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Test method

A simple test method for measuring water vapor resistance of porous polymeric materials

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ABSTRACT

A simple test method is proposed for measuring water vapor resistance of fabrics. A piece of cotton fabric connected to a container filled with distilled water through a plastic tube was used on a hot plate to generate a saturated water vapor condition on one side of the sample. The temperature of the cotton fabric (approximation of human skin covered with sweat) was measured by a thermocouple. The water vapor resistance of the sample was determined based on the water vapor pressure gradient across the sample and the heat flux. Five types of textile fabric laminated to PU/TPU membranes, plus one type of conventional fabric, were tested by using this simple apparatus as well as the sweating guarded hot plate instrument. The results showed that good agreement was observed between these two test methods. In addition, the surface temperature of the cotton 'skin' varied with different fabrics. This is in accordance with the actual intended situation, i.e., the skin temperature of the body is related to the ability of clothing materials to transfer water vapor. Therefore, this simple test apparatus better simulates real-life conditions than the sweating guarded hot plate instrument.

1. Introduction

The ability of fabrics (porous polymeric materials) to transport water vapor plays a major role in determining thermal comfort of clothing systems. During heavy work or in hot environments, a high degree of water vapor permeability of clothing materials supports water vapor transfer from the skin of the wearer through the textile fabrics into the environment. If the resistance to water vapor diffusion is high, the moisture movement is impeded and the discomfort sensation of dampness and clamminess may arise.

There are several standard test methods available for measuring water vapor transmission rate of fabrics [1–4]. The water vapor transmission rate of fabrics is dependent on not only air temperature and relative humidity, but also wind speed. The water vapor resistance is determined by the ratio of water vapor pressure gradient to heat flow, i.e., the heat flow is normalized by the water vapor pressure gradient, and is more suitable than vapor transmission rate for comparing water vapor transfer behavior of different fabrics. This parameter can be determined by the sweating guarded hot plate instrument in terms of the measurement of the heat of evaporation [5,6].

The sweating guarded hot plate simulates the heat and moisture transfer from the body surface through the clothing system to the environment. It can offer reproducible and repeatable results [7,8]. The main disadvantage of this method, however, is that the sweating guarded hot plate apparatus, climate-controlled chamber and data acquisition system are expensive and complicated to use.

More recently, a new technique was introduced to measure water vapor diffusion resistance of fabrics [9]. A cylinder covered with a piece of waterproof but vapor permeable PTFE membrane laminate was utilized to produce the saturated vapor condition for one side of the sample. A dry nitrogen

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stream was used to sweep the moisture vapor away. The water vapor diffusion resistance was calculated based on the relative humidity of the outgoing nitrogen stream. Although this test method permits us to examine the ability of fabrics to transport water vapor by using a small piece of material in a short measurement interval, it requires a humidity sensor with high accuracy, and the cost is still high. Later, Zhang et al., designed a test apparatus and proposed two measuring parameters (dry bulb coefficient and wet bulb coefficient) [10]. However, these two parameters qualitatively reflected the ability of fabrics to transfer heat and water vapor.

The purpose of this paper is to introduce a simple test method for measuring the water vapor resistance of fabrics.

2. Methods

2.1. Measurement principle

The guarded hot plate instrument, invented in 1898, is now undoubtedly recognized as the most accurate technique for determining the thermal conductivity of insulation materials [11]. In accordance with GB 11048, the thermal resistance of a fabric can be measured by using a guarded hot plate. The sweating guarded hot plate is able to simulate both heat and moisture transfer from the body surface through the clothing layers to the environment. It measures the thermal resistance and water vapor resistance of fabrics. However, this instrument is expensive and few of universities or companies can afford it.

To measure water vapor resistance of fabrics, a guarded hot plate instrument, which was designed to measure thermal resistance of fabrics, was modified. As shown schematically in Fig. 1, the hot plate was covered by a piece of cotton fabric with a hole (200 mm by 200 mm) in the center. A piece of impermeable membrane was then placed above the cotton fabric. Another piece of cotton fabric (200 mm by 200 mm) was mounted on the membrane to fit the hole. This piece of cotton fabric was connected to a container filled with distilled water through a plastic tube. As we know, cotton fabric is capable of holding a large amount of liquid water through capillary force. The cotton 'skin' provided a reasonable approximation of human skin that is covered with sweat. A piece of waterproof but vapor permeable PTFE membrane was positioned on the cotton 'skin', forming an infinite source of water vapor. A thermocouple was sandwiched between the cotton fabric and the PTFE membrane for measuring the temperature of the cotton 'skin'.

The above apparatus was housed in a test chamber. The surface temperature of the plate was set at 35 °C. The air temperature of the chamber was controlled at 20 ± 1 °C, and it did not fluctuate more than ±0.1 °C during one test run. The relative humidity was maintained at 65%. The fabric sample to be tested, with a size of 300 mm × 300 mm, was placed on the PTFE membrane. The side of the specimen which is normally toward the human body should be facing downward. When testing a coated fabric, the coated side is supposed to face downward. The hot plate instrument was operated as usual, i.e., a test was run to measure thermal resistance of a fabric. The total thermal resistance of fabric assembly, including the impermeable membrane, the cotton 'skin' and the PTFE membrane, was obtained from the printout of the instrument. The total heat loss (H) was determined accordingly.

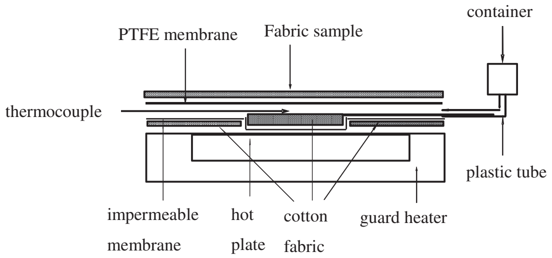

Fig. 1. Schematic diagram of test apparatus.

The water vapor resistance of the fabric was calculated by:

$$R_{et} = \frac{A(P_s - P_a)}{H_e} \quad (1)$$

where R_{et} is the total water vapor resistance provided by the fabric, the cotton skin, two piece of membranes and boundary air layer (m^2 Pa/W), A the area of the test section (m^2), P_s the saturated water vapor pressure at the temperature of the cotton skin (Pa), P_a is the water vapor pressure of the air (Pa), H_e the evaporative heat loss (W).

Since the air temperature of the chamber was lower than the temperature of the cotton 'skin', a non-isothermal condition was achieved. The total heat loss of the hot plate comprised dry heat loss and evaporative heat loss. The evaporative heat loss can be obtained by subtracting the dry heat loss from the total heat loss:

$$H_e = H - H_d \quad (2)$$

where H_d is the dry heat loss (W), H the total heat loss.

The dry heat loss is dependent on the thermal resistance of the fabric plus the PTFE membrane, which was measured by conducting a test on the hot plate.

$$H_d = \frac{A(T_s - T_a)}{R_t} \quad (3)$$

where T_s is the surface temperature of the cotton skin (°C), T_a is the air temperature of the chamber (°C), R_t the total thermal resistance of fabrics plus the cotton fabric, two piece of membranes and boundary air layer (m^2 °C/W).

The intrinsic water vapor resistance of the fabric was obtainable by subtracting the water vapor resistance of the cotton 'skin', two piece of membranes and boundary air layer, which can be measured by conducting a test without a specimen over the PTFE membrane.

$$R_{ef} = R_{et} - R_{eb} \quad (4)$$

where R_{ef} is the intrinsic water vapor resistance of the fabric, R_{eb} the water vapor resistance of the cotton 'skin', two piece of membranes and boundary air layer (m^2 Pa/W).

2.2. Test procedures

2.2.1. Sample selection

There has been increasing development of fabrics that are waterproof and windproof yet permeable to water