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An Innovative Foam Insulation Produced from Cellulose

Jae-Sik Kang[1], Gyeong-Seok Choi[2], Young-Cheol Kwon[3]

ASTRACT

Cellulose foam is made from paper pellets and polypropylene by foaming with steam in Korea and Japan. Cellulose foam board is an environmentally-friendly insulation because gases such as pentane or HCFC are not used in the manufacturing process. This paper introduces the manufacturing process for Cellulose Foam Board and its physical properties including environmental considerations. The various applications of Cellulose Foam Board will be discussed.

Cellulose foam insulation is composed primarily of cellulose and starch. Cellulose is extracted from recycled wastepaper and plant materials such as beans and corn are used for starch. Cellulose foam insulation does not contain a gas other that air or steam. The product is made by a water-vapor expansion method. Therefore, there is no global warming gas emitted during the production process and the insulation material naturally decomposes when discarded. Being environmentally friendly from the manufacturing process to the end of its useful life is an important strength of cellulose foam insulation (Cellulose Board Insulation).

The expanded foam has a fiber with perpendicular orientation and a majority of the cells in the product are closed. The low solubility of water in the closed-cell foam provides a water vapor transmission rate around 0.07 $g/m^3 \cdot hr \cdot mmHg$. Cellulose foam insulation has a density of 20 to 35 kg/m^3 and an apparent thermal conductivity of 0.034 to 0.038 W/m·K. The product does not contain harmful substances such as formaldehyde or volatile organic compounds (VOCs).

The performance of the foamed cellulose product is similar to that of expanded polystyrene (EPS) in terms of tensile strength, compressive strength, and water absorption. The major benefit of cellulose foam insulation is the use of recycled paper as a primary raw material.

Keywords: Cellulose foam, Insulation, Polypropylene, Environmental Friendliness

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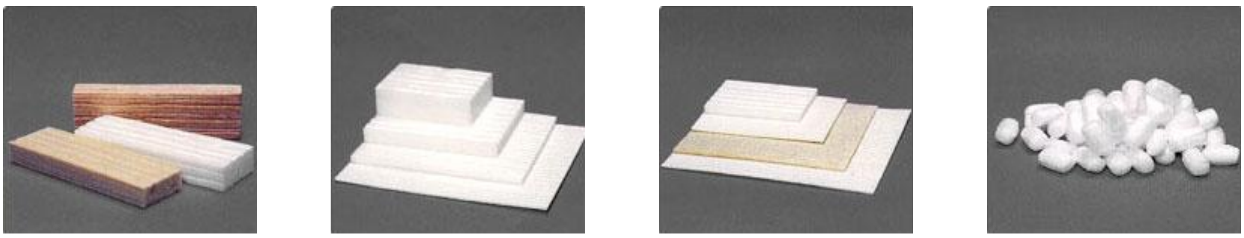
Introduction

The insulations currently used in buildings are the result of developments and refinements of various technologies and materials. Cellulose foam insulation discussed in this paper is composed primarily of cellulose and starch. Cellulose is extracted from recycled wastepaper and plant materials such as beans and corn are used for starch. Cellulose foam insulation does not contain a gas other that air and water vapor since it is made by a steam expansion process. Therefore, there is no global warming gas emitted during the production process and the insulation naturally decomposes when discarded. Being environmentally friendly throughout the life-cycle of the product is a major benefit of cellulose foam insulation. In this paper, the physical properties of cellulose foam insulation will be presented to support its applicability as an insulation material for buildings.

Cellulose Foam Insulation

The core material for cellulose foam insulation is cellulose extracted from waste paper. Cellulose can be extracted from paper waste that is usually incinerated being difficult to recycle. Such paper waste includes damaged fibroid material and shredded paper. The manufacturing process is as follows: First, waste paper and starch are mixed together. And a portion of polypropylene-type resin is added to the mixture. Then, the mixture undergoes the process of steam expansion and extrusion that produces insulation in the form of boards or loose-fill insulation. Cellulose foam insulation is composed of a substance that forms a nucleus during expansion and a substance that envelops the nucleus. The core technology is characterized by having no physical or structural changes done to the form of the cell after the expansion. The expanded closed-cell foam has a fiber texture with perpendicular orientation. The combination of low water solubility and closed-cell structure leads to water-vapor transmission rates of around 0.07 $g/m^3 \cdot hr \cdot mmHg$. Product density control is relatively simple being controlled by the expansion process parameters. Product density can be controlled in the range of 20 to 35 kg/㎥.
The raw materials for cellulose foam insulation, except for the polypropylene-type resin (an additive) are natural materials. Cellulose foam insulation does not contain harmful substances such as formaldehyde or volatile organic compounds (VOCs). Figure 1 shows examples of cellulose foam products having different densities and shapes. Figure 2 shows the shape and the cross-section for an insulation material for buildings. Figure 3 shows an internal insulation application and external insulation application on actual buildings. Gypsum boards usually cover the internal insulation to protect it from fire and force. In case of external insulation application, the insulation is protected from rain by using stone or aluminum panels.



a) Low Density Board   b) Mid-Density Board   c) High-Density Board   d) Loose-Fill

Fig. 1 Examples of Cellulose foam Insulation Forms

a) Product Example of Cellulose foam Insulation

b) Perpendicular Cross-Sectional View

Fig. 2 Sectional Details of Cellulose foam Insulation

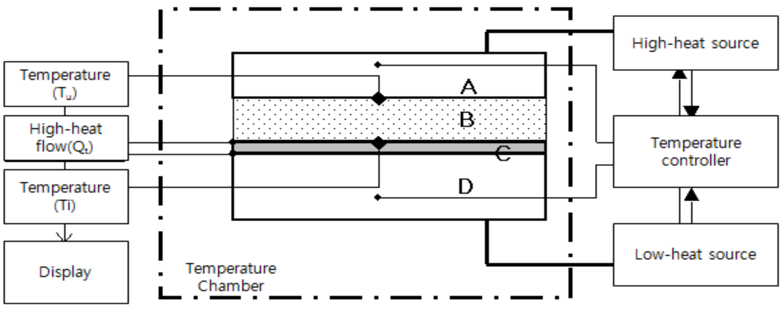
a) Internal Insulation Technique

b) External Insulation Technique

Figure 3. Examples of Cellulose foam Insulation Construction

Thermal Conductivity

Test results for the apparent thermal conductivity measured in accordance with ISO 8301 (Thermal Insulation-Determination of Steady-State Thermal Resistance and Related Properties) are shown in Tables 1 and 2. The measurements were obtained in a laboratory maintained at 23± 1℃ with relative humidity 50 ± 5%. The mean test temperature was 20± 1℃ and the temperature difference across the test specimens was 26℃. The experimental uncertainty of the apparatus was ± 2%~5%.
The thermal conductivity testing was conducted on products produced using two production settings according to the proportions of its components of paper pellets and polypropylene.
Three products with the densities 20, 26, and 31kg/m^3 were produced with the first set of conditions. The average apparent thermal conductivities for each density were 0.037, 0.035, and 0.034 W/m·K, respectively.
Two products were produced using the second setting had densities between 24 and 26 kg/m^3 and average apparent thermal conductivities of 0.035 and 0.034 W/m·K, respectively. Figure 4 is an overview of thermal conductivity testing method that was used. Figure 5 and 6 show the correlations for apparent thermal conductivity as a function of density.



A: High-heat plate B: Thermal conductivity tested specimen C: Heat flow meter D:Low-heat plate

Fig. 4 Overview of thermal conductivity testing method by Heat Flow Meter

Table 1. Thermal Conductivity of Products For Manufacturing Parameters No. 1

TYPE	Density (kg/ m³)	Average Thermal Conductivity (W/m·K)
1 - 1	22.2	0.0366
1 - 2	22.1	0.0366
1 - 3	21.9	0.0368
1 - 4	21.8	0.0366
2 - 1	25.8	0.0355
2 - 2	27.0	0.0353
2 - 3	27.5	0.0351
2 - 4	26.8	0.0354
2 - 5	26.6	0.0353
3 - 1	30.4	0.0342
3 - 2	30.7	0.0346
3 - 3	30.7	0.0343
3 - 4	32.0	0.0342

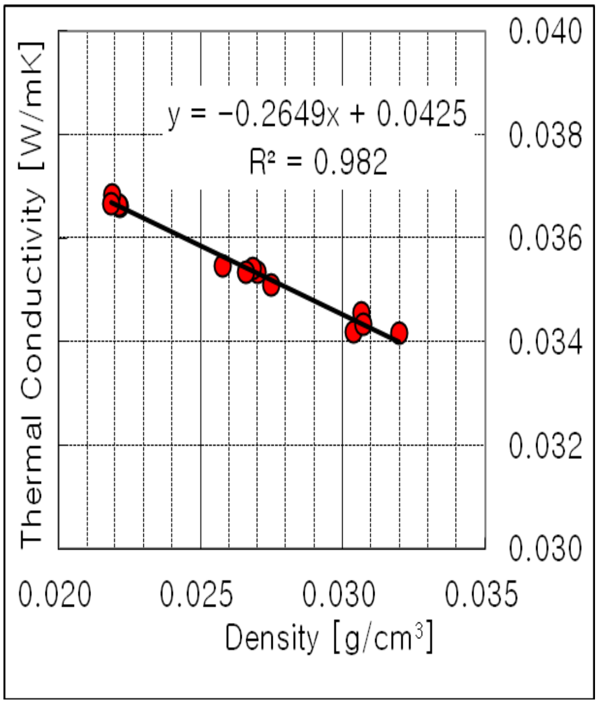


Fig. 5 Thermal Conductivity of Products for Setting No.1

Table 2. Thermal Conductivity of Products for Manufacturing Setting No.2

TYPE	Density (kg/ m³)	Average Thermal Conductivity (W/m·K)
4 - 1	23.9	0.0353
4 - 2	23.3	0.0353
4 - 3	23.0	0.0355
4 - 4	23.8	0.0354
4 - 5	24.5	0.0356
4 - 6	24.0	0.0354
5 - 1	27.0	0.0340
5 - 2	25.2	0.0341
5 - 3	24.7	0.0343
5 - 4	25.1	0.0345

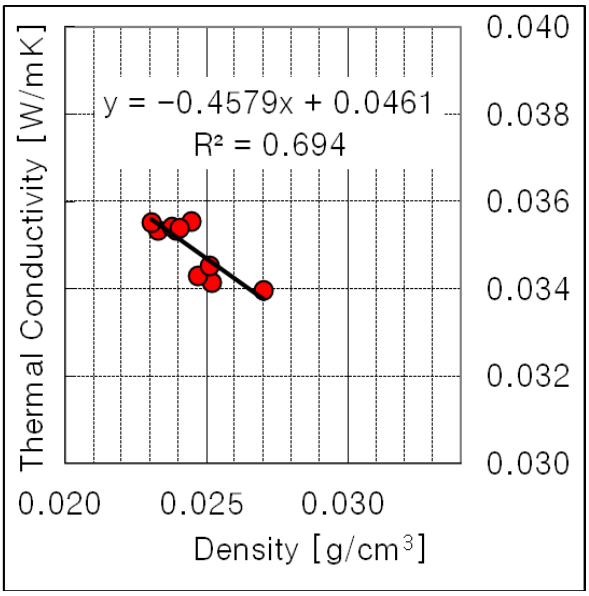


Fig. 6 Thermal Conductivity of Products for Setting No. 2

Table 3 shows the thermal conductivities of EPS-1(Expanded Polystyrene Foam), EPS-2(Neopor) and Cellulose Foam Insulation according to the densities.

Table 3. Comparison of Insulation Thermal Conductivity Data (W/m·K)

Insulation Type Density[kg/m³]	EPS-1	EPS-2 (Neopor)*	Cellulose foam Insulation (Setting No. 1)	Cellulose foam Insulation (Setting No. 2)
15	0.043	0.034	0.038	0.039
20	0.040	0.033	0.037	0.036
25	0.037	0.032	0.035	0.034
30	0.036	0.031	0.034	0.032
35	-	-	-	0.030

* Expanded polystyrene foam board developed by BASF, which is a flexible, open cell foam made from melamine resin, a thermoset polymer

4. Physical Properties of Cellulose foam insulation

Absorption test is required when the insulation is used on the exterior side of walls or roofs which are expected to be exposed to water. Figure 7 shows the Figures of absorption test performed in accordance with ISO 4898. Table 4 is the result of absorption test at three densities.

Absorption %(V/V)= $(G_1 - G_2)/G_2 \times 100$

Here G_1 : Weight after 48 hours from water soaking(g)

G_2 : Weight after 24 hours from drying(g)

V : Volume of specimen (㎤)

Table 4. Absorption by Density

Density [kg/㎥]	Absorption [%(V/V)]
22.7	2.7
25.6	3.5
31.9	3.1

Fig. 7 Results of absorption and dimensional stability testing

Table 5 shows the changes in dimensions measured after leaving the test specimens for one hour at 23℃ and 50% according to the ISO 291 Standard after heating for 48 hours at 70℃ in accordance with ISO 2796.

Figure 8 shows the locations for the measurement of changes in dimensions of specimens before and after heating. The size of a specimen is 100 ±1 mm x 100±1mm x 25±0.5mm.

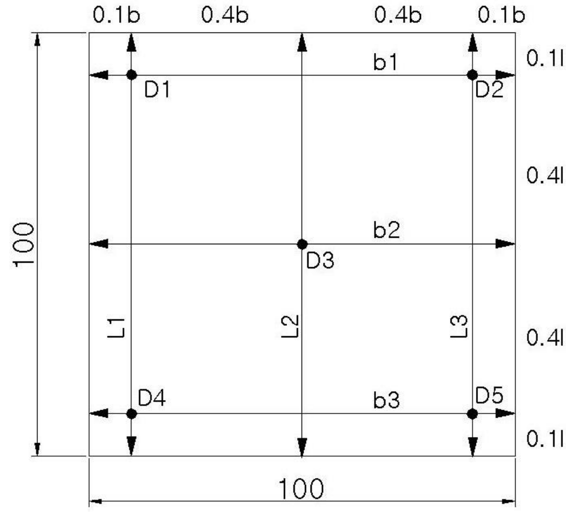


Fig. 8 Locations for the measurement of changes in dimensions

Measurement of changes in dimension due to heating shows that the rate of change is from 0.1 to 0.7%.

Table 5. Measurements of Dimensions Stability after Heating

Types		Dimensions before Heating [mm]	Dimensions after Heating [mm]	Change [%]
20 kg/m^3	Length	99.0	98.9	0.1
	Width	100.7	100.0	0.7
25 kg/m^3	Length	101.8	101.4	0.3
	Width	99.6	99.4	0.2
30 kg/m^3	Length	100.8	100.6	0.2
	Width	100.7	100.5	0.2

Moreover, cellulose foam insulation also reduces floor the sound of impact sound when used as part of a floor assembly. Table 6 contains test results for dynamic stiffness and loss factor before and after heating in consideration of floor insulation systems used in the residential buildings of Korea. The test was conducted according to the dynamic stiffness test method of KS F 2868 (Determination of Dynamic Stiffness of Materials Used under Floating Floors in Dwellings).

Table 6. Dynamic Stiffness and Loss Factor Before/After Heating

Types	Before Heating		After Heating		% Change in Dynamic Stiffness
	Dynamic Stiffness [MN/㎥]	Loss Factor	Dynamic Stiffness [MN/㎥]	Loss Factor	
20 kg/m^3	5.0	0.18	4.4	0.16	12.0 %
25 kg/m^3	6.2	0.23	5.4	0.26	12.9 %
30 kg/m^3	7.4	0.19	6.9	0.20	6.8 %

Table 7. Measurements of Compressive Strength and Flexural Strength

Density	Compressive Strength [N/cm^2]	Flexural Strength [N/cm^2]
20 kg/m^3	6.7	2.6
25 kg/m^3	7.9	5.4
30 kg/m^3	12.3	6.7

Fig. 9 Feature of flexural strength testing

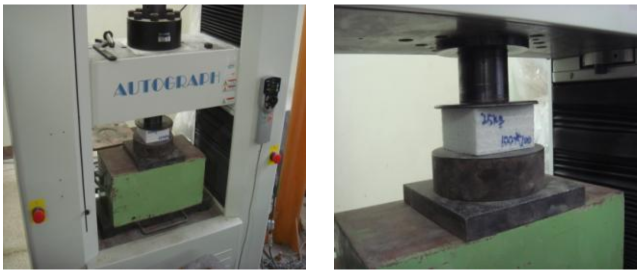


Fig. 10 Feature of compressive strength test

The current Korean Industrial Standard on this property of Cellulose Foam is forth shown in Figure 9. Table 8 shows the performance standard of Korean Industrial Standard of Cellulose Foam.

Table 8. Performance standard of Korean Industrial Standard of Cellulose Foam

Kind of Performance		Unit	Type			Testing method
			1	2	3	
Density		kg/m^3	> 30	> 25	> 20	KS M ISO 845
Thermal conductivity (Average testing temperature 23℃, (7~28 days)		W/(m·K)	< 0.034	< 0.035	< 0.037	KS L 9016 KS L ISO 8301 KS L ISO 8302
Dimensional stability (70℃, 48 hours)		%	< 1	< 1	< 1	KS M ISO 2796
Absorption		%(V/V)	< 4	< 4	< 4	KS M ISO 2896
Hazard (after 7 days)	Formaldehyde Emission Rate	mg/(m^2·h)	< 0.1			KS M 1998
	VOCs Emission Rate	mg/(m^2·h)	< 0.1			KS M 1998
Combustibility		-	Burning time to be less than 120 seconds and burning length to be no greater than 60 mm			KS M ISO 9772
(Reference) Water vapor permeability (23℃, 0~50%RH)		ng/Pa·s·m	< 9.5			KS M ISO 1663

5. Conclusion

Density control and production of cellulose foam insulation is based on control of the expansion step in the manufacturing process. Cellulose foam insulation as an insulation material for buildings is projected for densities in the range 20 to 35 kg/m^3. There is a good correlation between the apparent thermal conductivity of cellulose foam insulation and density that shows apparent thermal conductivity in the range of 0.034 to 0.038 W/m·K.

Cellulose foam insulation could be used as building insulation and as a substitute for foam board of the same thickness.

Cellulose foam insulation uses recycled materials as its primary component and does not emit global warming gases during expansion. Future studies will focus on economic assessment and environmental load reductions. Fire retardant properties of the material are being studied.

6. Reference

[1] ISO, ISO 8301; Thermal Insulation-Determination of Steady-State Thermal Resistance and Related Properties.

[2] Jai-Kie Hong, Jang-Yeul Sohn, 1985, An Experimental Study on Thermal Conductivity of Building Insulation Materials, Journal of the Architectural Institute of Korea, Vol. 23, No. 123, pp.87 ~ 92.

[3] Korea Institute of Construction Technology, 2001, Design Standard for Energy Conservation of Buildings.

[4] ISO, ISO 8302, Thermal Insulation - Determination of Steady-State Thermal Resistance and Related Properties - Guarded Hot Plate Apparatus.