

Cause of Surface voids in Concrete Attached to an Aluminum Form, and Measures for Prevention

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Abstract

Traditionally, the material used for the form in reinforced concrete construction has been wood or steel. But recently, aluminum forms have been widely used in wall structures such as apartment buildings. Aluminum is light, easy to handle, and economically advantageous, but the hydrogen gas created due to its reaction with the alkali component in concrete gives rise to air pockets on the concrete's surface, and deteriorates the surface's finishability. In this research, to determine the influence of aluminum material on concrete, the cement paste W/C and its chemical reactivity in alkali and acid solution were analyzed. As a prevention plan, the influence of the number of applications of calcium hydroxide and various surface coating materials was analyzed. Through the analysis, it was found that the surface voids on the aluminum form are the result of the reaction of hydrogen gas with an alkali such as $\text{Ca}(\text{OH})_2$. This can be prevented by the surface treatment of $\text{Ca}(\text{OH})_2$, separating material and coating material. However, poor surface form and damages to the form are expected to cause quality degradation because of the aluminum-concrete interaction. Therefore, thorough surface treatment, rather than the type of separating material or coating material, is considered the most important target of management.

Keywords : aluminum form, calcium hydroxide, hydrogen gas

1. Introduction

A form maintains the shape of a concrete structure, prevents moisture from being evaporated, and protects concrete from external impacts and temperature changes. Wood and steel have been the chief materials used for concrete forms, but recently a variety of other materials have been employed, including light metals like aluminum, plastic, paper, and composite and large panel system forms[1].

However, of the diverse materials, aluminum forms have been often used for wall-type structures, including apartment buildings, because aluminum has economic advantages: it is lightweight and less likely to be corroded, deforms little and is dimensionally stable, and is economic in terms of its life cycle cost.

However, the aluminum material is a positive metal and thus can be corroded by acid, alkali and salt, so its chemical stability deteriorates on contact surface with strong alkaline concrete due to its high ionization. That is, after the form was removed from concrete, there are some discolored parts on the surface of the concrete, and as shown in Figure 1, an air pocket was found on the concrete's surface that was a result of the

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hydrogen gas generated by the reaction with alkali components such as calcium hydroxide within concrete, which deteriorates the surface finishability[2,3].

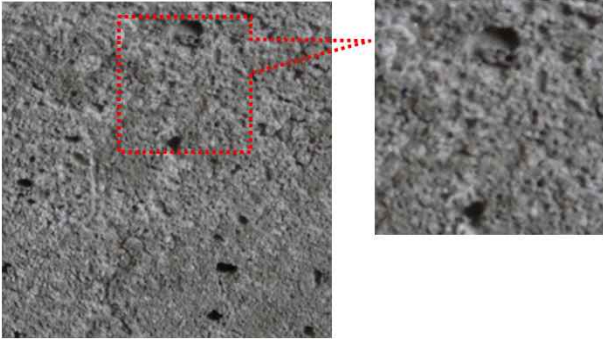


Figure 1. Air pocket of concrete surface by aluminum form

This study aims to provide fundamental data to improve the surface finishability of concrete. To do this, W/C and the chemical reactions of cement paste were analyzed when put in alkali and acidic liquid with different concentrations in order to examine the effect of aluminum as the form material on concrete, and the number of coatings of calcium hydroxide and the application of various surface coating materials were also tested to prevent surface deterioration.

2. Discussion of the reaction between aluminum and concrete hydrate

2.1 Aluminum

Aluminum(Al) has low density, high strength and good workability, which makes it a suitable construction material. However, aluminum reacts with oxygen in the air to generate aluminum oxide(Al_2O_3). The oxide layer $10^{-4}\sim 10^{-6}$ mm thick is created on the aluminum's surface, and serves to protect the aluminum atoms below it. Aluminum with a thin oxide layer has good resistance to corrosion but is easily eroded by acid and alkali.

In particular, when it directly contacts strong alkaline concrete, it becomes easily eroded, and for this reason care needs to be taken in its use.

2.2 Chemical reaction of aluminum with concrete hydroxide

Initial hydrates generated from concrete generally have a strong alkaline property due to its chemical component of cement. The representative alkaline materials include C_3S , C_2S , calcium hydroxide ($\text{Ca}(\text{OH})_2$) generated in the course of hydration reaction, Na_2O which is an alkaline hydrate that exists within concrete in small amounts, potassium hydroxide(KOH), and sodium hydroxide (NaOH) induced from K_2O . The chemical reactions with the alkaline substances are shown in Equations (1) through (3). As shown in the equations, hydrogen gas is generated, which generates corrosion on aluminum. In addition, aluminum is reacted with strong acid and alkali, which is also known to generate corrosion on it[4, 5].

3. Experimental plan and methodology

3.1 Experimental plan

The experimental plan is indicated in Table 1. First, to elucidate the mechanism of the surface air-void, cement paste was made to have water content of 40%, 45%, 50%, 55%, and 60%, and was filled into the container with dimensions of $50\times 50\times 50\text{mm}$, and then an aluminum specimen with dimensions $50\times 50\times 0.15\text{mm}$ was put into the paste. In addition, 0.1 mol of various solutions was used, each of which had a representative alkaline substance such as calcium hydroxide, potassium hydroxide, sodium hydroxide, and ammonium hydroxide and an acidic substance, sulfuric acid. An aluminum specimen of the aforementioned size was soaked in the solutions.

As for the experimental plan, the aluminum specimen was coated with 0.1mol solution of calcium hydroxide from 1 to 5 times to perform the test. As the release agent, liquid release agent and oil release agent were used, and as the coating material, fluorocarbon resin, aluminum primer, and liquid PE resin for PE film were used. Each of the release agents and coating materials was applied on the aluminum before it was soaked in the 1mol of solution. In the experiment, hydrogen gas emission for 24 hours, and the changes in weight of the aluminum specimen were measured.

Table 1. Experimental plan

Division	Experimental factors		Experimental levels				
	Factors	Contents	Levels	Contents			
Cause	Cement paste	W/C(%)	5	· 40, · 45, · 50, · 55, · 60			
	0.1 mol aqueous solution	Alkali	4	· Calcium hydroxide(Ca(OH) ₂)			
				· Potassium hydroxide(KOH)			
Prevention	Separating material application	hydroxide 0.1 mol	2	· Sodium hydroxide(NaOH)			
				· Ammonium hydroxide(NH ₄ OH)			
Prevention	Coating material application	Acid	1	· Sulfuric acid(H ₂ SO ₄)			
				Calcium hydroxide 0.1 mol aqueous solution	Digestion to calcium hydroxide	5	1~5 times
							· Water separating material
Prevention	Oil Separating material application	after treatment	3	· Fluorine resin paint			
				· Aluminum primer			
Prevention	PE film application			· PE film			

3.2 The materials used

Ordinary Portland cement manufactured by Company A was used to make the cement paste for this study, and the physical and chemical properties of the cement can be found in Tables 2 and 3, respectively.

As for the aluminum specimen, a 100% thin plate sold in Korean market was used, while for the solution calcium hydroxide with 95% purity, potassium hydroxide with 85% purity, sodium hydroxide with 98% purity, ammonium hydroxide with 30% purity, and sulfuric acid with 95% purity manufactured by S company of Korea were used. They were diffused to be a 0.1mol solution to use for the experiment.

Table 2. Physical properties of cement

Density (g/cm ³)	Blaine (cm ² /g)	Stability (%)	Setting time (Minute)		Compressive strength(MPa)		
			Initial time	Final time	3 days	7 days	28 days
3.15	3 390	0.05	230	345	22.6	36.3	51.8

Table 3. Chemical properties of cement

Chemical components(%)										LSF	SM	IM
LOI	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O				
0.35	21.88	4.02	3.66	64.18	2.01	1.83	0.07	0.92	90.44	2.52	1.37	

LOI : Loss on ignition, LSF : Lime saturation factor, SM : Silica modulus, IM : Iron modulus

3.3 Test method

3.3.1 Mix of cement paste

The cement paste was mixed in accordance with KS L 5109 Testing Method for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency.

3.3.2 Hydrogen gas emission

Hydrogen gas emission was measured after the aluminum specimen was soaked in each of the cement pastes and solutions for 24 hours. For the measurement, the upward displacement of water was used to collect hydrogen gas.

3.3.3 Changes in the weight of the aluminum specimen

To obtain the data of mass change rate before

and after the soaking, the weight of each aluminum specimen was measured using a 0.1g precision scale after soaking them in the cement pastes and solutions, and lightly cleansing the surface of the specimens with distilled water.



Figure 2. Measurement of hydrogen gas emissions

4. Test results and analysis

4.1 Causes of surface air-void

4.1.1 Chemical reactivity of cement paste by water content (W/C)

Figure 3 shows hydrogen gas emission, and Figure 4 shows the mass change rate of the aluminum specimens depending on W/C. Figure 5 a) shows the surface of the specimens before the test, and Figures 5 b) through f) show the surfaces of the specimens after the test.

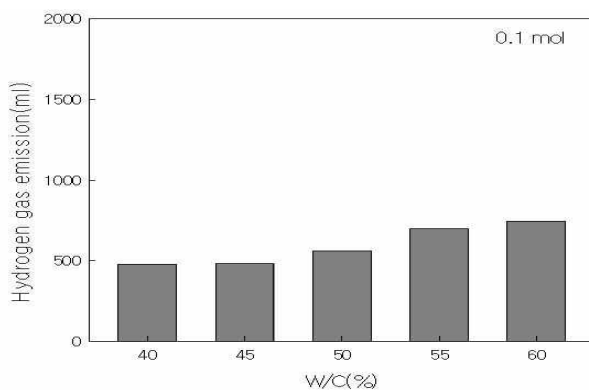


Figure 3. Hydrogen gas emissions by W/C

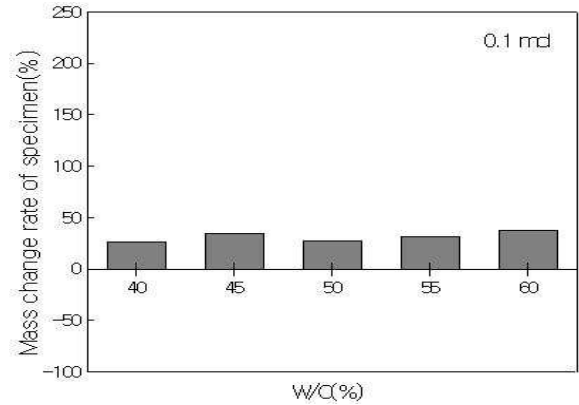


Figure 4. Mass change rate of specimen by W/C

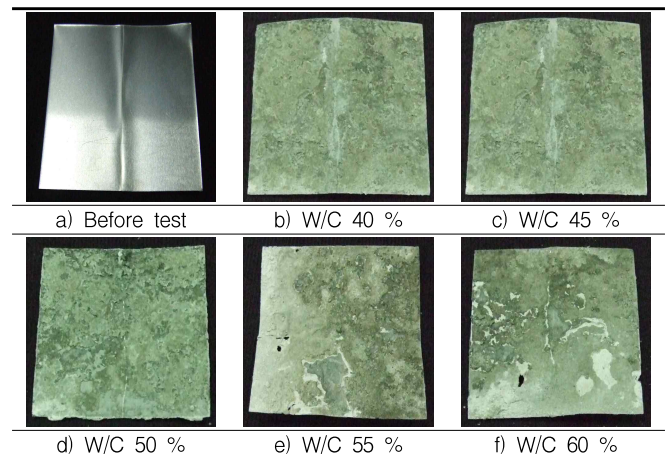


Figure 5. Specimen appearance by W/C

There was little reaction found immediately after the test, but active reaction was found about 2 hours after the onset of the test, and white floating matters considered as calcium components were observed on the surface of the cement paste.

First of all, contrary to the expectation that the higher the W/C of cement paste, the higher the alkali concentration, more hydrogen gas was generated in the specimens with a higher W/C. More specifically, in a specimen with a higher W/C, the hydration takes place slowly, and the setting and hardening were found to be delayed as well. As the result, the reaction time of the aluminum with cement hydrates was elongated, and the total amount of hydrogen gas was increased. Specifically, with W/C of 40% the

reaction was active up to about 8 hours, and then gradually decreased, and a total of 560ml hydrogen gas was generated for 24 hours. With W/C of 60%, the reaction was active up to about 10 hours and then gradually decreased, and a total of 745ml hydrogen gas was generated for 24 hours.

In terms of mass change, unlike the generation of hydrogen gas, there was no significant difference found before and after the test, and weight was shown to increase by about 30% overall. It is believed that the calcium carbonate generated was attached on the specimen due to its close bonding between cement paste and aluminum specimen.

However, in terms of deterioration observed with naked eyes, it was found that the higher the W/C, the more severe the deterioration.

4.1.2 Chemical reactivity by solution type

Figures 6, 7, and 8 show the hydrogen gas emission for each solution, the mass change rate for each solution, and the surface of specimen for each solution, respectively.

First of all, a violent reaction was observed for 24 hours in KOH and NaOH, both of which are alkaline, and the hydrogen gas emission was measured as more than 1700ml, which led to significant deterioration of the aluminum specimens. On the other hand, the reaction was not that great in $\text{Ca}(\text{OH})_2$ and H_2SO_4 , an acid substance, and the hydrogen gas emission was measured as 270ml and 190ml, respectively. In addition, the reaction was slight in NH_4OH , an alkaline substance, and almost no hydrogen gas was measured.

In terms of mass change, the mass was reduced due to corrosion. On the other hand, it was found that Ca^{2+} was attached to the surface of the metal in $\text{Ca}(\text{OH})_2$, and the mass was increased by about 220% after the reaction. The mass of the

specimens was found to decrease by about 20% in KOH and NaOH due to its violent reaction. On the other hand, there was almost no mass change found in NH_4OH and H_2SO_4 , where almost no reaction was found.

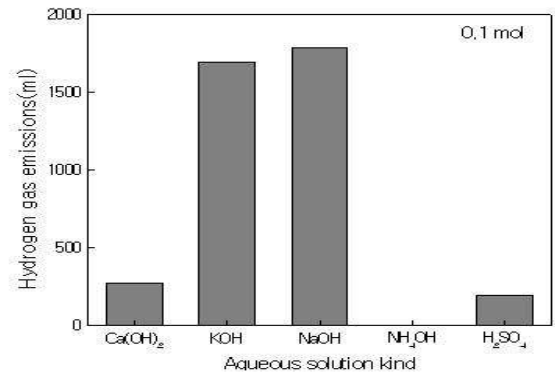


Figure 6. Hydrogen gas emissions by aqueous solution type

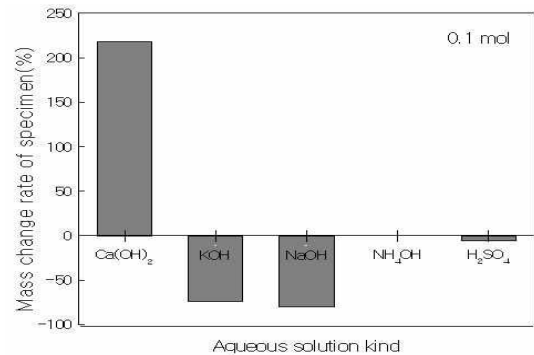


Figure 7. Mass change rate of specimen by aqueous solution type

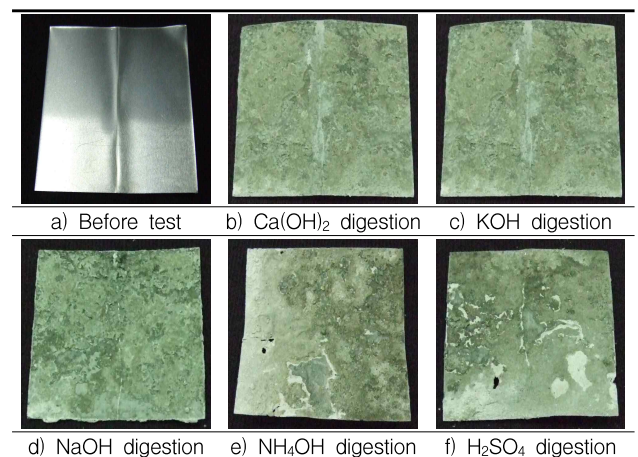


Figure 8. Specimen appearance by aqueous solution type

4.2 Measures to prevent surface air-void

4.2.1 Chemical resistance with the number of treatments of calcium hydroxide on the surface

To prevent the hydrogen gas emission and air pockets caused by the reaction of aluminum with alkali in concrete, it is recommended in ACI's Concrete International to treat the surface of the aluminum form with calcium hydroxide [6]. Therefore, Figure 9 shows the hydrogen gas emission depending on the number of treatments with calcium hydroxide, while Figures 10 and 11 show the mass change and the surface of the specimens, respectively.

First of all, the hydrogen gas emission was found to decrease as the number of treatment increased. When treated once or twice, a large amount of hydrogen gas was generated from the beginning of the test. However, when treated more than three times, it was found to significantly decrease.

The difference in mass before and after the test was found to decrease as the number of treatments increased. When treated once or twice, the mass increased by up to 200% and 60% due to the attachment of calcium precipitate. However, when treated more than three times, almost no change in mass was found.

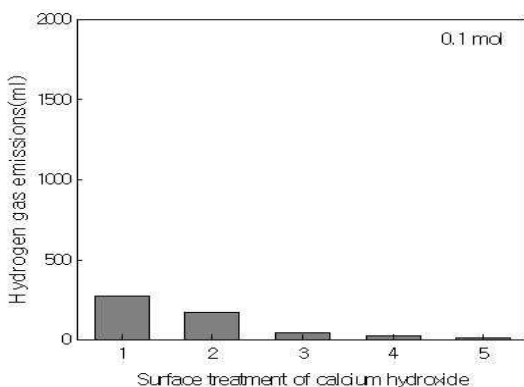


Figure 9. Hydrogen gas emissions according to the number of surface treatments with calcium hydroxide

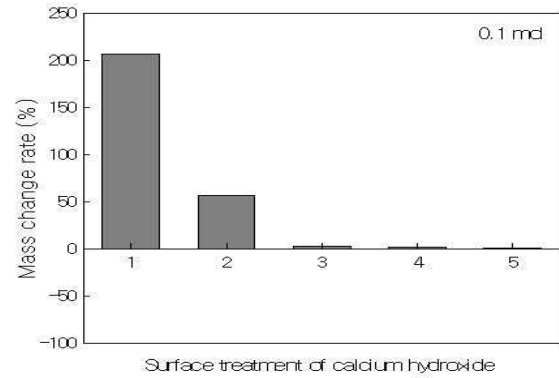


Figure 10. Mass change rate of specimen according to the number of surface treatments with calcium hydroxide

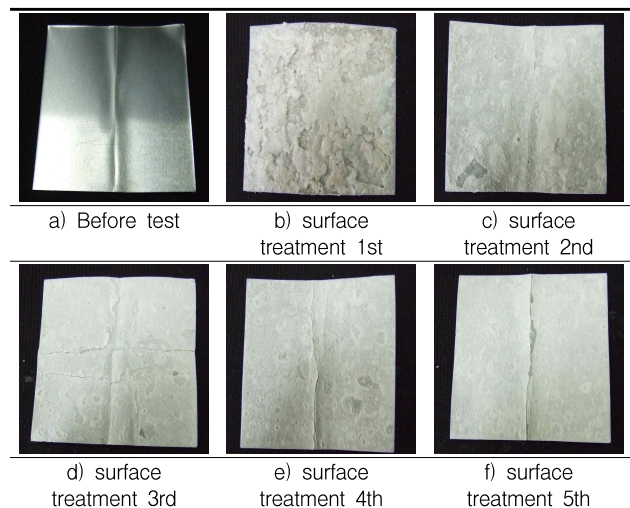


Figure 11. Specimen appearance by surface treatment of calcium hydroxide

It is believed that when treated with calcium hydroxide more than three times, Ca^{2+} was generated on the aluminum's surface, which was formed as a thin coating film and prevented additional reaction.

4.2.2 Chemical reactivity by release agent

Table 4 indicates the results of tests to prevent surface air-voids for each release agent. The results demonstrate that the liquid and oil release agents prevented the aluminum from reacting with calcium hydroxide, and no hydrogen gas was generated.

Table 4. Test by release agent

Type	Hydrogen gas emissions(ml)	Mass change rate (%)	Result
Water separating material	0	0	No reaction
Oil Separating material	0	0	No reaction

4.2.3 Chemical reactivity by coating material

Table 5 indicates the result of the test of chemical reactivity based on the coating material of synthetic resin. The results indicate that no hydrogen gas was found on fluorocarbon resin, aluminum primer, and PE film. However, it was found that if the coating or release agent was not treated completely, hydrogen gas was found on any incompletely coated part, which affected the entire surface of the aluminum specimen in a preliminary test. In treating the surface with release agent or coating material, ensuring a complete treatment is more important than the type of agent or material used.

Table 5. Test by coating material

Type	Hydrogen gas emissions(ml)	Mass change rate(%)	Result
Fluorine resin paint	0	0	No reaction
Aluminum primer	0	0	No reaction
PE film	0	0	No reaction

5. Conclusion

The aim of this study was to provide fundamental data to help prevent damage to finishability, including surface air-void of concrete caused by the aluminum form. To do this, the chemical reactivity of aluminum material by W/C, alkaline and acidic solution was analyzed to understand the effect of aluminum material on concrete. To prepare measures to prevent corrosion, the treatment of calcium hydroxide,

release agent, and coating material were analyzed. The findings of this research are as follows:

- 1) Of the factors that influence surface air-void, in terms of the chemical reactivity by W/C, the hydration decreased as the W/C became higher. However, the hydrogen gas emission increased with the passage of time.
- 2) In terms of chemical reactivity by solution, violent reaction was found in KOH and NaOH, both of which are alkaline, leading to the greatest emission of hydrogen gas, followed by $\text{Ca}(\text{OH})_2$ and acidic H_2SO_4 . There was almost no hydrogen gas emission found in NH_4OH . In addition, in terms of mass change rate, Ca ions were attached to aluminum surface in $\text{Ca}(\text{OH})_2$, leading to an increase in mass, while the mass was found to decrease in other alkaline and acidic solutions.
- 3) Of the preventive measures for surface air-void, it was found that the more treatment was done on the surface with calcium hydroxide, the more hydrogen gas was reduced due to its chemical resistance. When surface treatment was performed more than 3 times, almost no reaction was found. In addition, the mass change after the test decreased as the number of surface treatments increased.
- 4) In terms of chemical reactivity by release agent and coating material, when treated with release agent or coating material, the calcium hydroxide solution was completely blocked, leading to almost no hydrogen gas emission and mass change. However, if some part was left untreated with coating material of release agent, hydrogen gas was generated, which affected the entire aluminum specimen.

In sum, the surface air-void found on the

aluminum form is analyzed as a result of the reaction of hydrogen gas with alkali substance such as $\text{Ca}(\text{OH})_2$. If release agent and coating material were used to treat the $\text{Ca}(\text{OH})_2$ surface, the hydrogen gas emission was found to be prevented. However, ensuring a complete treatment on the surface is more important than the type of coating material or release agent chosen.

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