# AGING OF THERMAL INSULATION MATERIALS BY ACCELERATED LABORATORY TEST METODS

**Jae-Sik Kang**[1, 2]

Gyoung-Seok CHOI[1]

Young-Sun JEONG[1]

Seung-Eon Lee[1]

[1] Korea Institute of Construction Technology, 2311, Daehwa-Dong, Ilsan-Gu, Goyang-Si, Gyeonggi-Do, 411-712, Republic of Korea

[2] To whom correspondence should be addressed

Jae-Sik Kang

2311, Daehwa-dong, Ilsan-gu, Koyang-shi, Kyonggi-do, 411-712, Republic of Korea

Building Research Dept.

Korea Institute of Construction Technology

Tel: 82-31-910-0353

Fax: 82-31-910-0361

E-mail: jskang@kict.re.kr

## Abstract

The plastic typed thermal insulation material has a characteristic of decreasing thermal conductivity as time passes. In this research, two types of architectural thermal insulator (extruded expanded polystyrene and hardened urethane foam) have been studied in accordance with the 'ISO 11561 Aging of thermal insulation materials - Determination of the long-term change in thermal resistance of closed-cell plastics'. These two test objects were cut thinly into about 10 mm width in the direction of the thickness using two methods, heat rays and knife, and the change in the thermal conductivity from long-term elapse of time in the thermo hydrostat room under such constant conditions of 23± 2℃ room temperature and 40% ± 3% relative humidity was measured. Moreover, long-term thermal conductivity of uncut thermal insulators has been measured simultaneously as well.

The result of the research showed that the thermal conductivity of the thermal insulations sliced with heat rays and a knife has stabilized into a fixed value after 1,000 hours. About 30~40% change in the thermal conductivity occurred for the extruded expanded polystyrene in accordance with the cutting method and about 25% of change occurred for the hardened urethane. This research has presented an estimation model for the long-term thermal conductivity change in the plastic typed thermal insulators from the relation between a result on the long-term thermal conductivity through slicing and a result on the long-term thermal conductivity through non-slicing.

**Keywords**: closed-cell plastics, the long-term thermal, conductivity, aging

## 1. Introduction

Among the different types of plastic thermal insulation material, extruded expanded polystyrene and hardened urethane foam have a characteristic of decreasing thermal conductivity resistance with the passage of time. In other words, plastic thermal insulation material forms closed cells within the insulator and uses blowing agent to heighten its thermal insulation performance. The reason for plastic thermal insulation material experiencing the decrease in the thermal insulation performance with the passage of time is known to be due to nitrogen and oxygen in air penetrating into cells to cause the primary decrease in the thermal insulation performance within 5 years and the secondary decrease as blowing gas in the cells is slowly released outside in the time span of 10 years. Such changes from elapsed time (ageing characteristic) is explained as a primary stage and a secondary stage in ISO 11561 (Aging of Thermal Insulation Materials - Determination of the Long-Term Change in Thermal Resistance of Closed-Cell Plastics).

In this research, accelerated laboratory test from slicing was carried out in a laboratory on the two types of architectural thermal insulation material (extruded expanded polystyrene and hardened urethane foam) that have the ageing characteristic in accordance with ISO 11561 (Ageing of Thermal Insulation Materials - Determination of the Long-Term Change in Thermal Resistance of Closed-Cell Plastics). These two test objects were cut into about 10 mm width in the direction of thickness using two methods of heat rays and knife and the change in the thermal conductivity resistance from elapsed time under the thermal hydrostat room with 23± 2℃ room temperature and 40% ± 3% relative humidity was measured and the long-term thermal conductivity resistance of uncut thermal insulators has been measured as well.

Table 1. Thermal Insulation Materials for Laboratory Test

| Test Objects | Density |
|---|---|
| Extruded Expanded Polystyrene | 35.4 $kg/m^3$ |
| Hardened Urethane Foam | 41.0 $kg/m^3$ |

## 2. Test Method and Instrument

### 2.1 Experiment Method

The experiment was carried out in accordance with the test methods of KS L 9016 of Korean Industrial Standards, ISO 8301 and ASTM C 518. The architectural thermal insulation material used as test objects had been sampled among the materials that have been less than 3 days since the production from a factory.

The thermal conductivity resistance of the test objects was measured every 10 minutes in the initial period of experiment and the total of 1,000 hours was used to measure the thermal conductivity resistance until the thermal conductivity resistance was stabilized at a fixed level.

In the case of repeated experiment in every 10 minute interval, the test objects were placed within the measuring instrument and the experiment was carried out with the objects placed in a chamber that maintains the constant condition of thermal hydrostat room (room temperature: 23℃± 2, relative humidity:40%± 5) with a separate heating/cooling adjusting device outside the measurement time. On the other side, the test object set up and counter of the thermal conductivity measuring device are located within the thermal hydrostat room.

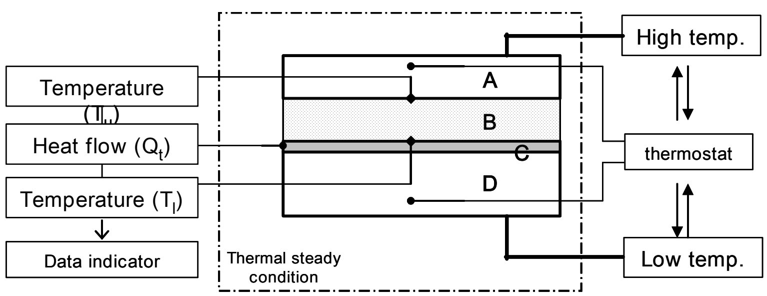
## 2.2 Experiment Instrument

The temperature condition of the experiment equipment was set at 20± 1℃ for the average experiment temperature by maintaining the highest heat source at 33℃ and the lowest heat source at 7℃. This is in accordance with the test method of architectural thermal insulator regulated in KS L 9016 of Korean Industrial Standards. In order to calculate thermal conductivity, surface temperature (Tu, Tl) from both sides of high temperature and low temperature of the heat insulating test objects, heat flow amount (Qt) measured by the heat flow meter and the thickness (d) of the thermal insulation sample were measured.

As for the test instrument, Rapid-k (RK-30) of Holometrix Company and two types of Heat Flow Meters HFM 436 Lambda Series were used as the thermal conductivity experiment equipments. The measuring device is an instrument of flat heat flow meter method in accordance with ASTM C 518 (Standard Test Method for Steady-State Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus) and ISO 8301 (Thermal Insulation Determination of Steady-State Thermal Resistance and Related Properties). The following Table 2 shows the information of test instrument.

Table 2. Information of Instrument of Thermal Conductivity Measurement

| | |
|---|---|
| Thermal Conductivity | 0.015~0.43 W/mK |
| Accuracy | ±2%~±5% |
| Reproducibility | ±1% |
| Specimen Size | 300mm×300mm,<br>d=5~100mm |




A: high temperature plate B: test specimen C: heat flow meter D: low temperature plate

*Figure 1 Outline of Thermal Conductivity Test Method by Flat Heat Flow Meter Method*

*Figure 2 Thermal Conductivity Test Instrument (Two Types)*

## 2.2 Test Object Sampling

These two test objects were cut into about 10 mm width in the direction of thickness using two methods of heat rays and knife and the change in the thermal conductivity resistance from elapsed time under the thermal hydrostat room with 23± 2℃ room temperature and 40% ± 3% relative humidity was measured and the long-term thermal conductivity resistance of uncut thermal insulators has been measured as well.

In the accelerated laboratory test, which was carried out after cutting the test objects into about 10 mm width in the direction of thickness, the test objects were cut using two methods of heat rays and knife. The test objects were obtained from the extruded expanded polystyrene through the cutting method of heat rays and knife, and since there occurred heat damage on the side when using heat rays to cut the hardened urethane foam thermal insulator, only the slicing method of knife was used for the hardened urethane foam.

*Figure 3 Architectural Thermal Insulation Laboratory (Thermal Hydrostat Room)*

# 3. Experiment Result

## 3.1 Extruded Polystyrene Thermal Insulation

Figure 4 shows the change of thermal conductivity with the passage of time after cutting the extruded polystyrene using heat rays. The thermal conductivity was 0.0206 w/mK at the elapsed time of hour and half after the slicing and was 0.0218 w/mK at the elapsed time of 4 hours and 50 minutes. After the elapsed time of about 400 hours since the slicing, the thermal conductivity showed a stable pattern of within 0.033 W/mK.

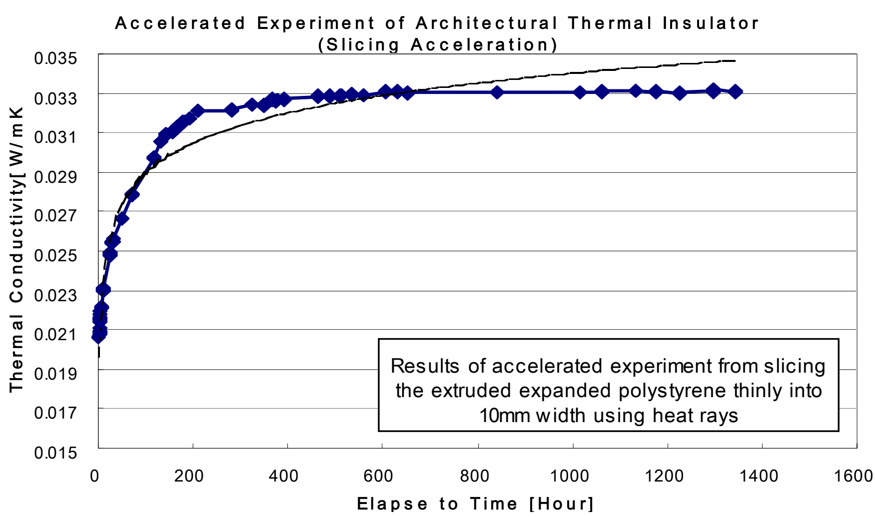



*Figure 4 Change in the Thermal Conductivity of Extruded Polystyrene Thermal Insulation cut with Heat Rays*

Figure 5 shows the change in the thermal conductivity with the passage of time after cutting the extruded polystyrene using a knife. The thermal conductivity was 0.0248 w/mK at the elapsed time of about four and half hours after the slicing and showed a stable pattern of within 0.035 W/mK after the elapsed time of about 400 hours.

There occurs a difference in the thermal conductivity in accordance with the slicing method of the test objects extracted from an object with the same density, thus showed a necessity for a detailed test method on the slicing method for accelerated laboratory test.

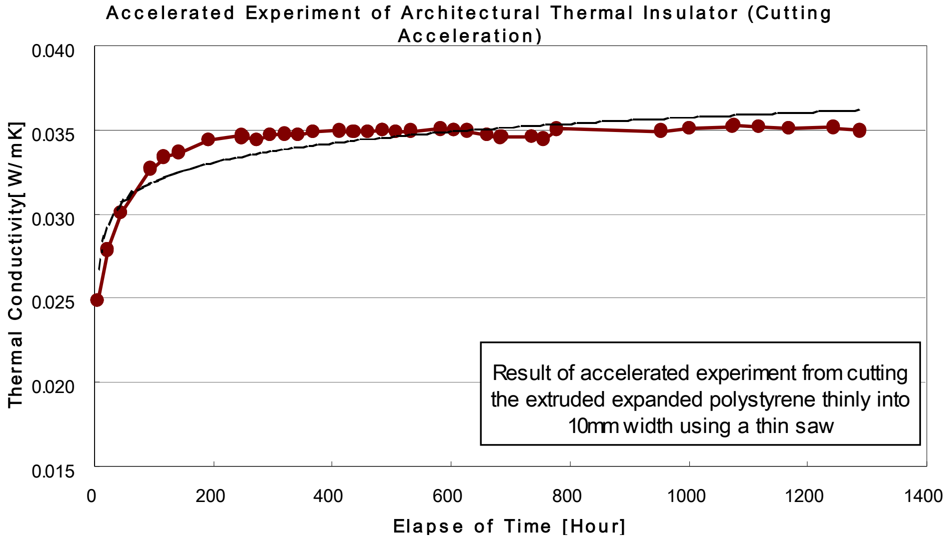



*Figure 5     Change in the Thermal Conductivity of Extruded Polystyrene Thermal Insulation cut with a knife*

### 3.2     Hardened Urethane Foam Thermal Insulation

The change in the thermal conductivity on the polyurethane foam thermal insulation with the passage of time is shown in Figure 6. In the initial period of the experiment, that is before cutting with a knife, the thermal conductivity was 0.0190 W/mK and showed stability of 0.0255 W/mK after about 600 hours later. Accordingly, it showed about 35% change in the thermal conductivity in the accelerated laboratory test by slicing.

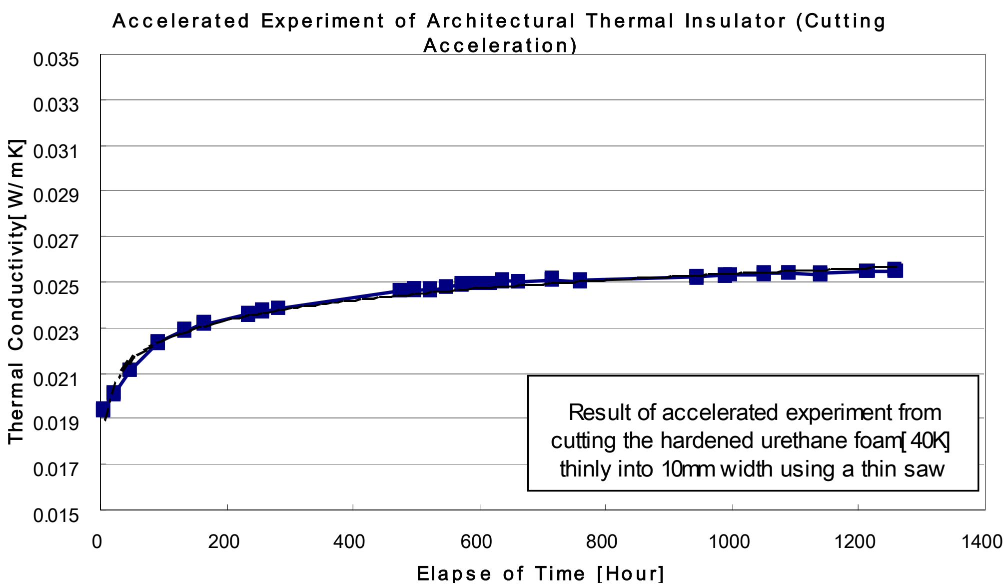



*Figure 6     Change in the Thermal Conductivity of Polyurethane Foam Thermal Insulation cut with a knife*

## 4. Thermal Conductivity Change Model from Aging Characteristics

### 4.1 Model of Accelerated Laboratory Test

The measurement of thermal conductivity from the passage of time is limited in the accelerated laboratory test of sliced thermal insulators. Therefore, a model formula as shown in Formula 1 has been established to carry out curve-fitting for predicting the change in long-term thermal conductivity from such a limited measurement result.

Curve-fitting refers to the making of thermal conductivity measured with limitations into a function by finding a mathematical model that could precisely reflect the ageing characteristics of thermal conductivity with the passage of time. On the other side, this mathematical model will be used in predicting the change in long-term thermal conductivity of each thermal insulator more promptly and precisely from the relation between the accelerated laboratory test result to be carried out hereafter and the ageing characteristics of the actual structure.

$f(x) = a \times (b - EXP(-c \times t_i)$ (Formula 1)

$a, b, c$ : Constant, $t_i$ : time

Table 3. Variables applied to Curve-Fitting of Accelerated Laboratory Test Result

| | Extruded Polystyrene from heat ray cutting | Extruded Polystyrene from knife cutting | Polyurethane Foam from knife cutting |
|---|---|---|---|
| a | 0.012055 | 0.01054 | 0.006455 |
| b | 2.769377 | 3.29062 | 4.12919 |
| c | 0.010955 | 0.018016 | 0.002942 |
| R | 0.991 | 0.995 | 0.9744 |

Figure 7 shows the curve-cutting of the change in thermal conductivity on three test objects applied in this accelerated laboratory test. As it is shown in Table 3, the mathematical model of the extruded polystyrene from heat ray and knife cutting showed a high correlativity of over 0.99 coefficient of determination for the thermal conductivity with the passage of time.  The polyurethane foam showed 0.97 coefficient of correlation when cut with a knife.

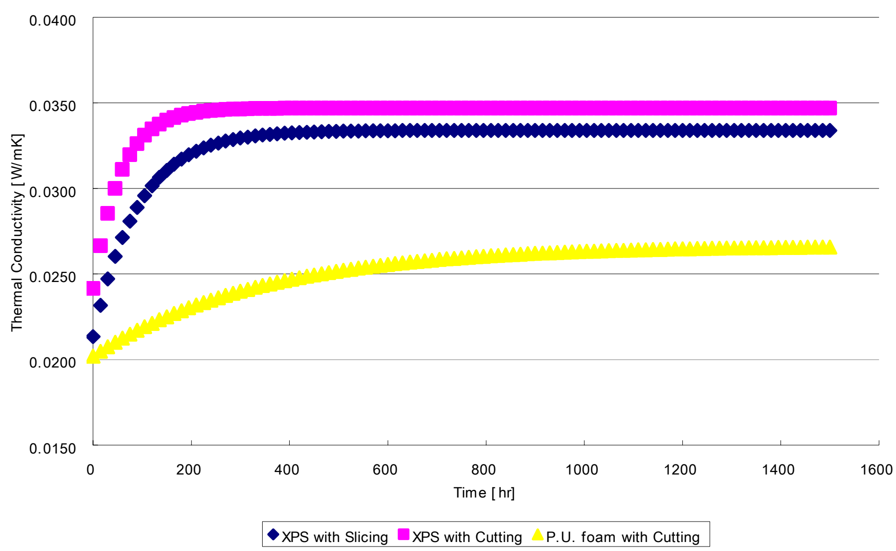



*Figure 7 The Curve-fitting of the thermal conductivity*

### 4.2 Thermal Insulation Model Applied on Actual Structure

Figure 8 shows the result of experimenting the change of long term thermal conductivity for the extruded polystyrene and polyurethane foam thermal insulators under the condition of without any cutting or slicing.

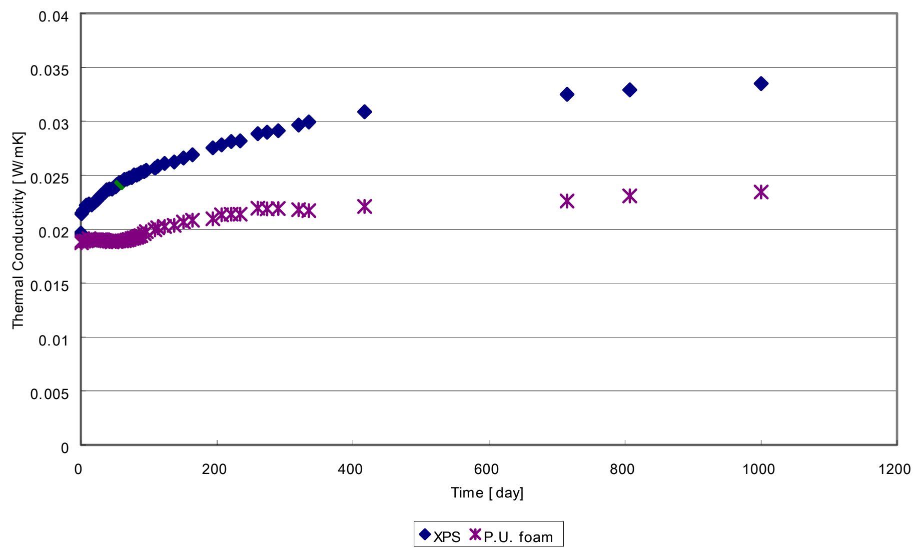



*Figure 8 Changes in Thermal Conductivity of Thermal Insulator in Actual Structure*

Curve-fitting refers to the making of thermal conductivity measured with limitations into a function by finding a mathematical model that could precisely reflect the ageing characteristics of thermal conductivity with the passage of time. On the other side, this mathematical model will be used in predicting the change in long-term thermal conductivity of each thermal insulator more promptly and precisely from the relation between the accelerated laboratory test result to be carried out hereafter and the ageing characteristics of the actual structure.

Figure 9 shows the curve-cutting of change in the thermal conductivity occurring in an actual structure. As shown in Table 4, the mathematical model of the extruded expanded polystyrene showed a high correlativity of over 0.98 coefficient of determination for the thermal conductivity with the passage of time and the polyurethane foam showed 0.97 coefficient of correlation.

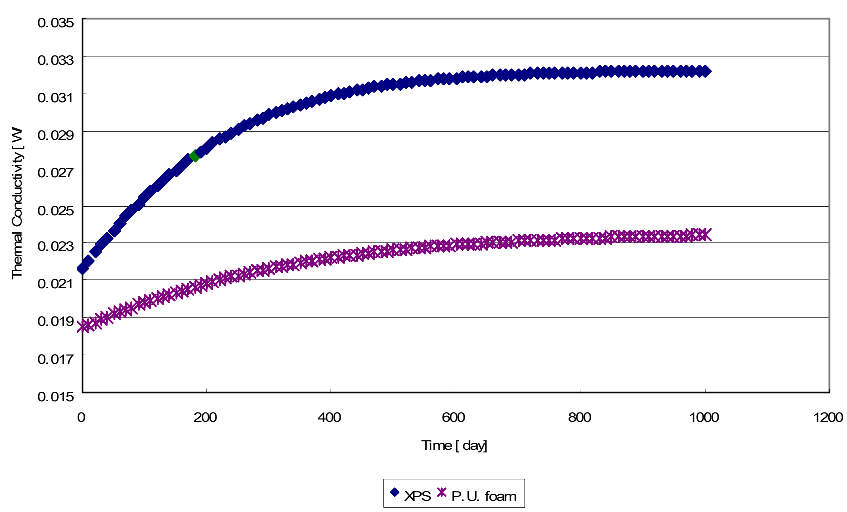



*Figure 9 The Curve- fitting of change in the thermal conductivity in Actual Structure*

Table 4. Variables applied to Curve-Fitting of Accelerated Laboratory Test Result measured from an Actual Structure

| | Extruded Polystyrene | Polyurethane Foam |
|---|---|---|
| a | 0.7587 | 0.5849 |
| b | 2.0435 | 3.6288 |
| c | 0.006 | 0.00376 |
| R | 0.98 | 0.97 |

## 6. Conclusion

This research has measured long-term thermal conductivity on the sliced test objects of accelerated laboratory test with extruded polystyrene and polyurethane foam thermal insulators where aging characteristic occurs with the passage of time and the test objects of actual structure condition. A model formula will be developed hereafter for the effective prediction of change in the heat characteristics of thermal insulators that occurs in a long time frame from the relation between the accelerated laboratory test result and actual structure condition test result.

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