standards:

- ISO 8301:1991: Thermal insulation – Determination of steady-state thermal resistance and related properties – Heat flow meter appratus.

- ISO 8302:1991: Thermal insulation – Determination of steady-state thermal resistance and related properties – Guarded hot plate apparatus.

- ASTM C518: Standard test method for steady-state heat flux measurements and thermal transmission properties by means of the heat flow meter apparatus.

- ASTM C177: Standard test method for steady-state heat flux measurements and thermal transmission properties by means of the guarded hot plate apparatus.

- DIN EN 12667/12939:2001: Thermal performance of building materials and products – Determination of thermal resistance by means of guarded hot plate and heat flow meter methods – (thick) products of high and medium thermal resistance.

- DIN EN 13163:2001: Thermal insulation products for buildings – Factory made products of expanded polystyrene (EPS) – Specification.
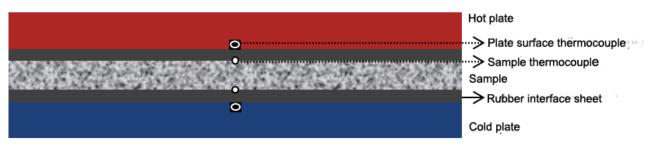
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With the absolute GHP method an accuracy of ±2% can be achieved. The HFM method requires a calibration of the instrument. Depending on the reference material, accuracies of ±2% can also be obtained.

How to Handle Rigid Samples with Rough Surfaces

However, both methods may require careful sample preparation and special techniques for accurate surface temperature measurements. The above mentioned materials (e.g., concrete) can have rough surfaces and preparation of highly flat and parallel surfaces can be difficult. As a result, a significant interface thermal resistance (temperature drop) may be present in any air gaps between the instrument plates and sample surfaces. If this thermal resistance becomes significant compared to the sample thermal resistance, temperature sensors mounted in the plate surface can no longer be used to measure the temperature difference across the sample. One technique is to mount additional small diameter thermocouples on the sample surfaces and place a compliant interface sheet such as silicone rubber between the plates and sample surfaces as shown in figure 3 below.

3   HFM and GHP arrangement for sample surface thermocouples

Measurement Parameters

For this study, three pairs of concrete samples (305 mm by 305 mm by approximately 50 mm thickness) were tested using the GHP method (double-sided), and then each of the six samples was tested using the HFM method. For each method, sample surface mounted thermocouples and silicone rubber interface sheets approximately 2 mm thickness were used.

The HFM 436 was calibrated using the NIST 1450b (Standard Reference Material®) fiberglass board with a thickness of 25 mm. The temperature measurement was achieved by plugging the sample thermocouples into the data acquisition channels used for the plate thermocouples and then the automatic offset adjustment in the software could adjust the plate temperatures during the test to get the specified sample temperature difference. The equilibrium parameters were set to 1% (rough) and 0.1% (fine).

The tests were carried out at room temperature (mean sample temperature, see table 1). The temperature difference between the two GHP plates was approximately 26 K with 12 K temperature difference across the sample. For the HFM, plate temperature difference was approximately 18 K with 8 K across the sample.

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Test Results

The results are presented in Table 1. The thermal conductivity of 1.8 W/(m·K) for the higher density concrete sample C is significantly higher compared to 1.2 - 1.3 W/(m·K) for A and B, as expected. The agreement between the methods is quite good, especially considering the low thermal resistance of the samples and imperfect surfaces. The average of the thermal conductivity measured by HFM for the individual samples ranges from 4.1% lower to 2.4% higher compared to the GHP measurement of both samples

Sample	Thickness (mm)	Density (Kg/m³)	Mean temperature (°C)	Thermal conductivity (W/(m·K))	Thermal resistance (m·K/W)
A1, A2 (GHP)	52.6	1896	24.1	1.36	0.0387
A1 (HFM)	53.6	1897	23.9	1.38	0.0387
A2 (HFM)	51.6	1895	23.9	1.23	0.0421
A1, A2 (avg., HFM)	52.6	1896	23.9	1.31	0.0404
Variation				*-4.0%*	
B1, B2 (GHP)	51.1	1909	25.0	1.27	0.0402
B1 (HFM)	51.1	1935	23.9	1.23	0.0416
B2 (HFM)	51.0	1882	24.1	1.21	0.0423
B1, B2 (avg., HFM)	51.1	1909	24.0	1.22	0.0419
Variation				*-4.1%*	
C1, C2 (GHP)	51.4	2297	25.2	1.76	0.0292
C1 (HFM)	51.7	2298	23.4	1.92	0.0269
C2 (HFM)	51.1	2296	23.8	1.69	0.0303
C1, C2 (avg., HFM)	51.4	2297	23.6	1.80	0.0286
Variation				*2.4%*	

Tab. 1   Thermal conductivity measurements of concrete by GHP and HFM

Conclusion

Both, the absolute GHP and the relative HFM method, are qualified to determine the thermal conductivity and thermal resistance of rigid and higher thermal conductivity (>1 W/(m·K)) building materials – even with rough surfaces. It was shown that accurate surface temperature measurements can be achieved by using additional thermocouples and compliant sheets between the plates and the sample. The small deviation between the GHP and HFM test results already indicates the high performance capability of both methods.

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