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Cellulose Insulation for Use as Building Insulation in Korea

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***Abstract*—Cellulose insulation was introduced into Korea in the 1980s when several small companies started production. The cellulose industry in Korea is still in an early stage of development with current production of about 1000 tons a year. The Korean equipment used to produce cellulose insulation was imported from the United States and installed by U.S. technicians. A typical cellulose manufacturing plant includes facilities for storing and moving large quantities of waste paper, chopping and shredding, milling or fiberizing, adding chemicals, and packaging. For broader use of cellulose insulation in buildings in Korea, it is necessary to establish its thermal performance. To this end, the effect of density and temperature on the thermal conductivity of loose-fill cellulose insulation manufactured in Korea and U.S. was reported. The apparent thermal conductivity of a particular type of spray-applied cellulose insulation was also determined and compared with previously published data. Apparent thermal conductivity (k_a) measurements of Korean-made loose-fill cellulose insulations were completed using equipment that was built and operated in accordance with ASTM C 518. Korean loose-fill cellulose has thermal conductivity about 5% greater than the corresponding U.S. product at the same density. This is likely due to differences in the recycled material being used. Both spray-applied and loose-fill cellulose insulation lose about 1.5% of their thermal resistivity for 5.5°C increase in temperature.**

Keywords-cellulose; insulation; thermal conductivity

I. INTRODUCTION

Cellulose insulation for use in building applications is primarily manufactured from recycled newsprint or cardboard using shredders and fiberizers. Cellulose insulation as a product is about 80 wt.% cellulosic fiber and 20 wt.% chemicals, most of which are fire retardants such as boric acid and ammonium sulfate[1]. Cellulose insulation was introduced into Korea in the 1980s when several small companies started production. The cellulose industry in Korea is in an early stage of development with current production of about 1000 tons a year[2]. Its current market share as building insulation is only about 0.3%. Organic insulations such as polystyrene foam board and polyurethane foam represent about 71% of the total Korean insulation market, and inorganic insulations such as fiberglass and rock wool make up about 29%[3]. On the other hand, in North America, cellulose insulation has been used since the 1940s and many studies have been done to improve its physical properties and performance. About 750,000 tons of paper has been recycled as cellulose insulation annually early 2000s in the U.S. That would imply a production volume of about 940,000 tons of cellulose insulation per year. The market share for cellulose insulation in residential buildings is 8-10 % and it claims 20-25% in the commercial spray-insulation market[4]. Cellulose insulation in the U.S. generally conforms to one of three ASTM Standard Specifications. ASTM C 739[5] is the Standard Specification for loose-fill cellulose insulation commonly used in attics or similar horizontal applications. ASTM C 1497[6] is the Standard Specification for stabilized cellulose generally intended for horizontal applications. Stabilized cellulose is made by adding an adhesive to loose-fill insulation to reduce post-installation settling. Self-supported spray-applied cellulose insulation described in the ASTM C 1149[7] is commonly used in commercial applications. Spray-applied cellulose insulation contains a significant amount of adhesive that permits it to be installed on walls and ceilings without support.

The Korean equipment used to produce cellulose insulation was imported from the United States and installed by U.S. technicians. A typical cellulose manufacturing plant includes facilities for storing and moving large quantities of waste paper, chopping and shredding, milling or fiberizing, adding chemicals, and packaging. Figure 1 shows the flow of paper and chemicals through a fiberizer plant[1]. The manufacturing process being described involves the mixing of fiberized paper and chemical additions to form a product that is packaged in bags or bales for shipment. While both Korean and U.S. cellulose insulation is produced by the same fiberizing processes, the feed stocks in the two countries are different. Korean newspaper is usually made of paper that has been recycled many times with the result that Korean cellulose insulation has shorter fibers and is more brittle than the corresponding U.S. product [2].

For broader use of cellulose insulation in buildings in Korea, it is necessary to establish its thermal performance. To this end, the effect of density and temperature on the thermal conductivity of loose-fill cellulose insulation manufactured in Korea and U.S. was reported[8]. The apparent thermal conductivity of a particular type of spray-applied cellulose insulation was also determined and compared with previously published data[9].

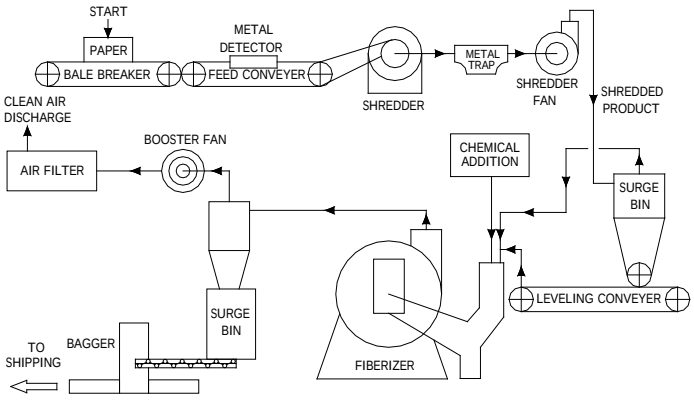

FIGURE I. FLOW PROCESS FOR THE MANUFACTURE OF CELLULOSE INSULATION

II. MATERIALS AND METHOD

The labeled density of Korean loose-fill cellulose insulation was surveyed and found to be in the range of 25 to 30 kg/m^3. On the other hand, a survey of six major U.S. cellulose insulation manufacturers indicates loose-fill cellulose insulations are labeled in the density range of 23.5 to 27.0 kg/m^3 for attic products

Apparent thermal conductivity (k_a) measurements of Korean-made loose-fill cellulose insulations were completed using equipment that was built and operated in accordance with ASTM C 518[10]. The commercially-built heat-flow meter was calibrated using high-density fiberous glass board, SRM 1450b[11]. The heat-flow meter measurements were made using 30.5×30.5cm specimens at thickness varying from 2.5 to 10cm. Test data were also collected for a new type of spray-applied cellulose insulation (SACI) and compared with previously published data[12,13].

The new type of SACI is made with a foamable adhesive and has densities in the range 47.8 to 79.1 kg/m^3.

III. THERMAL TEST RESULTS AND CORRELATIONS

Cellulose insulation material in the US is labeled with properties measured at a mean temperature of 24°C (75°F). Korean products are usually labeled at 20°C. However, for the purpose of comparison, the thermal properties at 24°C were used in this paper. The test specimens of US and Korean cellulose used for comparison were not chemically treated. The specimens were hand-loaded to achieve specific densities. Based on these measurements, the apparent thermal conductivity (k_a, W/m·K) as a function of temperature is given by Eq. (1) for Korean cellulose and Eq. (2) for US cellulose both at a density of 25.5 kg/m^3.

$$k_{aKorean} = 0.0365+0.000146T \quad (1)$$

$$k_{aUS} = 0.0346+0.000138T \quad (2)$$

These two equations were obtained from previously reported data[8]. The value for k_a at 24°C for Korean cellulose at 25.5kg/m^3 is 0.0400W/m·K while the corresponding k_a for US cellulose is 0.0379 W/m·K. The difference in k_a between the two products is about 5%. The temperature coefficient, dk_a/dT, is 0.000146 W/m·K^2 for Korean cellulose and 0.000138 W/m·K^2 for U.S. cellulose. Data obtained by Tye showed dk_a/dT value of 0.000220 W/m·K^2 at 24.0kg/m^3 and also 0.000136 W/m·K^2 at 32.0kg/m^3[14]. The insulation from both sources gain about 2% of their thermal conductivity for each 5.5°C increase in temperature. The corresponding number for dry air is 1.6%[15]. The results for k_a as a function of temperature of Korean and U.S. cellulose of the same density are shown in Table 1. The result shows that the k_a of Korean cellulose insulation is about 5% greater than the corresponding U.S. product.

TABLE I. THERMAL CONDUCTIVITY OF KOREAN AND US CELLULOSE AT 25.5 KG/M^3

Mean Specimen Temperature (°C)	**k_a (W/m·K)**		
	Korean (Eq. 1)	***US (Eq. 2)***	***% Difference***
4	0.0371	0.0352	5.2%
10	0.0379	0.0360	5.2%
17	0.0389	0.0369	5.2%
24	0.0400	0.0379	5.4%
31	0.0410	0.0388	5.3%
38	0.0420	0.0399	5.2%
43	0.0428	0.0406	5.2%

The Eq. (1) for Korean cellulose insulation gives k_a of 0.0394 W/m·K and an R-value per mm of thickness of 0.0254 m^2·K/W at 20 °C. This product, consequently, will provide thermal resistances of R-5.28, R-7.04, and R-8.81 when installed in typical attic applications of 20.8 cm, 27.7 cm and 34.7 cm of insulation.

Table 2 shows the U-values in Korean Building Insulation Code[16]. The minimum thickness of an envelope in a certain area can be calculated using Eq. (3).

$$U = 1/R = 1/[(0.1075) + \Sigma(d/k_a) + (0.03448)] \quad (3)$$

U: Thermal Transmittance (W/m^2·K

R: Thermal Resistance (m^2·K/W)

0.1075 & 0.03448: Inside and outside surface resistances

d: Thickness of Insulation (m)

k_a: Thermal Conductivity (W/m·K)

In case of an exterior wall in Seoul, which belongs to Central Region in Korea, the minimum thickness (d) of 25.5kg/m^3 cellulose insulation by itself is 0.182 m to satisfy the U-value requirement of 0.21W/m^2·K. If several envelope materials such as brick or gypsum board are added to the cellulose insulation, the minimum thickness of cellulose insulation can be reduced.

TABLE II. REQUIRED U-VALUE OF REGIONAL BUILDING ENVELOPES IN KOREA(REVISED ON JULY 1, 2016) (UNIT : W/㎡ K)

Building Envelope \ Region			Central Region	Southern Region	Jeju Island
Exterior Wall	Adjacent to Outside directly	Apartment House	less than 0.210	less than 0.260	less than 0.360
		Others	less than 0.260	less than 0.320	less than 0.430
	Adjacent to Outside indirectly	Apartment House	less than 0.300	less than 0.370	less than 0.520
		Others	less than 0.360	less than 0.450	less than 0.620
Roof	Adjacent to Outside directly		less than 0.150	less than 0.180	less than 0.250
	Adjacent to Outside indirectly		less than 0.220	less than 0.260	less than 0.350
Floor of lowest floor	Adjacent to Outside directly	Floor heating	less than 0.180	less than 0.220	less than 0.290
		No floor heating	less than 0.220	less than 0.250	less than 0.330
	Adjacent to Outside indirectly	Floor heating	less than 0.260	less than 0.310	less than 0.410
		No floor heating	less than 0.300	less than 0.350	less than 0.470
Floor Slab with floor heating system			less than 0.810	less than 0.810	less than 0.810
Window or Door	Adjacent to Outside directly	Apartment House	less than 1.200	less than 1.400	less than 2.000
		Others	less than 1.500	less than 1.800	less than 2.400
	Adjacent to Outside indirectly	Apartment House	less than 1.600	less than 1.800	less than 2.500
		Others	less than 1.900	less than 2.200	less than 3.000
Entrance Door of Apartment house	Adjacent to Outside directly		less than 1.400	less than 1.600	less than 2.200
	Adjacent to Outside indirectly		less than 1.800	less than 2.000	less than 2.800

*__CentralRegion__: __Seoul__, Incheon, Gyunggido, Gangwondo(except Gangneung, Donghae, Sokcho, Samchuk, Gosung, Yangyang), Chungchongbuko(except Youngdong), Chungchongnamdo(Chunan), Gyungsangbukdo (Chungsong)
** Southern Region : Busan, Daegu, Gangju, Daejun, Gangwondo(Gangneung, Donghae, Sokcho, Samchuk,Gosung, Yangyang), Chungchongbukdo(Youngdong), Chungchongnamdo(except Chunan), Jeonlabukdo,Jeonlamamdo, Gyungsangbukdo(except Chungsong), Gyungsangnamdo

Cellulose insulation used in wall cavities in normally at a higher density than that used in attic applications. Table 3 contains some apparent thermal conductivity data reported for spray-applied cellulose produced with a foamable adhesive[9]. The data are compared with previously published data in Figure 2.

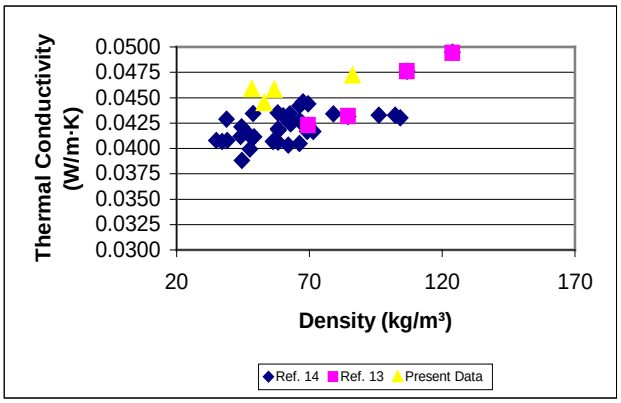

FIGURE II. A COMPARISON OF K_A FOR SPRAY-APPLIED CELLULOSE FROM THREE SOURCES

Measured k_a values for spray-applied cellulose insulation at 24°C have been obtained for densities from 34.9 to 123.8kg/m^3 and they are shown as square[13]. Data points from Yarbrough et al.[12] are shown as diamonds and data from the present study are indicated by triangles. The k_a of spray-applied cellulose insulation measured in this project was 0.004 to 0.007 W/m·K above the data published in 1990.

Table 3 contains the test results for the spray-applied cellulose specimens. The units for thermal conductivity (k_a) are W/m·K and density (ρ) is expressed as kg/m^3.

TABLE III. TEST RESULTS FOR THE SPECIMENS OF SPRAY-APPLIED CELLULOSE INSULATION (SACI)

T-mean (°C)	k_a (W/m·K)			
	47.8 kg/m^3	50.6 kg/m^3	55.4 kg/m^3	79.1 kg/m^3
4	0.0429	0.0417	0.0431	0.0453
10	0.0437	0.0425	0.0439	0.0460
17	0.0448	0.0434	0.0448	0.0468
24	0.0459	0.0445	0.0458	0.0472
31	0.0468	0.0453	0.0465	0.0475
38	0.0477	0.0461	0.0472	0.0479

From the Table 3, the k_a of 47.8kg/m^3 is represented by Eq. (4).

$$k_{aSACI} = 0.04274+0.000142T \quad (4)$$

From the Eq. (4), the R-value at 20 °C for a typical wall cavity installed with 47.8kg/m^3 spray-applied cellulose insulation would be R-1.1 at 5 cm, R-2.2 at 10 cm, and R-3.3 at 15 cm thick.

The 24°C thermal data in Table 2 was compared with corresponding loose-fill values in Figure 3. Spray-applied cellulose products containing adhesive have greater k_a than loose-fill products at the same density. The recently obtained data and previously reported data support this observation. The data in Figure 3 show recently measured k_a for “Fiberiffic”[17] insulation made with cellulose and that for loose-fill cellulose published by McElroy et al[18].

The spray-applied cellulose has on the average a k_a about 5 % greater than the loose-fill insulation at the same density. The spray-applied insulation, however, is less likely to settle with time.

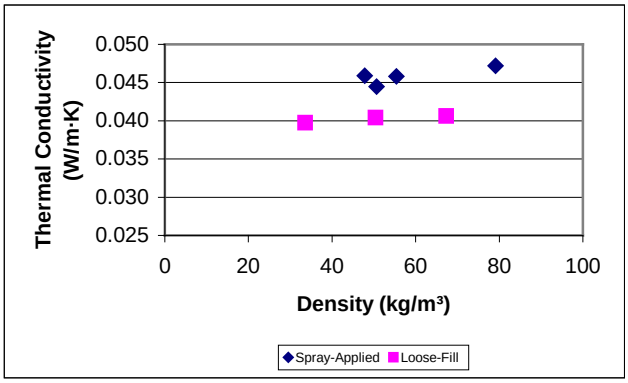

FIGURE III. A COMPARISON OF K_A FOR SPRAY-APPLIED CELLULOSE INSULATION WITH LOOSE-FILL INSULATION

IV. VARIATION OF APPARENT THERMAL CONDUCTIVITY WITH TEMPERATURE

Figures 4 shows the variation of thermal conductivities of the spray-applied cellulose insulation with temperature in the range of 4 - 43°C.

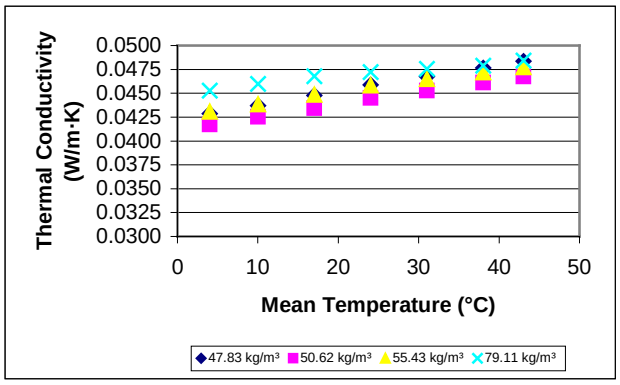

FIGURE IV. THERMAL CONDUCTIVITY OF SPRAY-APPLIED CELLULOSE INSULATION

The temperature coefficient, dk_a/dT is 0.000129 for SACI at a density of 55.4kg/m^3. Data obtained by Yarbrough for SACI showed dk_a/dT values of 0.000061 at 62.9kg/m^3 and 0.000084 at 68.0kg/m^3[13]. The insulation gains about 1.5% of their thermal conductivity for each 5.5°C increase in temperature. The thermal conductivities of the SACI and the LFCI are compared in Table 3 and Figure 5. The specimen was hand-loaded to achieve the density of 55.4 kg/m^3.

Table 4 and Figure 5 show a comparison of the thermal conductivity of SACI and LFCI over the temperature range 4 to 43°C. The difference between the two types of insulation averages about 14%.

TABLE IV. THERMAL CONDUCTIVITY OF SACI(ρ=55.4 KG/M^3) AND LFCI(ρ=55.4 KG/M^3)

Mean Specimen Temperature(°C)	Thermal Conductivity (W/m·K)		
	SACI	LFCI	% Difference
4	0.0431	0.0372	13.8%
10	0.0439	0.0378	13.9%
17	0.0448	0.0385	14.1%
24	0.0458	0.0392	14.3%
31	0.0465	0.0400	13.9%
38	0.0472	0.0408	13.5%
43	0.0477	0.0413	13.4%

k_{aSACI} = 0.0427+0.000129T k_{aLFCI} = 0.0367+0.000104T

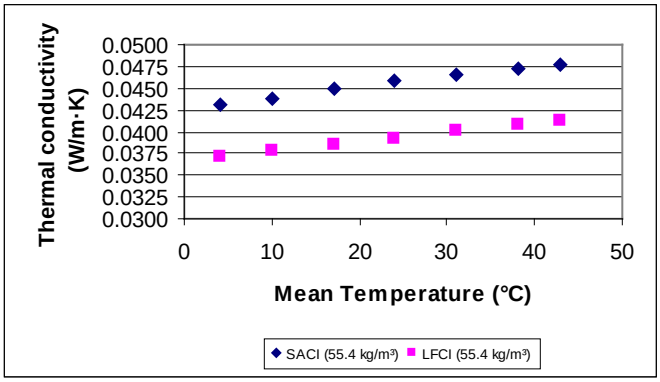

FIGURE V. APPARENT THERMAL CONDUCTIVITY OF SACI AND LFCI

V. CONCLUSIONS

1. Korean loose-fill cellulose has k_a about 5% greater than the corresponding U.S. product at the same density. This is likely due to differences in the recycled material being used.

2. Spray-applied cellulose yields R-value in the range R-1.1 to R-3.3 at 20°C and thickness of 5cm to 15cm. These values are based on a density of 47.8 kg/m^3.

3. A new type of foamable spray-applied cellulose has k_a slightly higher than previously tested spray-applied cellulose.

4. Both spray-applied and loose-fill cellulose insulation lose about 1.5% of their thermal resistivity for 5.5°C increase in temperature.

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