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Analysis of the Efficiency of Improved Bubble Sheet for Heat Curing in Cold Weather

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Abstract

When building with concrete in cold weather, an insulation method of heat curing must be determined, and a holistic curing plan that considers the characteristics of structures, the heat loss coefficient of a curing sheet, the joint condition of the curing materials and the quantity of heat produced by a heating apparatus is an essential prerequisite for protection against early frost damage. But on a number of national construction sites, there have been serious problems in cold weather concreting due to the unreliability of the information obtained from practical experience. In the construction field in Japan, there is a specification for heat curing prepared by Japanese Architectural Society, which provides an equation for calculating heat quantity. It is also necessary to adopt a detailed specification for a standard heat curing method that is applicable to all national construction sites. In this study, the effect of bubble sheets on the economic feasibility of cold weather concrete is investigated through a comparison with the blue sheets commonly prescribed in national construction sites. In conclusion, this study found that bubble sheets had the effect of reducing the cost of curing materials and the fuel cost consumed by a heating apparatus, compared to the use of blue sheets.

Keywords : cold weather concrete, heat supplying curing, heat loss coefficient, improved bubble sheet, thermal conductivity

1. Introduction

When construction is done with cold weather concrete, measures to prevent initial frost are more important than anything else. In relation to the initial curing, it is necessary to consider heat curing and insulation curing in the standard specification. For this reason, at most cold weather concrete construction sites, the space-heating method is used, in which the structure is surrounded with a temporary material such as a curing sheet, and the space is heated[1,2,3,4].

To establish the heat curing plan, the condition of the structure, the loss coefficient of the curing sheet material, the splicing material and the heat of the heating facility must be considered in a comprehensive way, but in reality at most construction sites in Korea heat curing relies on site workers' experience, resulting in a deterioration of concrete quality as well as economic waste due to inconsistent temperature distribution. In particular, the blue sheets used as curing sheets for heat curing at domestic construction sites are affordable and easy to handle, but air-tightness and insulation are poor, having a high heat loss coefficient, the curing sheets are also easily torn due to their low tensile strength and have

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sequential rupture, leading to a deterioration in efficiency of the heat curing since it is hard to keep the temperature at a certain level.

On the other hand, in the previous studies on cold weather curing, a single or double-layered bubble sheet was developed for economic insulation curing by stacking polyethylene air caps (hereinafter PE air cap). As its efficiency in preventing initial frost of the concrete was proven, this method has entered wide use at cold weather concrete construction sites. But due to its low tensile strength, the bubble sheet cannot be used to surround the structure for heat curing, and it cannot replace the blue sheet. For this reason, we developed an improved bubble sheet by stacking single-layered bubble sheet with mesh-tarpaulin made of mesh of lattice formed PE resin to reinforce its tensile strength. The insulation performance and tensile strength of the improved bubble sheet were verified as equivalent to or better than blue sheet[5,6,7].

Therefore, a heating supplying curing plan was established to present an economical heat curing method by comparing the use of the improved bubble sheet as curing sheet for heat curing in the cold weather environment with the existing blue sheet curing. As Korea has no criteria for heat curing, the criteria for cold weather concrete construction presented by the Japanese Architectural Society was used for the analysis.

1.1 Research scope and method

The experiments in this study were conducted at the construction site for the 00 condominium development project located at Ui-dong, Seoul, Korea indicated in Table 1 and Figure 1, the heat curing plan was established as stipulated in the cold weather concrete construction guidelines and cold weather theory of the Japanese Architectural Society, and the number of heaters was calculated based on the materials to calculate construction cost and analyze economic feasibility.

The research proceeded as follows:

1) Through the theoretical review, the overall procedures and factors to consider were understood by analyzing the heat curing plan method proposed by the Japanese Architectural Society;
2) The heat curing plans were established using either improved bubble sheet or using blue sheet to compare the two plans in terms of the heat loss and the number of heaters required.
3) The reduction in the construction cost when using the improved bubble sheet was analyzed, and an economic approach to heat curing was presented.

Table 1. Summary of the building

Section	Content
Construction	○○ Condominium development work
Construction location	Ui-dong, Gangbuk-gu, Seoul, Korea
Scale	· All 14 (# 109 Dong) · 332 rooms and amenities
Gross floor area	80,060 ㎡
Lot area	99,607 ㎡

Figure 1. Site Layout

2. Calculation of the number of heaters for heat curing presented by the Architecture Institute of Japan

According to the cold weather concrete construction guidelines and cold weather theory of the Architecture Institute of Japan, the number of heaters should be determined by considering the heat loss of the curing sheet, and this was done based on the standard specification of the Japanese Architectural Society (hereinafter JASS), as follows[8].

1) The average temperature, the heat curing temperature, was set by using the equation for calculating average temperature of initial curing period and the temperature of the area where the target structure is built, and the area of the heating floor and the volume of the heating space of the target structure are calculated.
2) The heat loss of the curing sheet caused by heat transfer is calculated by adding the area with the heat loss coefficients at upper and lower parts and the side of the curing sheet, and the heat loss per hour was calculated by multiplying the difference between the estimated average temperature and the target heating temperature. The heat loss of the curing sheet through heat transfer is calculated based on Table 2.

Table 2. Heat loss coefficient of material(W/㎡K(Kcal/㎡h℃))[8]

Material	Heat loss coefficient
Plywood 12 mm + Sheet	7.0(6.0)
Iron sheet	14.0(12.5)
Sheet	10.0(8.6)
Polycarbonate	8.5(7.5)
Thick poly film	9.3(8.0)
Ground, Concrete	2.9(2.5)

① Heat loss of the curing sheet through heat transfer

$$Q_1 = \sum K_n \cdot \ S_n \ \text{-----} \ (1)$$

Here, Q_1: heat loss of the curing sheet in an hour caused by heat transfer(W/K)
K_n: the heat loss coefficient of each curing sheet(W/m²K)
S_n: the area of each curing sheet material(m²)

② Heat loss of the curing sheet through air ventilation

$$Q_2 = 0.35 \cdot \ N \cdot \ V \ \text{-----} \ (2)$$

Here, Q_2: heat loss of the curing sheet in an hour caused by ventilation(W/K)
0.35: whole number(W/m³k)
N: ventilation recovery of air within the curing sheet by hour determined based on the ventilation recovery calculation method (the number of times/h)
V: air volume within the curing sheet including the structure(m³)

③ How to calculate ventilation recovery N

The ventilation recovery within the curing sheet(including the structure) is calculated using one of the following methods.

ⓐ Standard ventilation recovery (N)

Depending on the opening(s) on the top of the curing sheet, select either the upper or the lower part of Figure 2, and then the height of the heating space is selected based on the four pictures in a row. The wind velocity in the horizontal axis was determined based on the wind velocity for the area obtained from the Korea Meteorological Administration.

The curve corresponding to the curing floor area is selected from the selected picture in Figure 2, and the number of standard ventilation times (N_s) in the vertical axis is calculated at the point of intersection with the wind velocity of the horizontal axis. In some cases, the ceiling is open for subsequent work during day time while closed during night time. Depending on need, the number of ventilation times should be calculated based on one of two scenarios: open ceiling or closed ceiling. The standard number of ventilation times is calculated by dividing the hours into opening and closing.

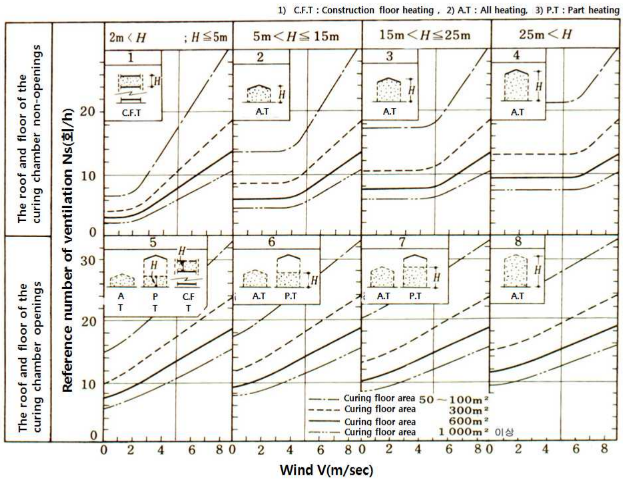

Figure 2. Standards number of ventilation curve[8]

ⓑ Corrected coefficient A considering the size of the curing sheet

The corrected coefficient A is calculated considering the size of the curing sheet based on Table 3.

Table 3. Correction factor based on the size of curing membrane - A[8]

Material	Size l_1	Size l_2	Memo $(1/l_1+1/l_2)$	Correction factor (A)
Structural Sheet	3.6	5.4	0.46	1.0
	3.6	4.8	0.49	1.1
	2.7	3.6	0.65	1.4
	1.8	5.4	0.74	1.6
	1.8	5.1	0.75	1.6
	1.8	4.8	0.76	1.7
	1.8	3.6	0.83	1.8
Plywood	0.9	1.8	1.67	3.6
	0.6	1.8	2.22	4.8

ⓒ Corrected coefficient B considering the joint condition of the curing sheet material

The corrected coefficient B is calculated consider the joint condition of the curing sheet material based on Table 4.

Table 4. Correction factor based on the joints of curing membrane - B[8]

Joint	Correction factor (B)	Gap	Note
Good	0.3	0～0.5	If there are no voids or openings by sealing curing
	0.5	0.5～1.0	If there is no space or openings by curing membrane and the same material as the space or excellent connection
Normal	1.0	1.0～2.0	Little space exists
Slightly bad	1.5	2.0～3.0	Exists a lot of openings of loose connections
Bad	3.0	3.0이상	A large space or a lot of openings exist

ⓓ Corrected coefficient C considering the planar shape of the curing sheet (side ratio)

If the curing sheet has a planar shape, the coefficient C is calculated assuming that it is a rectangle based on Table 5.

Table 5. Correction factor based on the platform of curing membrane - C[8]

Material	A majority offices, commercial buildings, etc.			A majority school, apartment, etc.	
Ratio of long side to short side - X/Y	1.0	2.0	3.0	5.0	7.0
Correction factor - C	1.0	1.2	1.5	1.8	2.1

ⓔ Corrected coefficient D considering the overlapping and joint condition of the curing sheet

The corrected coefficient D is calculated considering the overlapping and joint condition of the curing sheet based on Table 6.

Table 6. Correction factor based on the overlap and joints of curing membrane – D[8]

Section	Material type	Lap splice of inside curing membrane	Correction factor D
1 layer curing membrane	Sheet or plywood	–	1.0
2 layer curing membrane	Sheet	Good	0.7
		Normal	0.8
		Relatively bad	0.9
		Bad	1.0
	Plywood	Good	0.6
		Normal	0.7
		Relatively bad	0.8
		Bad	1.0

Through the process above, the number of ventilation times for the target area was calculated by multiplying the number of ventilation times(N_S) by the corrected coefficient A, B, C and D.

$$N = N_S \times A \times B \times C \times D ---- (3)$$

Heat loss of the curing sheet by heat transfer-ventilation

$$Q = (Q_1 + Q_2) \cdot (T_i - T_{me}) ---- (4)$$

Here, Q: hourly heat loss of the curing sheet by heat transfer-ventilation(W/K)

T_{me}: expected average temperature of the initial curing duration(℃)

T_i: target heating temperature(℃)

3. Heat curing using the improved bubbled sheet

3.1 Curing plan

For cold weather concrete, the initial curing should be determined considering the target curing temperature and duration. JASS recommends a target temperature of 5℃ or higher, and the heat curing was planned by setting the target temperature as 10℃. In addition, the initial curing duration was set at 3 days in this study to reach compressive strength of 5 MPa. On the other hand, considering the drastic deterioration in strength or cracks due to extreme changes in temperature of the concrete surface exposed to the cold external environment after the completion of initial curing, the concrete was cured continuously for four more days at the target temperature of 5℃ through insulation curing in Table 7 and Figure 3.

Table 7. Plan of curing

Curing type	Curing method	Day	Curing temperature	Maturity
Initial curing	Heating + Heat insulation	3	10℃	60°D·D
After curing	Adiabatic + Heat insulation	4	5℃	60°D·D

a) Blue sheet

b) Improved bubble sheet

Figure 3. Appearance of curing membrane

3.2 Materials used

The concrete used in this study had 24MPa nominal strength, and was made by a domestic company specialized in ready-made concrete (25-24-150), and the mix proportion of concrete is indicated in Table 8. Figure 4 shows the blue sheet and improved bubble sheet used in this study. The blue sheet is the most widely used 1st class sheet, and the improved bubble sheet was manufactured by Company J. The physical properties of the curing sheet material are indicated in Figure 4 and Table 9.

Table 8. Mix proportion of concrete

W/C (%)	S/a (%)	W (kg/m³)	AE/C (%)	Weight mixing (kg/m³)		
				C	S	G
50.3	48.0	180	0.009	348	759	905

a) Blue sheet b) Improved bubble sheet

Figure 4. Material of curing membrane

Table 9. Physical properties of test piece

Test piece	Size (mm2)	Thickness (mm)	Weight (g/m²)	Bubble size (mm)
Blue sheet	1000 × 1000	0.20	117.33	-
Improved bubble sheet		2.03	268.33	7

3.3 Calculation of heat when employing the improved bubble sheet

1) Basic presumptions and corrected coefficient according to the material

Table 10 and Table 11 indicate the basic presumptions required to calculate heat for the heat curing of the target structure and the corrected coefficient according to the material of the curing sheet.

As the presumption for the temperature condition, the temperature of the external environment at the concrete placement was assumed as -7.1 ℃, and the curing temperature was set at 10℃, as mentioned previously. In addition, the area of the curing sheet and heating floor and air volume should be calculated first to determine the heating area and volume. The heating floor area and air volume were 1485.2 m^2 and 4958.0 m^3, respectively. The standard number of ventilation times was twice and the heat of the heating facility, a lignite heater, was assumed at 15 800 kcal/h based on the manufacturer's data.

Table 10. Presumption data

Section	
Assumptions about the values calculated on the condition of temperature and structure	
Mean predicted temperature of placing of concrete	-7.1℃
Plan of curing temperature	10℃
Heating floor area	1 458.2 m²
Curing area of heating floor	4958.0 m³
Floor area of curing membrane	1733.9 m²
Wall area of curing membrane	1024.9 m²
Ceiling area of curing membrane	1733.9 m²
Curing area of curing membrane	9363.3 m³
Criteria number of times of ventilation	2 time
Heating equipment 1 per calorie	15800 kcal/h

Table 11. Correction factor based on the property of Material

Correction factor list	Blue sheet	Improved bubble sheet
Heat loss coefficient of material (Kn)	10	7.0
Heat loss coefficient of concrete (Kn)	2.9	2.9
Correction factor based on the size of curing membrane - (A)	1.6	1.6
Correction factor based on the size of curing membrane - (B)	1.0	0.5
Correction factor based on the platform of curing membrane - (C)	1.8	1.8
Correction factor based on the overlap and joints of curing membrane - (D)	0.8	0.7

On the other hand, in terms of the heat loss coefficient according to the material, the blue sheet was calculated at 10.0 W/m²K while the improved bubble sheet was calculated at 7.0W/m²K due to its low conductivity compared with the blue sheet. In addition, in terms of the corrected coefficient by curing sheet, a relatively lower corrected coefficient was applied to the improved bubble sheet in all conditions since it had better overlapping and joint condition compared with the blue sheet according to Table 3 through 6.

The corrected coefficients were verified through Figures 5 and 6 of the previous studies. That is, Figure 5 shows tensile stress-strain curves, from which the tensile stress was measured at 143N for the improved bubble sheet, 140N for the blue sheet with good quality(A), and 77N for the blue sheet with low quality(B). The improved bubble sheet had the highest tensile stress, and thus a low corrected coefficient for overlapping and joint could be applied. In addition, Figure 6 illustrates the heat conductivity for each material, on which basis the heat conductivity was measured at 0.25~0.27 W/mK for the blue sheet while at 0.04 W/mK for the improved bubble sheet due to its low heat conductivity caused by its independent air bubble layer. Thus, the heat loss coefficient of the improved bubble sheet could be calculated as relatively low[7,10,11].

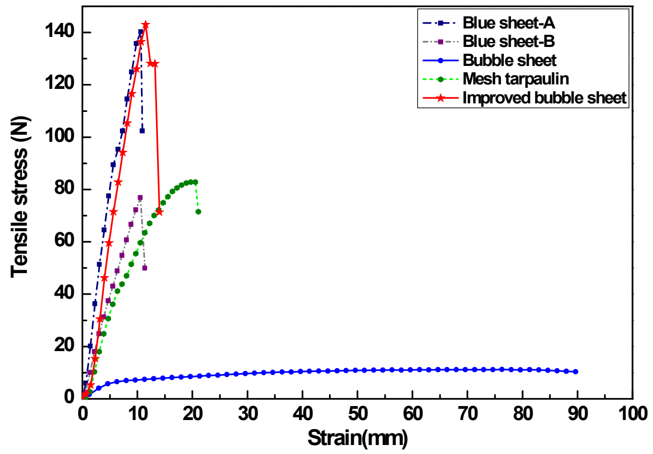

Figure 5. Stress-strain curve depending on materials

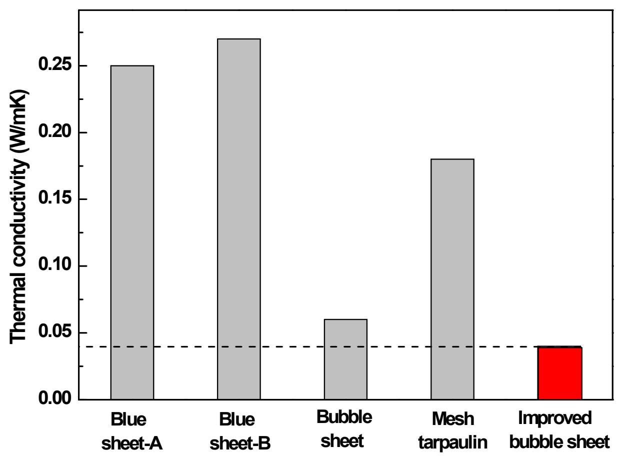

Figure 6. Thermal conductivity of materials

2) Heat loss during the heat curing using the improved bubble sheet

Table 12 and Figure 7 shows the result of a calculation of the number of heaters according to heat loss of the curing sheet caused by heat transfer in the procedure of JASS. First, in terms of the heat loss of the curing sheet by heat transfer, 35367.8 W/K was calculated for the blue sheet while 26264.3 W/K was calculated for the improved bubble sheet.

In addition, for the number of ventilation recovery times, 4.20 times/ h were calculated for the blue sheet while 2.02 times /h were calculated for the improved bubble sheet.

Table 12. Calculation of heat loss and number of heaters

Material	Calculated items	Calculated method
Blue sheet	Heat loss due to heat transfer of curing membrane (W/K)	$Q_1 = \sum K_n \cdot S_n$ = 10×3 034.5+2.9×1 732.0 = 35 367.8
	Number of times of ventilation (number/h)	N = Ns×A×B×C×D = 2×1.6×1.0×1.8×0.8=4.60
	Heat loss due to ventilation of curing membrane within (W/K)	$Q_2 = 0.35 \cdot N \cdot V$ = 0.35×4.60×9 363.3 = 15 074.9
	Heat loss due to heat transfer and ventilation of curing membrane (W/K)	$Q = (Q_1 + Q_2) \cdot (T_i - T_{me})$ = (35 367.8+15 074.9)×[10−(−7.1)] = 862 570(W/K)= 741 810(kcal/h)
	Number of heating equipment (number)	=The total heat loss / the caloric value per heating device = 925 044/15 800 = 47.0 → 47
Improved bubble sheet	Heat loss due to heat transfer of curing membrane (W/K)	$Q_1 = \sum K_n \cdot S_n$ = 7×3 034.5+2.9×1 732.0 = 26 264.3
	Number of times of ventilation (number/h)	N = Ns×A×B×C×D = 2×1.6×0.5×1.8×0.7=2.02
	Heat loss due to ventilation of curing membrane within (W/K)	$Q_2 = 0.35 \cdot N \cdot V$ = 0.35×2.02×9 363.3 = 6 619.9
	Heat loss due to heat transfer and ventilation of curing membrane (W/K)	$Q = (Q_1 + Q_2) \cdot (T_i - T_{me})$ = (26 264.3+6 619.9)×[10−(−7.1)] = 562 319(W/K)= 483 595(kcal/h)
	Number of heating equipment (number)	=The total heat loss / the caloric value per heating device = 483 595/15 800 = 30.6 → 31

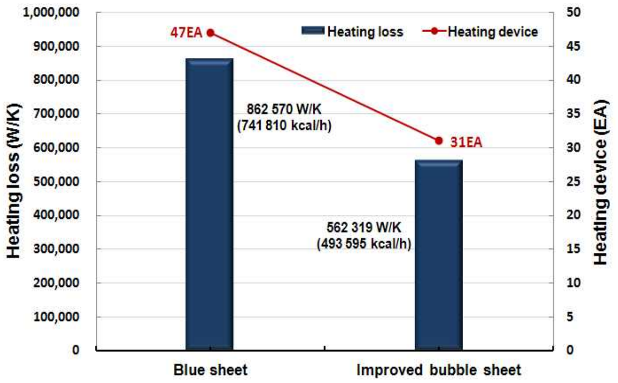

Figure 7. Number of comparisons by heat loss and heaters

This is believed to be because the joint condition considered in the computation of the number of ventilation recovery is better in the improved bubble sheet than in the blue sheet.In terms of heat loss within the curing sheet caused by ventilation, 15074.9 W/K was calculated for the blue sheet, while 6619.9 W/K was calculated for the improved bubble sheet. When using the improved bubble sheet, the heat loss of the improved bubble sheet caused by ventilation was measured as approximately 44% that of the blue sheet.

In addition, in terms of the total heat loss caused by heat transfer-ventilation (heat loss by heat transfer and ventilation combined), 862570 W/K(conversion-741810 kcal/h) was measured for the blue sheet, while 562319 W/K(conversion-483595 kcal/h) was measured for the improved bubble sheet. The heat loss of the improved bubble sheet was decreased by approximately 35% compared with that of the blue sheet. It is believed that both the relatively lower heat loss coefficient of the improved bubble sheet and the improved joint condition had an effect on the results.

To compensate for the total heat loss of the curing sheet caused by heat transfer and ventilation combined, sufficient heat should be provided to compensate for the heat loss. A conversion of the heat loss into the number of heaters is indicated in Table 12, based on which it was found that 47 heaters were needed for the blue sheet, while 31 heaters were needed for the improved blue sheet. In other words, approximately 34% fewer heaters were required when using the improved bubble sheet.

3) Comparison of heat curing cost by curing sheet material

Table 13 indicates the heat curing cost when using either the improved bubble sheet or the blue sheet.

First, in terms of material cost, the improved bubble sheet was approximately twice as expensive as the bubble sheet, making the improved bubble sheet disadvantageous from a material perspective. But the reduction in the heating cost resulting from the reduction in the number of heaters compensated partly for the material cost. In terms of capacity for repeated use (calculated based on the tensile performance data in this research and data provided by the curing sheet manufacturer, and the number of actual repeated uses at the construction site), the blue sheet could be used only twice since it is easily torn due to its low tensile strength and sequential rupture, while the improved bubble sheet could be used up to 5 times due to its good tensile strength. Assuming that cement was placed 10 times for the entire target structure during cold weather, the improved bubble sheet is expected to bring about a cost reduction of approximately 26% compared with the blue sheet.

However, the calculation of the heat loss and the number of heaters was conducted based on JASS since there are no criteria or guidelines for heat curing, which often causes confusion at construction sites. For this reason, there is an urgent need to develop and provide criteria or

Table 13. Cost of curing according to the curing membrane material

Section	item	Name of item	Unit	Amount of use	Price per unit	Amount(won)	Price (won)	Base of estimate
Blue sheet	Cost of sheet		㎡	1 800	1 100	1 980 000	1 980 000	Price per unit of manufacturer
	Cost of heating material	Heat instrument	EA	47	17 500	822 500	3 258 500	3 day curing (6.35kg per hour)
		Lignite	Sack(30 kg)	252	9 000	2268 000		
		Complexing agent	Box(40 EA)	12	14 000	168 000		3 EA / 1 time
	Labor cost	Installation worker	Person	5	70 000	350 000	880 000	5 worker
		Dismantlement worker	Person	5	70 000	350 000		
		Nighttime worker	Person	3	60,000	180 000		1 person × 3 day curing
	Subtotal		The cost of construction : 1 time				6118 500	
	Grand total		The cost of construction : 10 time - Cost of sheet : 1 980 000×5=9 900 000 - Cost of heating materia : 3 258 500×10=32 585 000 - Labor cost : 880 000×10=880 000				51285 000	Blue sheet : 2 times reuse
Improved bubble sheet	Cost of sheet		㎡	1 800	2 200	3 960 000	3 960 000	Price per unit of manufacturer
	Cost of heating material	Heat instrument	EA	31	17 500	542 500	2 106 500	3 day curing (6.35kg per hour)
		Lignite	Sack(30 kg)	166	9 000	1494000		
		Complexing agent	Box(40 EA)	5	14 000	70 000		3 EA / 1 time
	Labor cost	Installation worker	Person	5	70 000	350 000	880 000	5 worker
		Dismantlement worker	Person	5	70 000	350 000		
		Nighttime worker	Person	3	60,000	180 000		1 person × 3 day curing
	Subtotal		The cost of construction : 1 time				6 946 500	
	Grand total		The cost of construction : 10 time - Cost of sheet : 3 960 000×2=7 920 000 - Cost of heating materia : 2 106 500×10=21 065 000 - Labor cost : 880 000×10=880 000				37 785 000	Improved bubble sheet: 5 times reuse

* This table was calculated based on the standard quantity per unit of construction standard production unit system. The unit prices were calculated based on price trends provided by Korea Price Research Center. in July, 2012

guidelines for the heat curing for cold weather concrete, either at the society level or as a standard specification.

4) Additional efficiencies evaluation according to curing material

Table 14 compares additional efficiencies of each material. Six items were selected: transparency, appearance, repetitiveness, waste disposal/recycling, constructability and soundproof properties. First, in terms of transparency and appearance, vision is secured when using the improved bubble sheet, since it is transparent due to its PE material, and it was not torn by sequential rupture due to its resistance to wind. However, the workers had difficulty working with the blue sheet due to its opaqueness, requiring illumination; moreover, the appearance could be deteriorated through tearing by sequential rupture.

Table 14. Additional evaluation of efficiencies according to the curing membrane material

Performance	Material	
	Blue Sheet	Improved bubble sheet
Transparency	△	◉
Appearance	○	◉
Repetitiveness	○	◉
Waste disposal / Recycling	△	○
Constructability	○	△
Sound proof	△	○

* Rating : ◉-Good, ○-Normal, △-Bad

In addition, as mentioned earlier in terms of repetitiveness, the improved bubble sheet was shown to be superior to the blue sheet, and even in waste disposal the improved bubble sheet could be recycled as external insulation material for concrete placement for the external wall of underground floor to prevent condensation. However, the workability is believed to be slightly deteriorated due to its large volume and heavy weight compared with the blue sheet.

4. Conclusion

In this study, a comparative analysis of economic feasibility of the blue sheet and the improved bubble sheet was conducted to provide more economical heat curing in cold weather, and the findings are as follows.

1) From the calculation of heat loss of target structure according to curing sheet material, heat transfer and ventilation, heat loss was found to be decreased by 35% when the improved bubble sheet was used compared with when the blue sheet was used, which is believed to be because the improved bubble sheet had a relatively lower heat loss coefficient due to low heat conductivity, and a better joint condition due to its better tensile strength.
2) From the calculation of the number of heating facilities needed, the improved bubble sheet was shown to have superior economic feasibility to the blue sheet by achieving a 26% decrease in cost, assuming it is used 10 times repeatedly for the entire target structure during cold weather.
3) In terms of additional efficiencies, the workability of the improved bubble sheet was slightly lower compared with the blue sheet; however, in terms of transparency, appearance, repetitiveness, soundproof properties, and waste disposal, it was found to be an efficient material with good performance for heat curing.

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