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A simple dynamic measurement technique for comparing thermal insulation performances of anisotropic building materials

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Abstract

Measuring or estimating thermal properties of anisotropic building materials can be key obtaining the optimum performance for a particular application. The intensive researches on development of new building materials have necessitated in situ thermal testing apparatuses in most research laboratories. Only few standardized techniques are available for accurate thermal testing of anisotropic materials, and they are generally expensive. In the present study, common thermal testing methods are reviewed in brief. A simple and inexpensive thermal testing technique is proposed. The measurement is based on analysis of transient data, which is suitable for comparing effective thermal transmittances of both isotropic and anisotropic building materials. Sample measurements with ordinary concrete and rubberized concretes are performed. The effective thermal transmittances of rubberized concretes are found to be considerably lower than that of the ordinary one.

Keywords: Measurement methods; Thermal properties; Adiabatic-box technique; Anisotropy; Building composites

1. Introduction

The measurement of thermal transport properties for a solid material is a key issue to attain optimum performance for a particular application. Over the years a number of measurement techniques have been developed for this purpose [1]. The earliest group of measurement techniques is the steady-state techniques. The technique is based on establishing a temperature gradient over a known thickness of a sample and controlling the heat flow from one side to the other. Steady-state techniques are primarily suitable for analyzing materials with low or average thermal conductivities at moderate temperatures [2]. The transient (dynamic) techniques measure temperature–time response of the sample when a signal is sent out to create heat in the body. These methods can be used for measuring thermal diffusivity, thermal conductivity, or both, for broader range of temperatures and thermal properties [3]. A well-known transient method for thermal diffusivity is the Laser Flash [4–7]. A group of new apparatus known as Contact Transient Methods has recently become very attractive and popular for all types of materials since they can be used to measure several thermal properties simultaneously or separately [8–11].

The quick development of new and advanced materials for broad ranges of applications has necessitated the introduction of completely new techniques for producing reliable data for the growing demand. Part of this interest is a search for innovative building systems that combine higher efficiency and quality in the building process with improved thermal resistance. The most important aspects of innovation might be in the development of integrated insulation products [12]; such as the insulated, reinforced concretes [13], two or three-wythe precast sandwich wall panels [14], and rubberized concretes [15]. An issue that arises out of this activity is the need to establish the thermal properties of the alternative systems and products. Accurate thermal characteristics are required to guide product development and manufacturing. Methods and data exist for dealing with the common building walls and insulations, but new systems and products are generally lacking such data. The information, to be generally useful in the building industry, needs to be in a form that is accurate, easily applied, and versatile enough to span the typical variations in the building configuration and the properties of the materials [13].

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It is often not enough to get approximate data from standard tables since small variations in composition, processing parameters and utilization conditions of materials change the behavior and properties. Anisotropy due to crystal structure, material type and form and method of fabrication can cause large variations in property depending on the heat flow direction within the material [16]. Recent parametrical studies for insulated, reinforced concretes [13] and for three-wythe precast concretes [14], have successively demonstrated that these structural variables can have significant impacts on the thermal performance. Measurements of real samples of anisotropic building structures are thus necessary to support thermal design. As a consequence of the wide ranges of thermal property, a measurement method has to be selected depending on the following criteria: possible sample size and shape, temperature range, and thermal conductivity range [2–4].

In this paper, we review common steady-state and transient measurement techniques and introduce a new apparatus designed for thermal performance estimation of anisotropic building assemblies.

2. Short review of common measurement techniques

2.1. Steady-state measurement techniques

The steady-state measurement techniques are based on establishing a temperature gradient over a known thickness of a sample to control the heat flow from one side to the other. A one-dimensional flow approach has been employed most frequently, but also other geometrical arrangements are used. The thermal conductivity is simply determined by measuring the temperature gradient and the heat flow through the sample [17–19]. Most commonly used steady-state measurement techniques are summarized in Appendix A and schematically shown in Fig. 1.

The guarded hot plate apparatus [20] shown in Fig. 1(a) consists of uniformly wound heaters in a central metered section and in a thermally isolated guard area separated by a small co-planar gap. A number of temperature sensors are fitted tightly in all surfaces at appropriate positions in the central and guard sections. Measured dc-power is applied to the hot plate and the various temperatures in the cold plate and guard sections adjusted and carefully controlled to produce uniform temperatures at the specimen surfaces. The zero temperature difference across the gap and the desired temperature difference across the specimen pieces are required to obtain thermal conductivity.

For the heat-flow meter technique [21], a square sample with a well-defined thickness is inserted between two plates as indicated in Fig. 1(b). The heat flow through the sample is measured with calibrated heat flow sensors after a fixed temperature gradient is established. For larger samples and higher thermal conductivity ranges guarded heat-flow meters can be used. The measurement principle remains nearly the same, but the test section is surrounded by a guard heater, resulting in higher measurement temperatures.

The hot-box technique [22–24] is normally used measuring the overall heat transfer through large, inhomogeneous structures. The overall thermal resistance (R-value), which includes air film resistances in the cold and warm sides along with heat conduction resistance of the specimen, is obtained from such measurement. A large specimen is placed between a hot and a cold chamber operating at fixed temperatures, humidity and air flow conditions. In the guarded hot-box version [22], shown in Fig. 1(c), a guarded metering box is attached to the central section of the specimen. Temperature sensors are placed at positions approximately opposite those in the specimen to obtain the corresponding air temperatures. Testing is performed

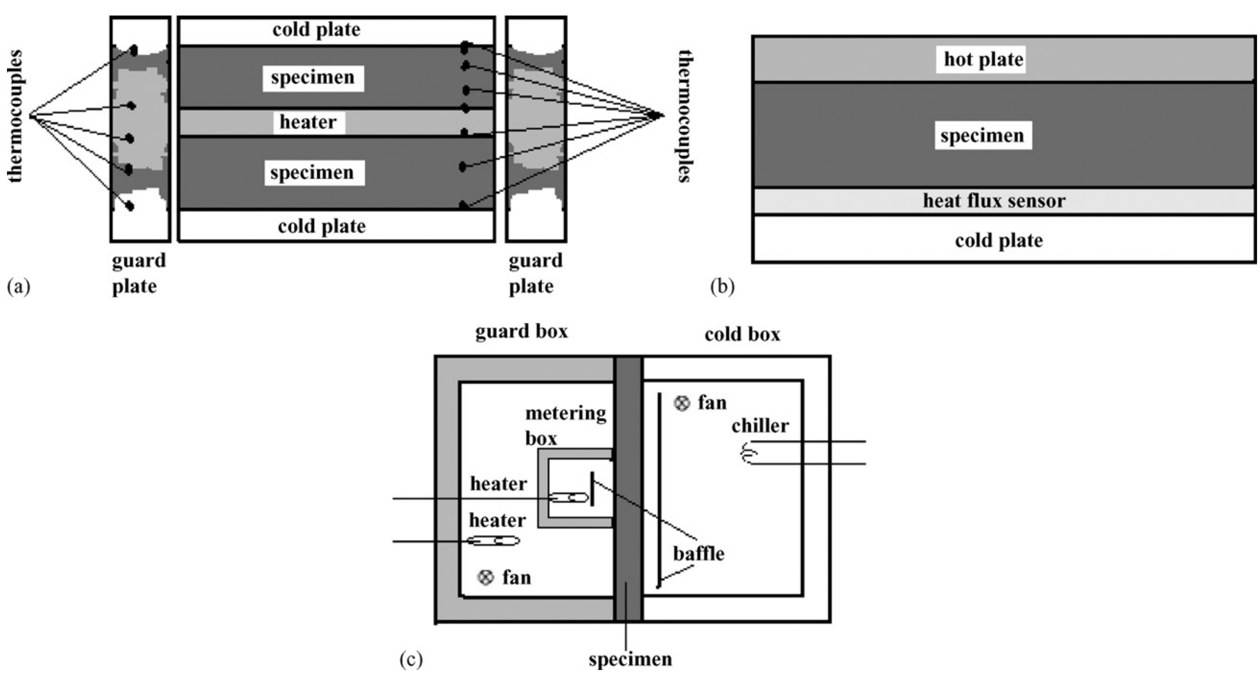

Fig. 1. Common steady-state measurement techniques: (a) guarded hot-plate, (b) basic heat flow-meter and (c) guarded hot-box.