Available online at www.sciencedirect.com
ScienceDirect
Thermochimica Acta 455 (2007) 75–79
thermochimica acta
www.elsevier.com/locate/tca

An experimental study on thermal properties of composite insulation

Gyoung-Seok Choi [a,b,*], Jae-Sik Kang [a], Young-Sun Jeong [a], Seung-Eon Lee [a], Jang-Yeul Sohn [b]

[a] Building & Urban Research Department, Korea Institute of Construction Technology, 2311 Daehwa-Dong, Ilsanseo-Gu, Goyang-Si, Gyeonggi-Do 411-712, Republic of Korea
[b] College of Architecture, Hanyang University, 17, Hangdang-Dong, Sungdong-Gu, Seoul 133-791, Republic of Korea

Available online 20 December 2006

Abstract

In accordance with the insulation standards reinforced since 2001 and the compulsory standards on floor impact sound insulation that have been enforced since 2004, insulation materials for actual buildings have been converted to composite materials and new insulation materials have been released in the market. However, Korea is lagging behind the world in fundamental experimental studies and resources. In case of some composite insulation materials, there also have been problems of distorted performance occurring as a result of tests being conducted without having verification and evaluation on the accuracy and inaccuracy of such tests. Therefore, this study grasped the thermal properties of composite insulation materials using thermal conductivity test equipment by heat flux method, and performed quantitative evaluation on the measurement precision and uncertainty of composite materials.

Keywords: Thermal properties; Thermal conductivity; Thermal resistance; Composite insulation materials; Heat flux method

1. Introduction

1.1. Background and purpose of study

Insulation in buildings is the most fundamental method for energy consumption reduction in buildings and has a direct effect on heating and cooling load and energy consumption, thus the insulation performance of building envelops is determined by the thermal properties and method of insulation materials in use. Researches and studies on insulation method and materials have been conducted diversely up until now but sufficient fundamental data on various insulation materials and insulation systems that are applied to recent buildings is much lacking. Especially, insulation materials that are applied to actual buildings have been converted to composite materials in accordance with the insulation standards, and the compulsory standards on floor impact sound insulation, but Korea is lagging behind in fundamental experimental studies and resources [1].

Evaluation on the thermal conductivity of insulation material is standardized into heat flux method and guarded hot plate method. Majority of nationally accredited test institutions in Korea possess test equipment for the heat flux method and perform accredited testing through such equipment. Test on composite materials is theoretically possible for the guarded hot plate method that has been designed with no side heat loss but since the heat flux method is not capable of testing composite materials due to the increase of side heat loss, performance evaluation on these composite materials with the rapid increase of recent development and field application has not been achieved [2]. Instead, they undergo the process of conducting performance evaluation on each material and then theoretically adding up the results of such individual performance test. Consequently, in case of some composite insulation materials, there have been problems of distorted performance report occurring as a result of tests being conducted without having verification and evaluation on the accuracy and inaccuracy of such tests.

Therefore, this study plans to grasp the thermal properties of composite insulation materials using thermal conductivity test equipment by the heat flux method and perform quantitative evaluation on the measurement precision and uncertainty of these composite materials.

* Corresponding author at: Building & Urban Research Department, Korea Institute of Construction Technology, 2311 Daehwa-Dong, Ilsanseo-Gu, Goyang-Si, Gyeonggi-Do 411-712, Republic of Korea. Tel.: +82 31 9100 309; fax: +82 31 9100 361.
E-mail address: bear717@kict.re.kr (G.-S. Choi).

0040-6031/$ – see front matter
doi:10.1016/j.tca.2006.12.013

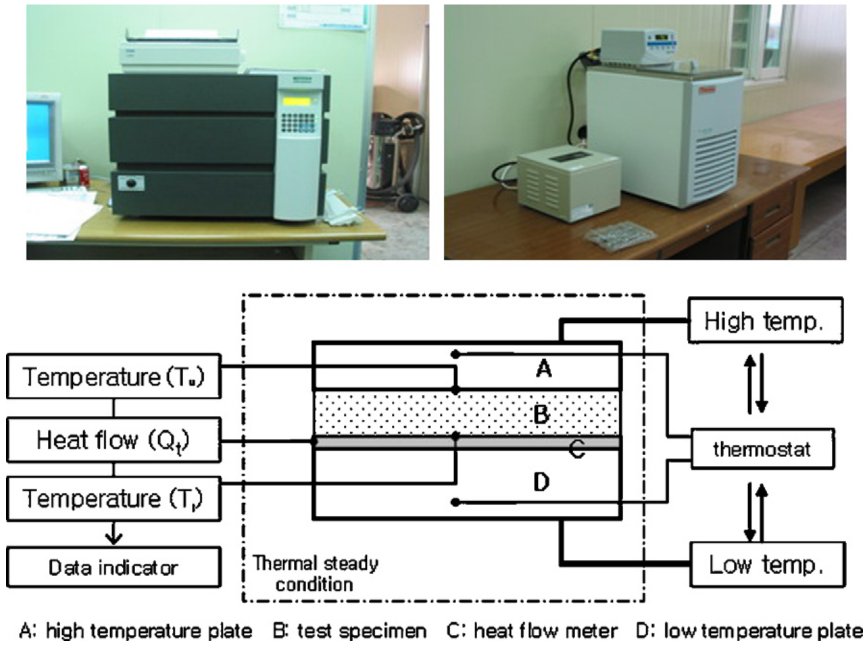

Fig. 1. Heat flow meter (HFM 436 Lambda Series, Netzsch).

1.2. Content and scope of study

To analyze the properties of thermal conductivity of composite insulation materials, this study performed a test on the representative insulation materials for buildings and evaluated variations from the increase in thickness of insulation materials, changes of double composite materials and changes in thermal properties from symmetric and asymmetric composite structures by classifying each of expanded polystyrene insulation materials (two types) and polyethylene foam into standard samples I–III.

2. Test method for measuring thermal properties

The test standard applied to the execution of insulation thermal conductivity test in this study is KS L 9016 (Method for Measuring Thermal Conductivity of Insulations) [3], the heat flux method from ISO 8301 [4] and ASTM test method C 518: 2004 [5], and thermal conductivity measuring device of Heat Flow Meters HFM 436 Lambda Series from Netzsch has been used (Fig. 1).

3. Thermal conductivity properties from thickness

In order to grasp the properties of thermal conductivity from the thickness, increase in thickness, that is the change in thermal conductivity properties, has been searched for after finding the thermal resistance value from measuring thermal conductivity of four expanded polystyrene insulation materials with about 23–25 mm thickness and similar thermal resistance. The measured value of thermal conductivity for the test objects were in the range of 0.0305–0.0308 W/m K with 0.7797–0.8307 m^2 K/W for thermal resistance, thus shown to posses very similar thermal insulation performance.

Thermal conductivity test was performed on each of the test objects after increasing the thickness by overlapping test objects N2, N3 and N4 that have similar thermal resistance on to the lower part of test object N1.

The theoretical value of thermal resistance from the increase in thickness means the sum of thermal resistance possessed by each unit of test objects, and an error [6] refers to the difference in thermal resistance values between the test result of thermal resistance and the value generated theoretically.

Expanded polystyrene (EPS) like other foam insulations show a dependence of the thermal conductivity versus thickness caused by different radiative heat transfer (this is, e.g. mentioned in EN 13163) [7].

There should be no change occurring from the thickness of a test object under the normal condition by the heat flux method but as a result of the measurement, the change in the thermal resistance occurred as much as about 4–8% when the thickness increased by four times. Such is considered to be the effect from the side heat loss of a test device (Table 1).

4. Thermal conductivity properties of double-layered composite material

Test method of thermal conductivity for insulation materials stipulated in the existing Korean Industrial Standard is only for testing a single material, thus for a composite material, the standard proposes to conduct experiment on each of the material individually and then evaluating the test results comprehensively. Consequently, composite insulation material has a problem of obtaining a different result than the original thermal property. Therefore, this section formed a double composite insulation material and evaluated the thermal conductivity properties of the composite materials on the materials with about

Table 1
Test result of thermal conductivity and thermal resistance from increase in thickness

Specimen	λ (W/m K)	R (m^2 K/W)	R' (m^2 K/W)	ΔR ($R' - R$)	Error (%)
N1	0.0305	0.7797	–	–	–
N1 + N2	0.0295	1.4808	1.6073	0.1265	+7.9
N1 + N2 + N3	0.0286	2.2741	2.4287	0.1547	+6.4
N1 + N2 + N3 + N4	0.0276	3.1343	3.2594	0.1251	+3.8

λ is the thermal conductivity, R stands for the thermal resistance, R' is the thermal resistance theoretical value and ΔR is the thermal resistance differential between experimental and theoretical value.

Table 2
Individual test results of a composite material with difference in thermal conductivity

Specimen	λ (W/m K)	λ ratio (%)	R (m^2 K/W)	R ratio (%)
Δλ: 5%				
N1	0.0305	100	0.7800	100
S1	0.0319	104.4	0.6405	82.1
Δλ: 50%				
NP1	0.0297	100	0.7349	100
PE2	0.0490	164.8	0.4258	57.9
Δλ: 400%				
N1	0.0305	100	0.7800	100
SCI-6	0.1328	434.9	0.2072	26.6

Δλ is the differences in thermal conductivity of two materials.

5%, 15%, 50% and 400% differences in thermal conductivity (Table 2).

Table 3 is a result of test on a double layered composite material with about 5% difference in thermal conductivity, the thermal resistance measured value of the composite material shows about 2.3% difference compared to the theoretical value experimentally looked for and calculated on each of the single material, but difference from the arrangement of thermal resistance has not occurred. Ultimately, in case of a double composite material that has thermal conductivity or thermal resistance of similar range, test result measured under the condition of a composite material showed a difference of within 3% compared to the testing on each of the material.

With the composite material that has about 5% difference in thermal conductivity showing a small difference of within 3% between the measured value and the theoretical value of the thermal conductivity, a test has been performed on a double composite material, that has the difference of as high as about 15%, by expanding the range of performance difference for the double composite material (Table 4).

Table 5 is the test result of thermal conductivity from a double composite material (NP1 + NP2) that has combined NP2 to the test object NP1 with the lowest thermal conductivity among the single materials constituting the double composite material, to a double composite material that has combined with the lowest SP4. As a result of the test, the actual measurement value is within 3% compared to the theoretical value for the thermal conductivity of a double composite insulation material composed of highly heterogeneous material with the value of thermal conductivity being 0.25–14.8% compared to NP1 that has the lowest thermal conductivity among the individual material. Therefore, thermal conductivity of heterogeneous material that actually has up to 15% difference in insulation performance does not show a big difference on thermal conductivity measured value of individual material.

To grasp the arrangement properties from the size of thermal resistance, a test on PE2 + NP1, which is a reversed section of the test object NP1 + PE2, has been performed. As a result of test on a double composite material that has over 50% difference in thermal conductivity, the measured value of thermal resistance for the composite material shows within 3% difference compared

Table 3
Test result of double composite material with about 5% difference in thermal conductivity

Specimen	λ (W/m K)	R (m^2 K/W)	R' (m^2 K/W)	ΔR ($R' - R$)	Error (%)
N1 + S1	0.0309	1.3881	1.4201	0.0320	+2.3
S1 + N1	0.0309	1.3882	1.4201	0.0319	+2.3

Table 4
Individual test results of a composite material with difference in thermal conductivity

Specimen	λ (W/m K)	λ ratio on NP1 (%)	R (m^2 K/W)	R ratio on NP1 (%)
NP1	0.0297	100	0.7349	100
NP2	0.0298	100.3	0.7336	99.8
NP3	0.0298	100.4	0.7272	99.0
NP4	0.0301	101.3	0.7249	98.6
NP5	0.0306	102.9	0.7082	96.4
SP1	0.0318	106.9	0.6362	86.6
SP2	0.0321	108.0	0.6198	84.3
SP3	0.0323	108.7	0.5911	80.4
SP4	0.0341	114.8	0.5970	81.2
SP5	0.0337	113.5	0.5964	81.2

Table 5
Result of thermal conductivity for double composite material with up to 15% difference in thermal conductivity

Specimen	λ′ (W/m K)	λ (W/m K)	Δλ (λ′ − λ)	Error (%)
NP1 + NP2	0.0305	0.02952	0.000976	3.2
NP1 + NP3	0.03044	0.02964	0.000800	2.6
NP1 + NP4	0.03049	0.02976	0.000725	2.4
NP1 + NP5	0.03039	0.02999	0.000396	1.3
NP1 + SP1	0.03145	0.03064	0.000816	2.6
NP1 + SP2	0.03163	0.03075	0.000882	2.8
NP1 + SP3	0.03180	0.03094	0.000864	2.7
NP1 + SP4	0.03218	0.03175	0.000427	1.3

Δλ is the thermal conductivity differential between experimental and theoretical value.

Table 6
Test result of double composite material with over 50% difference in thermal conductivity

Specimen	λ (W/m K)	R (m^2 K/W)	R' (m^2 K/W)	ΔR ($R' - R$)	Error (%)
NP1 + PE2	0.0374	1.1520	1.1603	0.00824	0.7
PE2 + NP1	0.0383	1.1286	1.1603	0.03163	2.7

Table 7
Test result of double composite material with over 400% difference in thermal conductivity

Specimen	λ (W/m K)	R (m^2 K/W)	R' (m^2 K/W)	ΔR ($R' - R$)	Error (%)
N1 + SCI-6	0.05451	0.8211	0.9868	0.16572	16.8

Table 8
Test result of thermal conductivity on three types of heterogeneous composite material

Specimen	λ (W/m K)	R (m^2 K/W)	R' (m^2 K/W)	ΔR ($R' - R$)	Error (%)
NP1 + SP4 + NP2	0.0303	2.1440	2.0656	0.07848	3.8
SP4 + NP1 + NP2	0.0304	2.1363	2.06556	0.07079	3.4
NP1 + NP2 + SP4	0.0304	2.1374	2.06556	0.07186	3.5

Table 9
Test result of thermal conductivity on four types of heterogeneous composite material

Specimen	λ (W/m K)	R (m^2 K/W)	R' (m^2 K/W)	ΔR ($R' - R$)	Error (%)
NP1 + NP2 + SP4 + SP5	0.0306	2.7646	2.6619	0.1026	3.9
NP1 + SP4 + SP5 + NP2	0.0305	2.7841	2.6619	0.1221	4.6
NP1 + SP4 + NP2 + SP5	0.0303	2.7956	2.6619	0.1336	5.0
SP4 + NP1 + NP2 + SP5	0.0302	2.7993	2.6619	0.1374	5.2
SP4 + SP5 + NP1 + NP2	0.0305	2.7722	2.6619	0.1102	4.1
SP4 + NP1 + SP5 + NP2	0.0302	2.8032	2.6619	0.1413	5.3

to the theoretical value experimentally looked for and calculated on each of the single material but there was no difference in test result from the arrangement of thermal resistance (Table 6).

As a result of test on thermal properties of a double composite material with a different thermal conductivity, the composite material possessing the heterogeneous insulation performance with over about 50% difference in thermal conductivity showed within 3% difference between the actual measurement value and the theoretical value (Table 6). Such a difference increased to about 17% at the time of composite formation on a material with over four times thermal conductivity (Table 7).

5. Thermal conductivity properties on double composite material in symmetrical/asymmetrical formation

The thermal conductivity and thermal resistance of a composite material composed of multiple number of composite materials and the arrangement of thermal resistance, that is the symmetrical and asymmetrical structure, have been evaluated. As for the test objects, 10 types of insulation materials in Table 4 were divided into 3 types of heterogeneous composite materials that take sectional formation of symmetry/asymmetry and 4 types of heterogeneous composite materials.

The measurement result on three types of heterogeneous composite materials is shown in Table 8, showing an error of within 4% compared to the theoretical value. Especially, it has been analyzed that there is very little effect of symmetrical/asymmetrical sectional formation from the location of SP4 that relatively has the lowest thermal conductivity.

Table 9 shows the measurement result of four types multiple composites. According to the result, thermal conductivity for four types of multiple composite materials was 0.0302–0.0306 W/m K regardless of the symmetrical or asymmetrical arrangement with thermal resistance being 2.7646–2.8032 m^2 K/W. Therefore, there was within 4–5% error between the theoretical value obtained from the measured result on each of the individual single material and the test results on composite materials. Also, like the three type composite materials, thermal properties from the location of heterogeneous insulation materials showed an error of within 4%.

As a result of testing the difference in thermal performance in symmetrical and asymmetrical formation from the arrangement of thermal resistance was very small, being within ±0.5% for both three types and four types. Thus, it has been shown that there is very little effect of multiple composite structures in test method by the heat flux method.

6. Conclusion

This study grasped the thermal properties of composite insulation materials using thermal conductivity test equipment by heat flux method, and performed quantitative evaluation on the measurement precision and uncertainty of composite materials. The result of such experiment displayed the following: (1) it has been verified that the changes in thermal resistance occurred in the range of about 4–8% when the thickness of the insulation material increased four times from 20 to 80 mm at the time of measuring using the heat flux method. This seems be the effect of heat loss from the side. (2) There is 3% difference between the actual measurement value and the theoretical value of a double layered composite insulation material that has heterogeneous thermal insulation performance with the occurrence of about 50% difference in thermal resistance, and a material with about 25% difference in thermal resistance showed 17% difference. Therefore, an error is most likely to occur in case of evaluating thermal conductivity of the resilient material, which possesses high thermal conductivity and used as floor impact sound buffer, as a composite material. (3) Three types of composite structures showed a difference of 3% between the theoretical value and the actual measurement value and four types of composite structures showed about 5% difference. Thus, it has been shown that there is very little effect of multiple composite structures in test method by the heat flux method.

References

[1] S.-E. Lee, J.-S. Kang, Y.-S. Jeong, H.-J. Choi, An experimental study on the thermal conductivity change of building insulation materials with environmental condition and long-time elapse, J. AIK 182 (2003) 235–241.

[2] Y.-S. Jeong, G.-S. Choi, S.-E. Lee, Estimation of uncertainty of measurement on thermal conductivity test for building insulation materials, J. AIK 190 (2004) 189–196.

[3] Korean Standards Association (KSA), KS L 9016:2005, Test methods for thermal transmission properties of thermal insulations, 2005.

[4] ISO 8301, Thermal Insulation – determination of steady-state thermal resistance and related properties – heat flow meter apparatus, 1991.

[5] ASTM C 518, Standard test method for steady-state thermal transmission properties by means of the heat flow meter apparatus, 2004.

[6] Korean Standards Association (KSA), KS A 3000:2004, Guide to the expression of uncertainty in measurement, 2004.

[7] EN 15163, Thermal insulation products for buildings – Factory made products of expanded polystyrene (EPS) – Specification, 2001.