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A Study on the Gas Emission of Constituent Materials making Metal Vacuum Panel

Bongjoo Kim [1,*], Sanghun Hong [2] and Namgyu Yoo [3,]

[1] Department of Architectural Engineering, Kongju National University, Budae-dong, Seobuk-gu, Cheonan-si, Chungcheongnam-do, 31080, Korea; 1; bingma@kongju.ac.kr
[2] Department of Architectural Engineering, Kongju National University, Budae-dong, Seobuk-gu, Cheonan-si, Chungcheongnam-do, 31080, Korea 2; thdgns1814@ kongju.ac.kr
[3] Department of Architectural Engineering, Kongju National University, Budae-dong, Seobuk-gu, Cheonan-si, Chungcheongnam-do, 31080, Korea 3;KNUYNG@ kongju.ac.kr
* Correspondence; bingma@kongju.ac.kr; Tel.: +82-41-521-9494

Abstract: This study examines whether gas is emitted from the materials used in the fabrication of metal vacuum panels or not and if emitted, their degree as time goes by. As experimental materials, metal sheets, foamed concrete as a core material, and polymer materials as a sealing material between metal sheets were selected. Experiments on the type and the degree of bending of metal materials showed that aluminum's vacuum reaching time of 0.001 torr was at least 40 sec to 90 sec in its flat plate, but its vacuum reaching time increased from 3 times to 4.5 times in case of 90 ° and 135 ° bending state. For this reason, it is judged that stainless steel or steel material is suitable because aluminum is inadequate in terms of processability at the time of fabricating the metal vacuum panel. Also, vacuum arrival times and weight changes with increasing foam content of inorganic foamed concrete increased from 22,000 sec to 42,000 sec with increasing foaming rate and also, the weight change increased from 1.7% to 8%. Also, the experimental results on the type of honeycomb materials, the PE (polyethylene) with a vacuum reaching time of 30,000 sec and with a weight change of 0.5% and the PTFE (Poly-tetrafluoro ethylene) with a vacuum reaching time of 29,000 sec and with a weight change of 2.2% showed the optimum value.

Keywords: metal vacuum panel; vacuum Insulation Panel; energy; gas emission; foam concrete; honeycomb materials

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1. Introduction

In the case of buildings that make up a significant amount of energy use, more than 40% of the energy is used for heating and cooling. It is very important to improve the thermal insulation performance of the outer cover for the purpose of saving the said energy use. [1-3] There is a study of new high-performance insulation due to insufficient performance of the existing insulation used for this purpose. [4-9]

Applicability of Vacuum Insulation Panel (hereinafter referred to as VIP) used in home appliances as well as aerogels to the buildings is being studied. Particularly in VIP case, its insulation is made in the manner that a vacuum is formed inside by and between special vinyl sheet with aluminum foil as a barrier and glass wool or fumed silica as core material. [10-13]

However, when such a vacuum insulation panel is used for the building, many problems such as the possibility of barrier damage at the time of installation, the difficulty in installation, their high prices, the difficulty in maintaining the vacuum state due to gas emission of core materials, and the impossibility of repair of reinforcement even when the insulation functioning is lowered due to the vacuum breakage.

For this reason, a replacement for the existing VIP is needed. As an alternative to this, a metal vacuum insulation panel is considered for which the metal plate material applied to insulation of a non-vision portion of a curtain wall is used so that it can be repaired and reinforced for insulation improvement. [14-20]

Such a metal vacuum insulation panel as mentioned above can solve both insulation and interior and exterior finishes simultaneously and also, has good workability as well. For this purpose, this study aims to provide basic data through the experiments on whether gas is emitted from panels, core materials and sealing materials according to their kind and form in order to select the optimum materials constituting the metal vacuum insulation panel.

2. Design of metal vacuum insulation panel

2.1. Structure and manufacture of existing vacuum insulation panel

The structure of the existing vacuum insulation panel is shown in Figure 1. Its constituent materials are the barrier made of aluminum foil and vinyl and the core material made of glass wool or fumed silica. The vacuum insulation panel is produced in the following manner that the above-said materials are placed inside a vacuum chamber as shown in Fig. 1 and then, the inside of the vacuum chamber is vacuumed, and the barrier around the core material is heat sealed. At this time, the vacuum rate arrive at close to 0.001 torr.

The initial heat insulation performance is as high as about 0.004 W/mk due to such a vacuum rate, but it is difficult to continuously maintain due to the gas generation of the core material and the air permeation of the outer skin after its production. In addition, since the aluminum foil, which is a barrier, has a thickness of 8um, gas generation and water permeation due to corrosion may occur over time. Glass fiber used as an inner core material may adhere to the outer skin over time and cause a reaction. The vacuum rate drops due to these reactions, which has a great influence on the heat insulation performance.

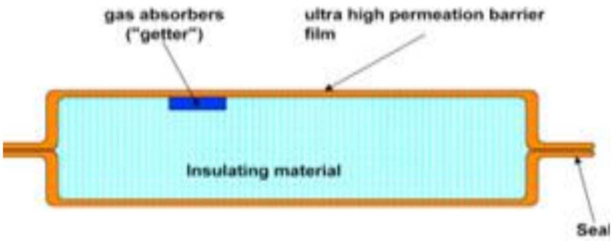

Figure 1. Structure of the Existing VIP.

2.2. Structure of metal vacuum panel components

The structure of the metal vacuum panel components is similar to that of the vacuum insulation panel, and the barrier of the metal vacuum panel components is made of a metal plate to minimize the influence from the external environment. The interior is made of lightweight foamed concrete, which is an inorganic material, and plastic material, which has a honeycomb structure.

The inner core material was designed to be located at the center of the metal vacuum panel components. In addition, the sealing material used for connecting the plate materials and fixing the core material by integrating the constituent materials is a polymer. The structure of the metal vacuum panel components using the above materials is shown in Figure 2.

The vacuum control valve for maintaining the vacuum state and for repairing the vacuum pressure according to the elapse of time is provided so that the maintenance is continuously made even after the installation.

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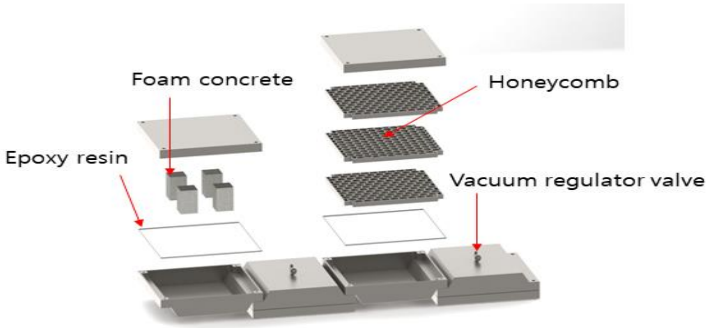

Figure 2. Structure of metal vacuum panel components.

3. Experimental plan and method

In this study, the vacuum characteristics of the materials constituting the metal vacuum panel components were examined according to the kind of materials.

Firstly, As the metal which is the outer surface of the metal vacuum panel, aluminum plate, stainless steel and steel were tested according to the thickness of 2mm, 3mm and the bending degrees of 0 °, 90 ° and 135 °. Secondly, the foam content of inorganic lightweight foamed concrete and the plastic material of honeycomb structure were tested as core material of metal vacuum panel. Thirdly, the types of polymers that fix the metal vacuum panel components and fix the core material were examined.

The vacuum reach times of the materials were measured in order for each material to arrive at 0.001torr which is the target vacuum degree of the metal vacuum panel. Since it was impossible to directly measure the amount of gas generated in the vacuum state of the vacuum panel, the time required for reaching 0.001 torr of each constituent material was relatively examined based on the time taken for reaching 0.001 torr of the vacant vacuum chamber.

3.1. Experimental plan

As the metal materials of the metal vacuum panel components which can be used as building exterior material and have durability, aluminum, stainless steel and steel were selected. Aluminums of A 1050, A 3003, A 5052 were selected according to the difference of tensile strength and yield strength. Stainless steels of STS 304, STS 316 were selected according to the chromium content. Iron of SS275 (SS400) which is easy to process was selected.

The metal materials with the thickness of 2mm and 3mm were selected and also, 0 °, 90 ° and 135 ° were considered in consideration of bending during processing of the metal panel. The inorganic lightweight foamed concrete out of the core materials of the metal vacuum panel components was mixed with cement, water and foams, and the foam ratio was 0, 10, 30, 50%. As the plastic materials with honeycomb structure, PVC (polyvinyl chloride, PVC), PC (polycarbonate, PC), PP (polypropylene, PC), PE (polyethylene, PE) and PTFE (poly-tetrafluoro ethylene, PTFE) were selected. As the polymer used as binder, A Type (Bond strength 2MPa), B Type (Bond strength 4MPa), and C Type (Bond strength 8MPa) were selected.

Table 1. Experimental factor and level.

Factor		Level	Number of Levels
Metal material	Metal plate machining angle (°)	0, 90, 180	3
	Metal type	A (aluminum), STS (stainless steel), SS (steel)	3
	Metal thickness (T)	2,3	2

Foamed concrete	Foam ratio (%)	0, 10, 30, 50	4
Core material	Plastic material with honeycomb structure	PVC, PC, PP, PE, PTFE	5
Sealing material	Polymer bond strength (MPa)	2, 4, 8	3

3.2. Materials

The basic characteristics of the metal materials of the metal vacuum panel components are shown in Table 1. Since stainless steel has different hardness depending on the content of chromium, the 2 types were selected and examined.

Aluminum was classified into the 3 types according to the difference in strength, the 2 types were selected and examined. Since steel is easy to handle but there is a problem about corrosion, 1 type was selected and examined.

Table 2. Characteristics of metal materials.

No	C	Si	Mn	P	S	Ni	Cr	Mo	Fe	Cu	Mg	Zn	Ti	Yield strength (N/㎟)	Tensile strength (N/㎟)
STS 304	0.08	1.00	2.00	0.05	0.03	10.00-14.00	16.00-18.00	2.00-3.00	-	-	-	-	-	205	520
STS 316	0.08	1.00	2.00	0.05	0.03	8.00-10.50	18.00-20.00	0	-	-	-	-	-	205	520
A 1050		0.25	0.03	-	-	-	-		0.35	0.05	0.03	0.05	0.03	45	85
A 3003		0.60	1.00-1.15	-	-	-	-		0.7	0.05-0.20	-	0.10	0.02-0.10	70	120
A5052		0.25	0.10	-	-	-	0.15-0.35		0.4	0.1	2.20-2.80	0.10	-	110	195
SS275 (SS400)	0.25	0.45	1.40	0.050.05	-	-	-	-	-	-	-	-	-	275	410

Figure 3. Metal sheets according to bending degree.

Ordinary port-land cement was used as inorganic lightweight foamed concrete used as core material and vegetable foaming agent was selected as foaming agent. The foamed concrete was experimented after its having been made the 28 days strength concrete in an over dry condition with no change in weight in the drying furnace at 100 ± 5 ℃. Six types of plastic with honeycomb structure such as PVC, PC, AC, PP, PE and PTFE were examined.

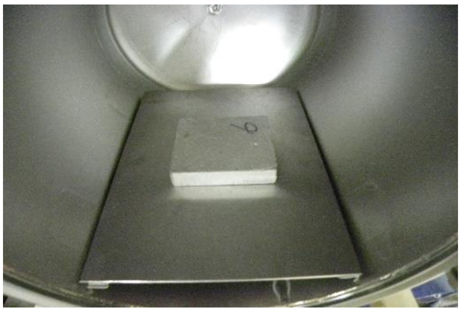

Figure 4. Vacuum arrival time measurement of foamed concrete with 50% foam rate.

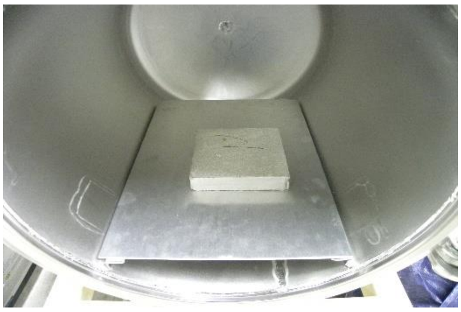

Figure 5. Vacuum arrival time measurement of foamed concrete with 30% foam rate.

Figure 6. Vacuum arrival time measurement of PVC.

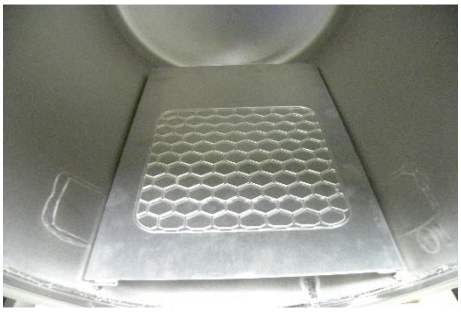

Figure 7. Vacuum arrival time measurement of PC.

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Figure 8. Vacuum arrival time measurement of AC.

Figure 9. Vacuum arrival time measurement of PP.

Figure 10. Vacuum arrival time measurement of PE.

Figure 11. Vacuum arrival time measurement of PTFE.

3.3. Experimental method

The vacuum time was measured until the vacuum rate reached 10^{-3} torr by using the materials of the metal vacuum panel and injecting each material into the vacuum chamber. In addition, their weights were measured before and after the injection into the vacuum chamber in order to check whether gas was generated or not.

Vacuum arrival time and weight measurement of this experiment were carried out in accordance with Korean Standard, i.e., KS.

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Figure 12. Vacuum chamber.

4. Results and Discussion

4.1. Vacuum Arrival Time according to the Type of Metal Material and the Degree of Bending

It took 240 sec as a result of 6 measurements made in order to compare the time of reaching 10^{-3} torr of the empty vacuum chamber before the experimental measurement of the constituent material. The following experimental results showed the results for the extended time except for the reference time. Weight change measurements were excluded from the experimental results due to small amounts of change and experimental errors.

As shown in Figure 10, the aluminum material reached a minimum of 40 seconds to the maximum of 90 seconds, and the arrival time of the stain-less steel material increased from at least 4 times to at least 8 times of the aluminum material. However, as shown in Figure 11 and Figure 12, the vacuum arrival time of the aluminum material in 90 °bending state increased from a minimum of 200sec to a maximum of 300sec and that of 3T of A 3003 aluminum in 135 ° bending state increased the maximum of 450sec, but in other cases, it was slightly lower than that of 90 °bending state case.

Aluminum materials are judged to be unsuitable due to problems such as bending during panel fabrication and gas generation due to breakage of the structure on the machined surface due to increase in vacuum reaching time according to the degree of bending.

On the other hand, even though the material of stainless steel or steel has a large amount of generated gas, it was judged to be suitable. It was because it had stable surface texture in terms of bending and processing.

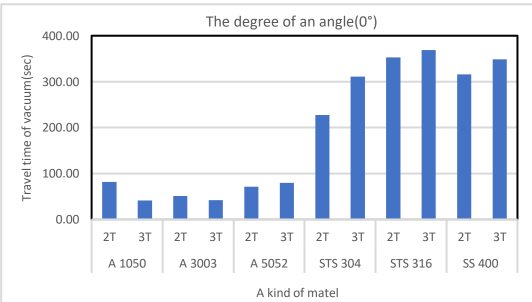

Figure 13. Vacuum arrival time with degree of 0 ° angle according to types.

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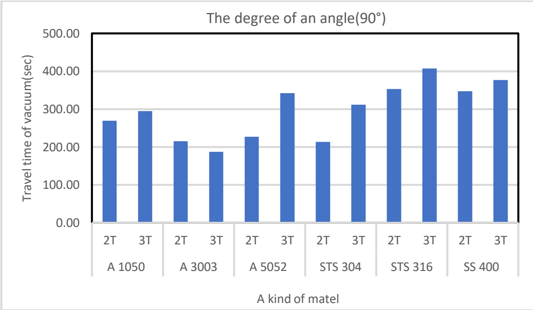

Figure 14. Vacuum arrival time with degree of 90 ° angle according to types.

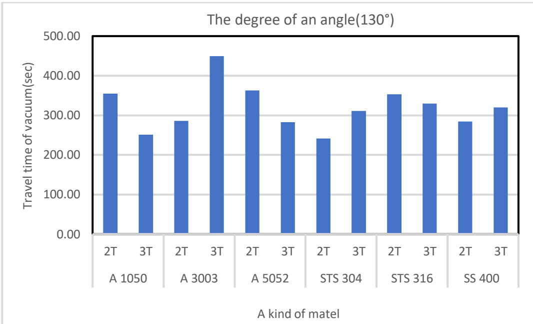

Figure 15. Vacuum arrival time with degree of 135° angle according to types.

3.2. Vacuum Arrival Time and Weight Change according to the Foam rate of Lightweight Foamed Concrete

As shown in Figure 13, the vacuum arrival time of the foamed concrete increased from a minimum of 10,000sec to a maximum of 20,000sec with the increase of the foam rate and the vacuum arrival time of the foamed concrete of 0% foam rate was 2 times more than that of 50% foam rate.

Figure 14 shows a weight reduction of 8% at 50% foam rate and 2.5% and 1.7% at 10% and 30% foam rate, respectively.

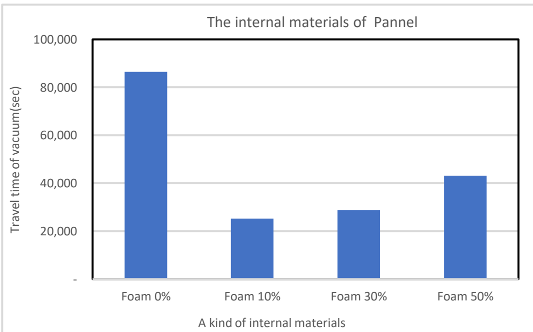

Figure 16. Vacuum arrival time according to Foam rate of foamed concrete.

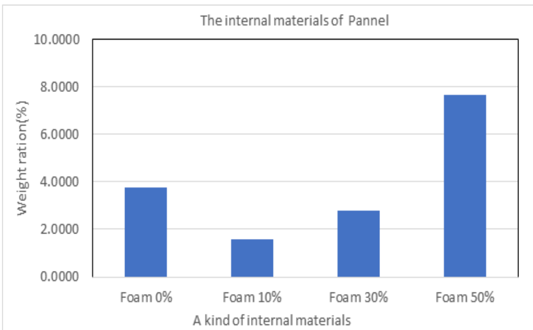

Figure 17. Weight change according to foam rate of foamed concrete.

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4.3. Vacuum Arrival Time and Weight Change according to the Type of Honeycomb Material

As shown in Figure 18 and Figure 19 respectively, the vacuum arrival time according to the type of honeycomb material was found to be the longest of 58,000sec in AC material type and its weight change was 10%. The shortest PE vacuum time was 30,000 sec, and its weight change was 0.5%. The changes of vacuum time and weight according to material type are considered to be dependent on the production process of the material and the porosity of the material surface.

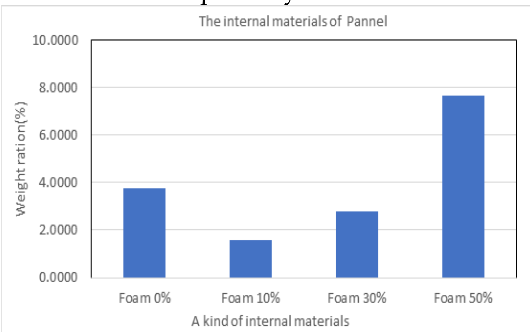

Figure 18. Vacuum arrival time according to the type of honeycomb material.

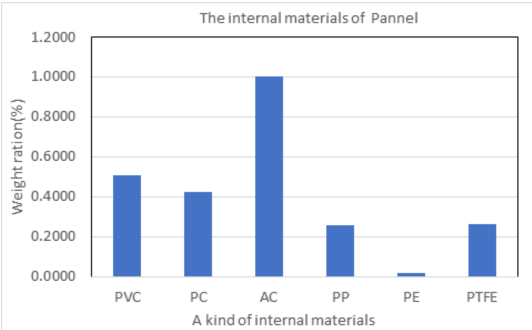

Figure 19. Weight change according to the type of honeycomb material.

4.4.Vacuum Arrival Time according to the Type of Sealing Material

As shown in Figure 20, the vacuum arrival time and weight change according to the type of sealing material were found to be the highest in C type vacuum reaching time of 2,200 sec.

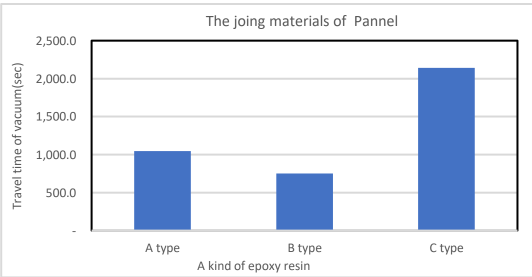

Figure 20. Vacuum arrival time according to the type of tealing material.

5. Conclusions

Through the measurement of the vacuum arrival time and weight change according to kind of constituent materials for the metal vacuum panel components, the results of the basic experiment for replacing the existing materials of the metal vacuum panel components and using them as the exterior materials of the building are as follows.

As a result of examining the change of vacuum arrival time and weight of metal materials, the

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vacuum arrival time of SS400 material was increased but no weight change was shown. Especially, considering the flexural and workability of the metal panel and its consequential durability, it is judged appropriate because the weight change according to the flexural strength did not occur. Vacuum arrival time and weight change according to foam rate of lightweight foamed concrete increased with increasing foam rate. This showed that the pore of the foamed concrete is a continuous one and the length of the airflow is long so that the process of sucking air in the pore is required. It is required to develop the core material having a short air flow length at a later time.

Experiments on the type of honeycomb material showed that the PE (polyethylene) with a vacuum reaching time of 30,000 sec and with a weight change of 0.5% and the PTFE (Poly-tetrafluoro ethylene) with a vacuum reaching time of 29,000 sec and with a weight change of 2.2% were found to be the most appropriate.

Then, based on the above test results, the possibility of use as an insulating material is to be examined through continuous increase of the vacuum rate of the metal vacuum panel components and measurement of the thermal conductivity thereof.

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, Bongjoo Kim.; Methodology, Sanghun Hong and Namgyu Yoo; Writing-Original Draft Preparation Bongjoo Kim.; Writing-Review & Editing, Bongjoo Kim, Sanghun Hong and Namgyu Yoo

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Conflicts of Interest: Declare conflicts of interest or state "The authors declare no conflict of interest." Authors must identify and declare any personal circumstances or interest that may be perceived as inappropriately influencing the representation or interpretation of reported research results. Any role of the funders in the design of the study; in the collection, analyses or interpretation of data; in the writing of the manuscript, or in the decision to publish the results must be declared in this section. If there is no role, please state "The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results".

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