A Study on the Bioreceptivity of Cement Composites for Living Concrete Panels

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Abstract. In this study, bioreceptivity was assessed according to three levels of binder to control the quality of cement composites for living concrete panels. Depending on the binder, the effects of a foaming agent, a super absorbent polymer, and additional water on bioreceptivity were investigated. The change in pH was not significant as a result of the bioreceptivity evaluation, and recent studies have shown that mixing the superabsorbent polymer with water can increase moisture retention. The optimal amount of the appropriate super absorbent polymer was 0.5 percent or less at a level that satisfied the desired performance. Furthermore, the foaming ingredient was mixed in a way that it created open pores rather than closed pores. As a result, the entrance of moisture from the outside has been determined to be simple. It was able to establish an environment conducive to the easy attachment of organisms by producing a rather rough surface with pores.

Keywords: Alumina, Bioreceptivity, Cement Composites, Dead Magnesia, Living Concrete, Panels

1. Introduction

Living concrete panels should be in a condition where moss adhesion is easy, and an environment should be created so that they can survive after adhesion (Eggert et al., 2006). However, since high pH is formed when cement is applied in terms of material to manufacture panels (Kim, et al., 2011a), it is not suitable for the survival and maintenance period of moss. In the case of structural aspects, it is difficult for moss to take root if the surface is smooth or dense. In addition, there is also a problem with the supply of nutrients or moisture for moss on the panel (Jeon et al. 2014). The growth conditions of moss and the chemical and physical properties of living concrete panels are closely related, and the relationship is different depending on the climatic conditions (Favero-Longo et al., 2009; Myung, 2015; Rios et al., 2009).

Therefore, the technology or product developed abroad cannot be directly applied to the domestic market (Papida et al., 2000). Accordingly, the process of research and development of living concrete panels to be suitable for domestic environmental conditions is absolutely

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necessary (Cha and Lim, 2011). Considering the current level of domestic technology, the number of published or known research cases is insufficient, and many experiments and experiences are needed depending on the limitations of data collection (Kim et al. 2001b; Lee et al., 2021). Therefore, many complementary studies on element technology should be accompanied (Lee et al., 2012; Park and Oh, 2011).

Potassium phosphate-magnesia composites is advantageous for bioreceptivity because it has a neutral characteristic with a relatively low pH compared to general cement (Chae and Suh, 1994; Guillitte and Dreesen, 1995; Manso et al., 2014). Therefore, it is a suitable material as a base material for living concrete panels. However, due to its fast-hardening properties, potassium phosphate-magnesia composites have traditionally been employed as a material for emergency repairs of structures that demand quick work. (Kim et al., 2015), In particular, in the case of related research, a standardized study of the potassium phosphate-magnesia composites has not been conducted (Kim et al., 2015 ; Perini et al., 2011), so it is used in different methods depending on research institutes and related organizations. Therefore, it cannot be referred to because the quality of potassium phosphate-magnesia composites varies widely, and finding research cases is difficult (Ma and Xu, 2017).

Therefore, a study was done to use potassium phosphate–magnesia composites as a base material for living concrete panels. The bioreceptivity of a cement composite based on conventional Portland cement, alumina cement, and magnesia cement, which are all acceptable binders, was tested in this work as the basic material for living concrete panels.

2. Materials and Methods

2.1. Material used

2.1.1. Cement

There were three types of binders utilized namely Ordinary Portland Cement (OPC), Alumina Cement (AC), and Dead Magnesia Cement (MgO, MC). Furthermore, magnesia cement that had been calcined at a high temperature of 1,500 °C or higher was utilized. In this case, Potassium Phosphate Monobasic (KH_2PO_4, P) was used as the curing agent, and Borax ($Na_2B_4O_7 \cdot 10H_2O$, R) was used as the retarder. Table 1 shows the main chemical components and physical properties of the binders used. Table 2 shows the physical properties of P, and Table 3 shows the physical properties of R.

Table 1: Chemical composition and physical properties of the binder

Type	CaO (%)	Al_2O_3 (%)	SiO_2 (%)	Fe_2O_3 (%)	MgO (%)	Density (g/cm^3)
OPC	61.6	4.50	19.80	3.57	3.01	3.15
AC	29.4	69.5	0.5	0.5	0.6	2.90
MC	-	0.1	1.1	-	95.68	3.60

Table 2: Physical properties of P

Type	Purity (%)	pH	Cl (%)	Density (g/cm^3)
KH_2PO_4	99	4.3	0.005	2.34

Table 3: Physical properties of R

Type	Purity (%)	Melting point (℃)	Boiling point (℃)	Density (g/cm^3)

$Na_2B_4O_7 \cdot 10H_2O$	99	75	320	1.73

2.1.2. Fine aggregate

As the fine aggregate, No. 8 silica sand of 95% or more of SiO_2 was used. No. 8 silica sand is used to aggregate with a relatively small particle size to facilitate the generation of pores in the magnesia composites. Table 4 shows the main physical properties of the fine aggregates used in the experiment.

2.1.3. Forming Material(FA)

A foamed cement composite was prepared by applying the post-foaming method to the cement composites. Since the post-foaming method has a mechanism of generating pores by reacting with the binder, different foaming agents were used depending on the binder. Aluminum Powder (Al) was used as the foaming agent for OPC and AC, and sodium hydrogen carbonate ($NaHCO_3$) was used for MC.

Al reacts with calcium hydroxide to generate pores, and sodium bicarbonate reacts with phosphate to generate pores by hydrogen gas. Table 5 shows the main chemical components and physical properties of sodium bicarbonate used in the experiment.

Table 4: Physical properties of fine aggregate

Type	Density (g/cm^3)	Note
Quartz sand	2.65	60 ~ 150 mesh, More than SiO2 95%

Table 5: Sodium bicarbonate chemical composition and physical properties

Type	Purity (%)	Cl(%)	Fe(%)	Density (g/cm^3)
$NaHCO_3$	99	0.005	0.003	2.15

2.1.4. Super Absorbent Polymer(SAP)

Super absorbent polymer (SAP) was added to improve the cement composites of moisture content and moisture retention. For SAP, powder-type acrylic acid polymer-sodium salt (Acrylic Acid Polymer, Sodium Salt) was used. Table 6 shows the main chemical components and physical properties of SAP used in the experiment.

Table 6: Chemical composition and physical properties of superabsorbent polymer

Type	Content (%)	pH	Flash point (℃)	Density (g/cm^3)
SAP	99	5.5 ~ 6.5	200	1.11

2.2. Experiment plan

In this study, the effect of the foaming agent and SAP according to the binder on the bioreceptivity of the cement composite material for the Living Concrete panel was reviewed in order to manufacture the Living Concrete panel. Mixes for Living Concrete panels are shown in Tables 8 to 10. In Tables 8 to 9, eW means water to be added in addition to W. Since SAP absorbs a large amount of water, additional water must be added to equal the amount absorbed. eW is calculated as a percentage of the mass of W. The experiment evaluated the pH characteristics, moisture retention, and surface roughness of cement composite materials. Table 7 shows the experimental design and variables, and Tables 8-10 show the mixing ratios.

Previous research was used to determine the best mixing ratio for each mixture. OPC and AC were also steam cured for 1 day at 60°C before being cured in water. MC was cured in water for 1 day after being exposed to ordinary curing conditions at room temperature.

Table 7: Experimental design and variables

Experimental variables	Contents
SAP (B × %)	0.25, 0.50, 0.75, 1.00
eW (W × %)	SAP 0.25 = 10% SAP 0.50 = 16% SAP 0.75 = 22% SAP 0.10 = 28%

Table 8: OPC-based cement composite material mix

Type (SAP-eW)	W/B (%)	Vs/Vm (%)	FA (B × %)	SAP (B × %)	SP (B × %)
Plain	20	20	0.5	0	0.5 ~ 1.0
0.25-10				0.25	
0.5-16				0.50	
0.75-22				0.75	
1.0-28				1.00	

Table 9: AC-based cement composite material mix

Type (SAP-eW)	W/B (%)	Vs/Vm (%)	FA (B × %)	SAP (B × %)	SP (B × %)
Plain	10	20	0.5	0	0.5 ~ 1.0
0.25-10				0.25	
0.5-16				0.50	
0.75-22				0.75	
1.0-28				1.00	

Table 10: MC-based cement composite material mix

Type (SAP-eW)	W/B (%)	Vs/Vm (%)	Binder		FA (B × %)	SAP (B × %)	SP (B × %)
			P (Vol.)	M (Vol.)			
Plain	35	10	1	0.5	0.5	0	3
0.25-10						0.25	
0.5-16						0.50	
0.75-22						0.75	
1.0-28						1.00	

2.3. Experimental method

2.3.1. pH Characteristics

The pH was measured according to KS M 0011 “Method for measuring pH of aqueous solution”.

2.3.2. Moisturizing Properties

Moisture properties (moisture content) were evaluated in a constant temperature and humidity chamber in accordance with KS F 2459 “Test method for apparent density, moisture content, water absorption, and compressive strength of aerated concrete”.

2.3.3. Surface Roughness Characteristics

The surface roughness characteristics were measured with the surface roughness tester 0918 model used for smooth surfaces such as metal and compared with the specimens not mixed with FA.

3. Results and discussion

3.1. pH Characteristics

Figure 1 shows the measurement result of pH of cement composites according to the binder. The pH characteristics of Living Concrete panels were evaluated only for SAP 0.25% when W/B 35%, Vs/Vm 10%, and foaming agent 0.5%. The range satisfying the target flow and compressive strength was found to be usable up to SAP 0.5%, and the pH characteristics were evaluated accordingly. In all cases, the pH increased according to the age, and there was a tendency to converge at the age of 28 days. OPC converges to about pH 13, and AC converges to about 10-11. In addition, MC converged to about pH 9.

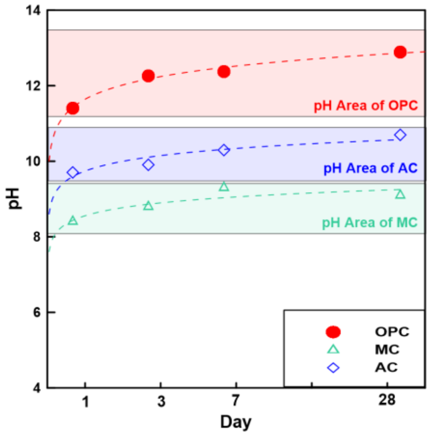


Fig. 1: Measurement result of pH of cement composites according to the binder.

3.2. Moisturizing Properties

Figure 2 to 4 shows the moisture content of cement composites according to the binder. The moisture content of the specimens was immersed in water for 24 hours. Thereafter, the moisture content over time was measured. Longer water content time means maintaining moisture retention.

The moisture content of Plain without SAP mixture was about 15% compared to the dry mass, and it decreased over time and was completely dried after 5 days When SAP was mixed, the moisture content was proportionally high as the mixing amount of SAP increased, and moisture retention was maintained for a longer time. The initial moisture content of SAP 0.25%, SAP 0.50%, SAP 0.75% and SAP 1.00% was about 20%, 25%, 30%, and 40%. These results are considered to be due to the material properties of SAP. In addition, in the case of MC, at the time of complete drying, the moisture retention time of MC-Plain, SAP 0.25%, SAP 0.50%, SAP 0.75%, and SAP 1.00% is about 5 days, 6 days, 8 days, 10 days, It was 12 days. Therefore, it is judged that the moisturizing property is increased for at least 2 days to a maximum of 7 days by the SAP effect. The difference between OPC and AC is not significant, so it is judged that the moisture retention is more dominant to SAP than to the effect of the binder.

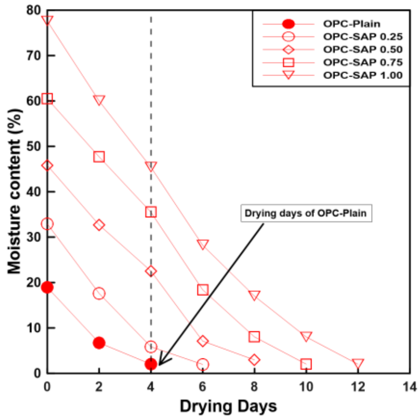


Fig. 2: Evaluation result of moisture content (OPC).

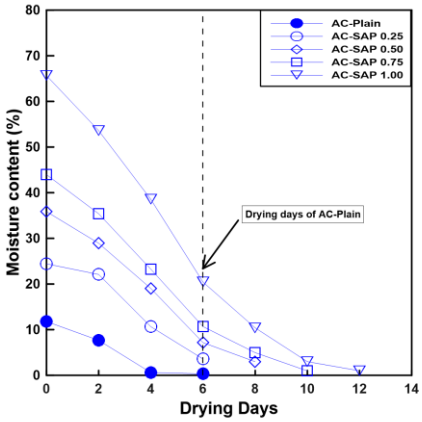


Fig. 3: Evaluation result of moisture content (AC).

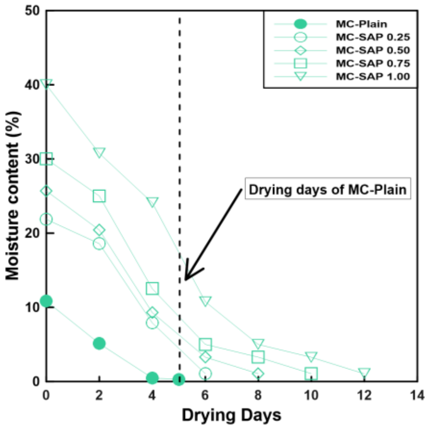


Fig. 4: Evaluation result of moisture content (MC).

3.3. Surface Roughness Characteristics

The surface roughness characteristics were evaluated for 3 levels (0, 0.25, and 0.50%) of the foaming agent mixing ratio according to W/B 35%, Vs/Vm 10%, and SAP 0.25%. Figure 5 shows the result of measuring the depth of pores generated on the surface, whereas Figure 6 shows the area ratio of pores on the surface. Figure 7 also shows the pore distribution diagram. In the range satisfying the target flow and compressive strength, up to 0.5% of the foaming agent can be used, so 0.75 and 1.00% of the foaming agent usage were excluded. In addition, since the surface morphology of OPC and AC was similar, the roughness was evaluated by limiting to MC. Compared to the case in which the foaming agent was mixed, Plain without a foaming agent had relatively fine pores, and the ratio of the pores to the total surface area was about 1%. Compared with Plain, the total proportion of pores on the surface was analyzed to be about 20% for FA 0.25 and about 30% for FA 0.50%. The average depth of pores in MC-Plain was about 0.2 mm, and the maximum was observed to be about 1 mm. In the case of FA 0.25%, the average pore depth was about 0.5 mm, and a maximum pore depth of about 2 mm was observed. In addition, in the case of FA 0.5, the average pore depth was about 1.5 mm, and a pore depth of up to 4 mm was observed.

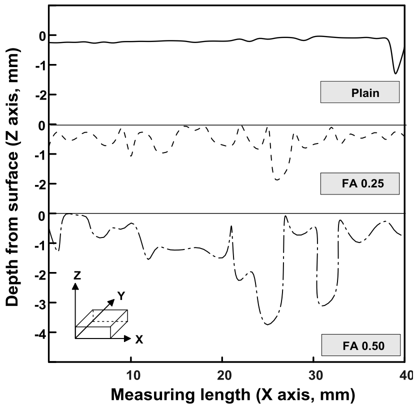


Fig. 5: Measurement result of surface pore depth.

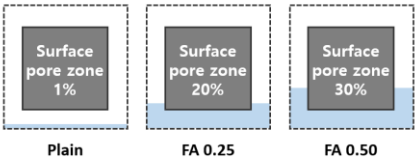
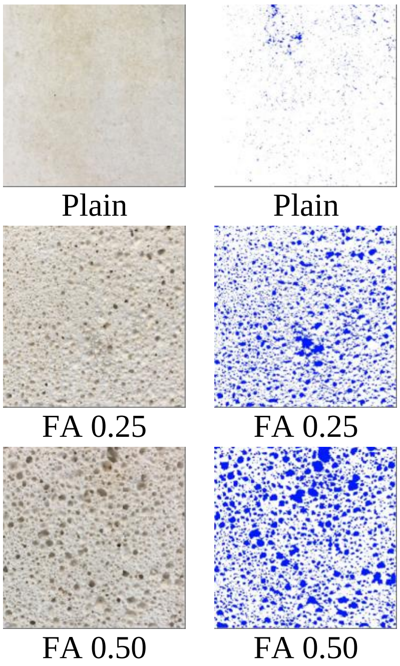


Fig. 6: Area ratio of surface pores.



Plain Plain

FA 0.25 FA 0.25

FA 0.50 FA 0.50

Fig. 7: Form of pore distribution by surface photography and imaging processing.

4. Conclusion

In this study, a cement composite was prepared based on common Portland cement, alumina cement, and magnesia cement, which are applicable binders, as the base material for living concrete panels, and the bioreceptivity was evaluated. The evaluation of bioreceptivity evaluated pH, moisturizing performance, and surface roughness, and the following conclusions could be obtained.

1. As a result of evaluating the pH characteristics according to the binder, OPC converges to about pH 13, and AC converges to about 10-11. Also, MC converged to about pH 9. These results are generally the same as the proven results. It is known that MC has a pH of 7 to 9 depending on the type of phosphate as a reaction material. Unlike general cement with a pH of 11 to 12 or higher, the base material itself is relatively close to the neutral region, so it is judged to be advantageous for bioreceptivity in the growth environment of living things.
2. As a result of evaluating the moisturizing properties according to the binder, there was no difference depending on the binder, and it is judged that the moisturizing property can be improved by using SAP. In addition, when moisture in the air and rain conditions are taken into consideration, it can be expected that the moisturizing effect will be improved. In addition, it is judged that it will have a positive effect on the moisture supply aspect of the organisms growing on the panel through the improvement of the moisturizing performance. However, an increase in the mixing amount of SAP leads to a decrease in compressive strength and durability. Therefore, it is judged that the optimal amount of SAP is preferably mixed with 0.25% and 0.5%.
3. As a result of the surface roughness characteristics according to the binder, the foaming agent can generate a large amount of pores larger than the micro size in the surface layer, and open pores are formed instead of closed pores. Accordingly, it is determined that moisture supply from the outside will be easy. In addition, by forming a relatively rough surface, it was possible to create environmental conditions in which organisms could easily take root.

Through the above results, when MC with low pH is used as a base material for living concrete panels, it is judged that it is suitable for the growth environment of living things, It is judged that it is desirable to mix the optimal amount of SAP to 0.5% or less to prevent deterioration of compressive strength and durability. In addition, it is judged that it is necessary to create an environmental condition in which a relatively rough surface is formed so that an organism can easily take root.

5. Acknowledge

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6. References

1. Cha, H. J. and Lim, J. H. (2011). The Effect of Urban Road Vegetation on a Decrease of Road Surface Temperature. *Journal of Korean Institute of Landscape Architecture*, 39(3), 107-116.
2. Chae, C. U. and Suh, C. H. (1994). Am Experimental Study on the Lightweight Precast Concrete Panel Development. *Proceeding of the Architectural Institute of Korea*, 14(1), 521-524.
3. Eggert, A., Haubner, N., Klausch, S., Karsten, U. and Schumann, R. (2006). Quantification of Algal Biofilms Colonising Building Materials: Chlorophyll a Measured by PAM-Fluorometry as a Biomass Parameter. *Journal of Biofouling*, 22(2), 79-90.

4. Favero-Longo, S. E., Castelli, D., Fubini, B. and Piervittori, R. (2009). Lichens on Asbestos-Cement Roofs: Bioweathering and Biocovering Effects. *Journal of Hazardous Materials*, 162(2-3), 1300-1308.
5. Guillitte, O. & Dreesen, R. (1995). Laboratory Chamber Studies and Petrographical Analysis as Bioreceptivity Assessment Tools of Building Materials, *Journal of Science of The Total Environment*, 167(1-3), 365-374.
6. Jeon, J. K., An, Y. S. and Kim, E. J. (2014). Performance Evaluation Study on Green-wall System Using Moss. *Magazine of the Korea Concrete Institute*, 26(3), 36-40.
7. Kim, J. H., Kang, S. P., No, H. N. and Lee, B. C. (2015). Characteristics and Application of Magnesia Phosphate Ceramic for Construction Materials. *Magazine of the Korea Concrete Institute*, 27(6), 57-62.
8. Kim, S. B., Kim, G. H. and Cho, J. H. (2001). The Urban Heat Island Phenomenon and Potential Mitigation Strategies. *Journal of Nakdong River Environmental Research Institute*, 6(1), 63-89.
9. Kim, T. H., Li, F. Q., Ahn, T. W., Choi, I. S. and Oh, J. M. (2011a). Research on Improvement of Water Purification Efficiency by Concrete using Bio Film. *Journal of Environmental Impact Assessment*, 20(6), 815-821.
10. Kim, Y. J., Kang, D. H. and Ahn, K. H. (2011b). Characteristics of Urban Heat-Island Phenomena caused by Climate Changes in Seoul, and Alternative Urban Design Approaches for Their Improvements. *Journal of the Urban Design Institute of Korea Urban Design*, 12(3), 5-14.
11. Lee, S. S., Kim, Y. G. and Choi, B. C. (2021). Study on Analysis and Property of Fine dust Adsorption Matrix for using Cork. *Journal of Next-generation Convergence Technology Association*, 5(5), 816-822.
12. Lee, J. S., Park, S. H., Kim, Y. S. and Shin, H. C. (2012). A Fundamental Experiment of the Artificial Soil Mixture using Stone Sludge Burning Pellet for Applying to Green Roof Soil. *Journal of the Korea Concrete Institute*, 24(2), 209-210.
13. Ma, H. and Xu, B. (2017). Potential to design magnesium potassium phosphate cement paste based on an optimal magnesia-to-phosphate ratio. *Journal of Materials and Design*, 118, 81-88.
14. Manso, S., Muynck, W. D., Segura, I., Aguado, A., Steppe, K., Boon, N. and Belie, N. D. (2014). Bioreceptivity Evaluation of Cementitious Materials Designed to Stimulate Biological Growth. *Journal of Science of The Total Environment*, 481, 232-241.
15. Myung, S. J. (2015). The Effect of Green Area in Urban Area on Mitigation of Urban Heat Island. *Proceeding of Korean Meteorological Society*, 2, 402-403.
16. Papida, S., Murphy, W. and May, E. (2000). Enhancement of Physical Weathering of Building Stones by Microbial Populations. *International Biodeterioration & Biodegradation*, 46(4), 305-317.
17. Park, E. H. and Oh, C. H. (2011). A study of CO_2 reduction effect by preventing heat island. *Proceeding of Korean Society of Environment and Ecology*, 21(1), 133-141.
18. Perini, K., Ottele, M., Haas, E. and Raiteri, R. (2011). Greening the Building Envelope, Facade Greening and Living Wall Systems. *Journal of Ecology*, 1(1), 1-8.
19. Rios, A., Camara, B., Cura, M. A. G., Rico, V. J., Galvan, V. and Ascaso, C. (2009). Deteriorating Effects of Lichen and Microbial Colonization of Carbonate Building Rocks in the Romanesque Churches of Segovia. *Journal of Science of The Total Environment*, 407(3), 1123-1134.