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# Fundamental Investigation of Functional Property of Concrete Mixed with Functional Materials

**Jong-Chan Lee[1], Moon-Hwan Lee[2], Sae-Hyun Lee[2], Young-Sin Park[3], and Jae-Myung Park[3]**

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**Abstract:** Environment-friendly materials are increasingly used as building construction materials nowadays, and the market share of those is growing. Accordingly, the research and developments in terms of environmental value are progressing steadily now. The main characteristics of environmental products are far-infrared radiation, negative-ion emission, electromagnetic wave shielding, and antimicrobial property. These products are often used in mortar and as spray on the finishing material. Nevertheless, there are hardly any research on the functional properties of concrete, the main material in construction field. Thus, we evaluated such basic properties of concrete as slump, compressive strength and air content while using such functional materials as sericite, wood-pattern sandstone, carbon black and nano-metric silver solution to focus on their functional properties like far-infrared radiation, negative ion emission, electro magnetic wave shielding, and antimicrobial activity in this research. The results indicated that the most useful material in the functional materials was carbon black. Sericite and nano-metric silver solution had a little effect on the functional property. Moreover, although wood-pattern sandstone had very high functional property, it exhibited too low compressive strength to be applied to concrete as a factory product. Antimicrobial property of nano-metric silver solution in the concrete was not clear demonstrated, but if these specimens were to be aged in $CO_2$ gas for a long time, it might be apparent.

**Keywords:** functional property, far-infrared, negative ion, electromagnetic wave, antimicrobial property

## 1. Introduction

The existing construction materials being mass-produced in factory have resulted in environmental hazardousness, and people have become aware of its direct harmful effect to the pubic health. Accordingly, the users are voicing their preference for the environment-friendly materials made of natural resources. Most of the construction material suppliers are now responding to this demand for environment-friendly materials to make them readily available in the market. Additionally, construction buildings over a certain size need to comply to systematic regulations, which impose some guidelines for environmentally sound practices as well as issuing some sort of certification for such compliance. For example, there have been some standards for the quality of air inside the construction structures to limit and restrict the use of construction materials, which might emit pollutants otherwise. Thus, these environment-friendly construction materials are taking its place as a new trend, and the market share for these will certainly continue to increase. Accordingly, it is only logical to develop the construction materials of environmental soundness.

The environment-friendly functionality of these products can be represented by far-infrared radiation, the emission of negative ions, shielding of electromagnetic waves, antimicrobial capacity, etc. These beneficial materials are then coated on the finishing mortar or the finishers to exert the effect.[2,4-6,8] However, the most typical and widely-used construction material is concrete, it is important to devise a method to produce functional concrete by adding the desired functionality to existing concrete. The reason that the functional construction material is restricted to the finishers is because the finish materials are the closest to the end users and can result in the most effect with a small amount of coating.

However, there may be some parts of the construction materials, which do not require finish materials, and exposed concrete may be given such functionality as well. Based on this perspective, this study applied materials, which can render such functionalities as far-infrared radiation, emission of negative ion, shielding of electromagnetic waves, and antimicrobial capacity to ordinary concrete, in order to evaluate the manifested performance of the concrete in response to various mix proportions of each functional material as an effort to investigate the practicality of using such functional materials in the production of concrete.

## 2. Experimental method

### 2.1 Overview

The experiment to evaluate the functional performance of the concrete mixed with functional materials was carried out by determining the mix proportional range for the mixing

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[1] KCI member, Building & Urban. Research Dept., KICT, Goyang 411-712, Korea. *E-mail: mcljc@korea.com*
[2] KCI member, Building & Urban. Research Dept., KICT, Goyang 411-712, Korea.
[3] R&D Team, Halla Concrete Corp., Seoul 138-734, Korea.

materials based on the preliminary test and related data. The preliminary test mix varied the mixing amount of the material replacing the cement by its proportional weight to the cement. The evaluated properties by each mix proportion involved such basic performance parameters as slump, air content, and compressive strength as well as the functional performance parameters of the emission of far-infrared ray, emission of negative ion, shielding of electromagnetic waves and antimicrobial activity. Here, the basic performance parameters refer to the expected performance characteristics of the concrete and were set to be within the range of 18 ± 2.5 cm and 4.5 ± 1.5% for slump and air content and above 26.6 MPa for the manifested compressive strength.

## 2.2 Materials used

### 2.2.1 Basic materials

(1) Cement

Ordinary Portland Cement was used pursuant to KS (Korean Industrial Standards) L 5201.

(2) Aggregate

Coarse aggregate of 2.62 g/cm$^3$ density and maximum grain size of 25 mm and fine aggregate of desalted sand of 2.6 g/cm$^3$ density were used as the aggregates.

(3) Air entraining high range water reducing agent

AE superplasticizer of polycarboxylic ether composition was used as the water reducing agent. Its specific gravity is 1.15 ± 0.02 without chlorides, and its recommended dose is 0.8~1.2%.

### 2.2.2 Functional materials

The functional materials were specifically selected for their known functionality in this study, and their material compositions were analyzed by XRD and XRF.

(1) Sericite

Sericite is used as the main material for pharmaceutical or cosmetic products and has the property of radiating far-infrared ray. It is mainly used in ceramic industry, and cement and mortar mixed with it have been developed. The density and specific surface area are 2.728 g/cm$^3$ and 18,180 cm$^2$/g, respectively, and it was processed by ball-milling before its use in this study. The XRD test revealed that the main phase and auxiliary phase were composed of calcium carbonate and quartz. The XRF analysis result is summarized in the following Table 2.

**Table 1** Materials for functional properties.

| Functional performance | Materials | Symbol |
|---|---|---|
| Far infrared radiation | Sericite | SE |
| Negative ion radiation | Wood-pattern sandstone | WS |
| Electro-magnenic wave shielding | Carbon black | CB |
| Anti fungus | Nanometric silver solution | NS |

**Table 2** Main ingredients of sericite.

| Ingredient | MgO | $Al_2O_3$ | $SiO_2$ | $K_2O$ | CaO | $TiO_2$ | $Cr_2O_3$ | $Fe_2O_3$ |
|---|---|---|---|---|---|---|---|---|
| Content (wt%) | 0.255 | 6.67 | 20.7 | 3.91 | 65.3 | 0.178 | 0.189 | 2.42 |

(2) Wood-pattern sandstone

Although there is no specific scientific name for it, it is called wood-pattern sandstone, for it resembles the annual ring of a tree. It is believed that it originated from China and is known to emit negative ions along with tourmaline and chlorite. The density of the material is 2,870 g/cm$^3$, and its specific surface area is 61,170 cm$^2$/g. It was also processed by ball-milling prior to its use in this experiment. The XRD analysis revealed that its main phase was composed of quartz, and its auxiliary phase consisted of calcite and muscovite. The result of XRF analysis is shown in the following Table 3.

(3) Carbon black

Carbon black is black or grayish black powder soot obtained from incomplete combustion of organic matters (hydrogen carbonate). Unlike simple carbon particles, its different composition makes it a useful conductor of electricity. It is very light with the density of 1.962 g/cm$^3$. The main phase as revealed by XRD analysis was, not surprisingly, carbon black. The analysis of XRF for its main composition is summarized as follows.

(4) Nano-metric silver solution

The silver particles of nano ($10^{-9}$ m) size are in colloid form at the concentration of 5 ppm. This colloidal solution was dried, and the resulting powder was subjected to XRF analysis to provide us its main composition.

### 2.2.3 Analysis of the property of functional materials

Among the ingredients of functional materials, aluminosilicate has the best emission of negative ions, and $SiO_2$ or $Al_2O_3$ is known to take the lion's share of far-infrared radiation.[6,7] Thus, it can be inferred that most ceramics exhibit great emission of negative ions and far-infrared radiation. As it was indicated by the composition analyses, wood-pattern sandstone is composed mainly of 49.2% $SiO_2$, 14% $Al_2O_3$, and 9.2% CaO, and the main composition of sericite is 65.3% CaO, 20.7% $SiO_2$, and 6.67% $Al_2O_3$. Thus, although sericite is expected to exhibit greater negative ion emission and far-infrared radiation, this study selected wood-pattern sandstone and sericite as the functional material for negative ion emission and far-infrared radiation property, respectively. Because carbon black consists of carbon mostly, it is believd to possess great conductivity for electricity. Additionally, the nano-metric silver solution was analyzed to possess 87.1% of silver (Ag).

**Table 3** Main ingredients of wood-pattern sandstone.

| Ingredient | $Al_2O_3$ | $SiO_2$ | $P_2O5$ | $K_2O$ | CaO | $Fe_2O_3$ | $ZrO_2$ | $La_2O_3$ | $CeO_2$ | $Nd_2O_3$ |
|---|---|---|---|---|---|---|---|---|---|---|
| Content (wt%) | 14 | 49.2 | 1.64 | 7.77 | 9.2 | 2.86 | 1.17 | 2.71 | 5.62 | 2.1 |

**Table 4** Main ingredients of carbon black.

| Ingredient | $Al_2O_3$ | $SiO_2$ | $SO_3$ | CaO | $Fe_2O_3$ | ZnO | C |
|---|---|---|---|---|---|---|---|
| Content (wt%) | 0.03 | 0.06 | 0.41 | 0.01 | 0.04 | 0.02 | 99.5 |

**Table 5** Main ingredients of nanometric silver.

| Ingredient | Na | Mg | Al | S | Fe | Ag |
|---|---|---|---|---|---|---|
| Content (wt%) | 6 | 0.162 | 0.899 | 2.66 | 3.07 | 87.1 |

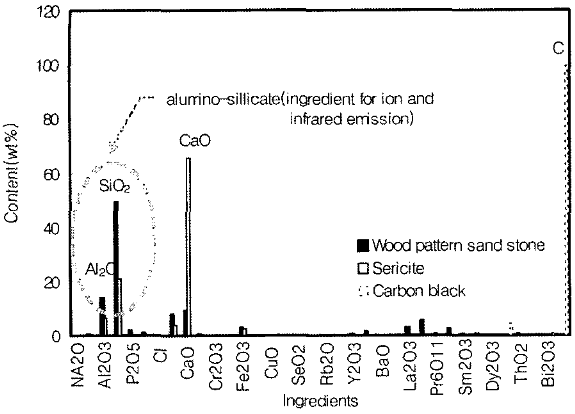


**Fig. 1** main ingredients of functional powder.

## 2.3 Mix design

This experiment added functional materials by the weight to the cement, and the replacement ratios varied carbon black by 2, 4, 6% for the shielding of electromagnetic waves, sericite by 10, 20, 30, 40% for far-infrared radiation, wood-pattern sandstone by 5, 10, 15, 20% for negative ion emission, and nano-metric silver solution by 1 kg/m$^3$, 2 kg/m$^3$, and 3 kg/m$^3$ for antimicrobial (antifungal) activity.

## 2.4 Test method

### 2.4.1 Basic performance test

(1) Slump

The slump test for the test specimen followed KS F 2402 (method of test for slump of concrete).

(2) Air content

The air content was measured by Washington-type air meter of 10% error range in accordance with KS F 2421 (method of test for air content of fresh concrete by pressure method).

(3) Compressive strength

The test specimens were fabricated pursuant to KS F 2403 (method of making and curing concrete specimens). The specimen was taken out of the mold after one day and then was wet-cured at 20 ± 3°C. Following KS F 2405 (method of test for compressive strength of concrete), the compressive strength of the specimens was measured at 7 and 28 days of age using UTM of 100 kN.

### 2.4.2 Functional test

(1) Far-infrared radiation measurement test

When fabricating the specimen, 5 mm sieve was used to pick out coarse aggregate, and the specimen consisted of mortar only. Its dimension was 40 × 40 × 3 mm. It was wet-cured for two weeks and then air-cured at 20 ± 3°C and RH of 60 ± 5% for another two weeks. Then, FT-IR (Fourier Transform Infrared Spectrometer) was used to measured the radiation energy and radiation rate against black body at 40°C.[1]

(2) Negative ion measurement test

Four rectangle test specimens of 300 × 50×5 mm dimension were fabricated from the mortar with the coarse aggregate strained out of 5 mm sieve. They were wet-cured for two weeks and then air-cured at 20 ± 3°C and RH of 60 ± 5% for another two weeks. Then, the baseline negative ion emission inside an empty chamber of 1 m$^3$ was measured with a negative ion emission measuring device, KOBE DEMPA KSD 900. Then, the four specimens were placed around the four corners of the probe of the negative ion emission measuring device (indicator) to measure the amount of negative ion emission.[1]

(3) Electromagnetic wave shielding test

After the concrete specimen of 600 × 500 × 50 mm dimension was fabricated, it was wet-cured for two weeks and air-cured at

**Table 6** Mixing proportion.

| Property | Replacement rate of cement (wt%) | | W/B (%) | s/a (%) | Unit weight(kg/m$^3$) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | W | C | RM** | S | G |
| Plain | None | | 50.7 | 47 | 175 | 345.0 | 0.0 | 812 | 923 |
| Electro magnetic wave | CB | 2 | | | 175 | 338.1 | 6.9 | 812 | 923 |
| | | 4 | | | 175 | 331.2 | 13.8 | 812 | 923 |
| | | 6 | | | 175 | 324.3 | 20.7 | 812 | 923 |
| Far infrared emission | SE | 10 | | | 175 | 310.5 | 34.5 | 812 | 923 |
| | | 20 | | | 175 | 276.0 | 69.0 | 812 | 923 |
| | | 30 | | | 175 | 241.5 | 103.5 | 812 | 923 |
| | | 40 | | | 175 | 207.0 | 138.0 | 812 | 923 |
| Negative ion emission | WS | 5 | | | 175 | 327.8 | 17.3 | 812 | 923 |
| | | 10 | | | 175 | 310.5 | 34.5 | 812 | 923 |
| | | 15 | | | 175 | 293.3 | 51.8 | 812 | 923 |
| | | 20 | | | 175 | 276.0 | 69.0 | 812 | 923 |
| Anti fungus | NS* | 1 | | | 175 | 345.0 | 1.0 | 812 | 923 |
| | | 2 | | | 175 | 345.0 | 2.0 | 812 | 923 |
| | | 3 | | | 175 | 345.0 | 3.0 | 812 | 923 |

*Added mass(kg/m$^3$)
**Replaced material content

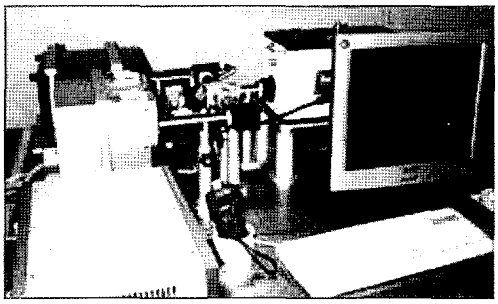


**Fig. 2** Far-infrared indicator.[9]

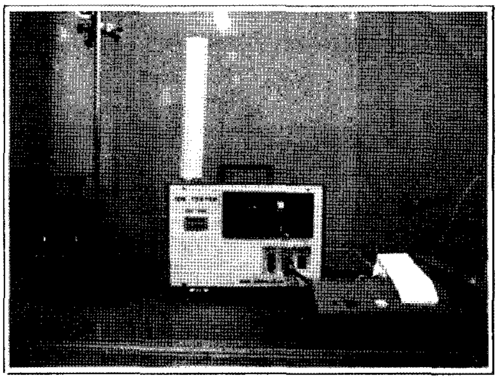


**Fig. 3** Negative ion indicator.[9]

20 ± 3°C and RH of 60 ± 5% for another two weeks. Then, the specimen was placed 30 cm away from the source$^4$ of electromagnetic wave of 100 V/m. A German electromagnetic wave measuring device of EFA-300 was placed in a electromagnetic shield box to measure the filtered electromagnetic wave of 60 Hz.

(4) Antimicrobial (antifungal) test

As aforementioned, the mortar, which removed coarse aggregate with 5 mm sieve during concrete fabrication, was used to prepare a platelike test specimen of 50 × 50 × 5 mm dimension. It was then wet-cured for two weeks and air-cured for one week at 20 ± 3°C and RH of 60 ± 5%. Furthermore, the specimen was neutralized with 10% $CO_2$ gas for one more week at the same condition of 20 ± 3°C and RH of 60 ± 5%. Finally, the test specimen was incubated with five kinds of mixed microbes, Aspergillus niger, Penicillium pinophilum, Chaetomium globosum, Gliociadium virens, Aureobasidium pullulans for weeks during which the growth of the bacteria culture was carefully observed.

## 3. Experimental results and analysis

### 3.1 Result of basic performance test

The result of measuring basic performance test for the functional concrete is summarized in the following Table 7. As aforementioned, slump, air content, and compressive strength were measured. Here, the additives were controlled for the dose so that the amount of additives would fall within the target range of slump and air content.

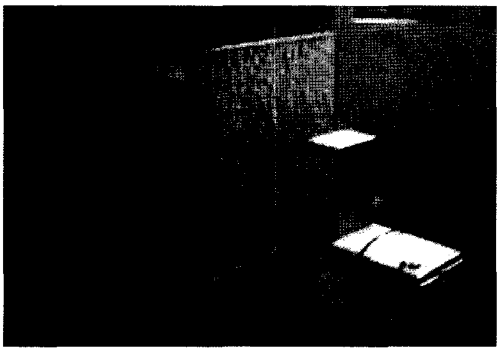


Fig. 4 Electromagnetic wave measuring equipment.

Table 7 Basic performance test results.

| Type | | Compressive strength(MPa) | | Slump (cm) | Air content (%) | HRWRA (%) |
|---|---|---|---|---|---|---|
| | | 7days | 28days | | | |
| Plain | | 22.3 | 29.3 | 190 | 3.8 | 0.7 |
| CB | 2 | 16.0 | 19.1 | 195 | 4.2 | 0.7 |
| | 4 | 18.1 | 23.9 | 185 | 3.4 | 0.7 |
| | 6 | 15.4 | 27.7 | 175 | 3.4 | 1.0 |
| SE | 10 | 17.1 | 27.0 | 190 | 4.1 | 0.7 |
| | 20 | 16.5 | 20.2 | 185 | 4 | 0.7 |
| | 30 | 12.3 | 17.7 | 185 | 3.7 | 0.9 |
| | 40 | 8.7 | 11.5 | 170 | 3.2 | 1.0 |
| WS | 5 | 20.9 | 21.5 | 190 | 3 | 0.7 |
| | 10 | 18.4 | 20.5 | 195 | 3.1 | 0.7 |
| | 15 | 18.9 | 22.4 | 185 | 3.9 | 0.9 |
| | 20 | 16.9 | 21.3 | 180 | 4.4 | 1.0 |
| NS | 1 | 21.1 | 26.4 | 190 | 3 | 0.7 |
| | 2 | 19.8 | 23.0 | 190 | 3 | 0.7 |
| | 3 | 17.7 | 19.3 | 200 | 3.3 | 0.7 |

### 3.1.1 Slump

As shown in Fig. 5, slump was satisfactory to fall within the target range of 180 ± 2.5 cm with the addition of high-performance AE water-reducing agent at the dose between 0.7~1%. However, as the replacement rate of functional materials increased, slump started to decrease even though the dose of high-performance AE water-reducing agent increased. Thus, it is construed that functional materials affect the slump of the concrete negatively. This can be explained by the fact that carbon black is of light and multi-porous material and that sericite or wood-pattern sandstone has so high fineness that it increases viscosity and moisture absorption. On the other hand, the increase in slump with the addition of more nano-metric silver solution can be explained by the fact that the water content increases with addition of more nano-metric silver solution.

### 3.1.2 Air content

All the air content of the concrete mixed with all functional materials satisfied the target range of 4.5 ± 1.5% as shown in Fig. 6. This is because the air content like the aforementioned case for slump was controlled with the addition of high-performance AE water-reducing agent. Examining the result of air content measurement by the addition of functional materials,

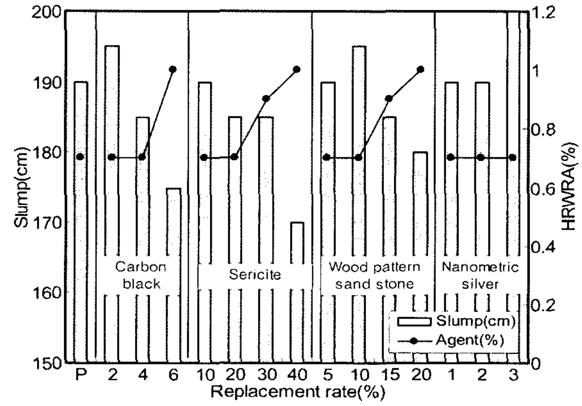


Fig. 5 Slump test result and replacement rate of the additives.

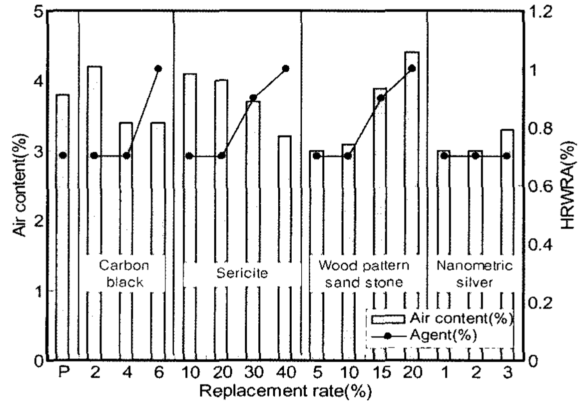


Fig. 6 Air content test result and replacement rate of the additives.

the air content was lowered as the replacement rate of carbon black and sericite increased even though more high-performance AE water-reducing agent was added. On the contrary, the air content of the concrete showed an increasing trend with the addition of wood-pattern sandstone. Moreover, the air content also increased as more nano-metric silver solution was added regardless of the dose of high-performance AE water-reducing agent.

### 3.1.3 Compressive strength

The compressive strength of the standard (plain) concrete at seven days was measured at 22.3 MPa as shown in Fig. 7. The concrete replaced with carbon black, sericite, wood-pattern sandstone, and nano-metric silver solution exhibited decreasing compressive strength of 18~15.3 MPa, 17~8 MPa, 20.0~16.9 MPa, and 21~17.7 MPa, respectively, at seven days with increasing replacement rate of each corresponding functional material. Of particular notice is that the concrete replaced with sericite exhibited the lowest strength at seven days, indicating that it is not advisable to use sericite for the case in need of earlier manifestation of the concrete strength.

The standard (plain) concrete exhibited the highest strength at 29.3 MPa at 28 days. The concrete replaced with carbon black, sericite, wood-pattern sandstone, and nano-metric silver solution exhibited compressive strengths of 27.7~19.1 MPa, 27~17.7 MPa, 22.4~20.5 MPa, and 26.4~19.3 MPa, respectively, at 28 days with various replacement rate of each corresponding functional material. Thus, when the target strength is set at or above 26.5 MPa, three concrete mixes replaced with 6% carbon black, 10% sericite, and 1% nano-metric silver solution satisfy this criterion. Fig. 8 shows the compressive strength at 28 days in relation to the replacement rate of each functional material. It can be seen that the compressive strength showed decreasing trend with increased replacement rate of sericite and nano-metric silver solution. On the contrary, the compressive strength of the concrete replaced with carbon black exhibited a steadily increasing trend as the replacement rate of carbon black increased. Finally, the compressive strength of the concrete replaced with wood-pattern sandstone remained about the same and varied between 21.3~22.5 MPa regardless of the replacement rate of wood-pattern sandstone in the concrete specimen.

## 3.2 Result of functional test

The result of the experiments to test the functional performance of the concrete mixed with functional materials is shown in Table 8. The tests involved far-infrared radiation, negative ion emission, shielding of electromagnetic waves, and antimicrobial activity.

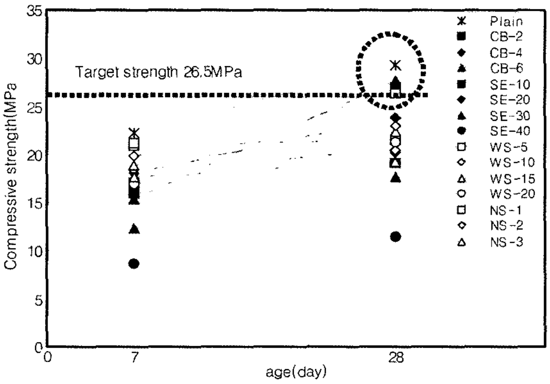


**Fig. 7** Compressive strength with elapsed time.

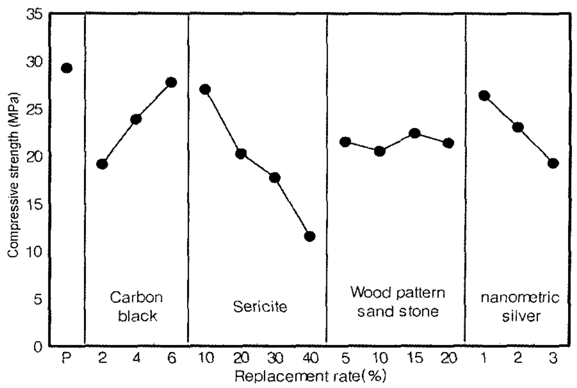


**Fig. 8** Compressive strength vs. replacement rate of functional materials.

### 3.2.1 Far-infrared radiation test

The far-infrared radiation test involved the ratio of the radiation energy of the specimen to the radiation energy of a black body at 40. As seen in Fig. 9 below, when the radiation energy of the standard (plain) concrete was 367 W/m$^2$, the

**Table 8** Functional property tests result.

| Property | | Electro magnetic wave (V/m) | Far infrared emission (%) | Negative ion emission (Ion/cc) | Anti fungus |
|---|---|---|---|---|---|
| Plain | | 101.5 | 0.911 | 79 | OK |
| CB | 2 | 75.2 | - | - | - |
| | 4 | 72.5 | - | - | - |
| | 6 | 45.7 | - | - | - |
| SE | 10 | - | 0.913 | - | - |
| | 20 | - | 0.914 | - | - |
| | 30 | - | 0.914 | - | - |
| | 40 | - | 0.916 | - | - |
| WS | 5 | - | - | 142 | - |
| | 10 | - | - | 226 | - |
| | 15 | - | - | 321 | - |
| | 20 | - | - | 381 | - |
| NS | 1g | - | - | - | OK |
| | 2g | - | - | - | OK |
| | 3 | - | - | - | OK |

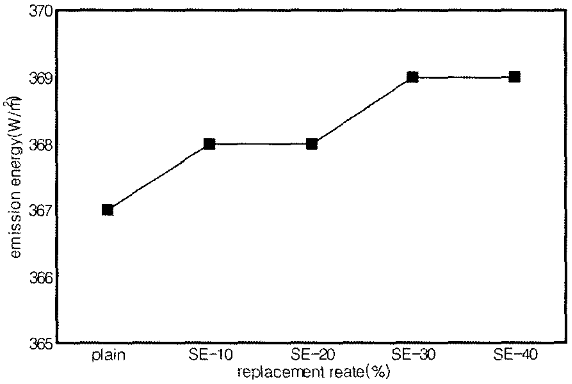


**Fig. 9** Emission energy of concrete with sericite.

radiation energy increased up to 369 W/m$^2$ as the mix proportion of the sericite increased.

When this is shown as the ratio to the radiation energy of a black body in Fig. 10 below, the radiation energy increased from 91.3% (the same as plain concrete) to 91.6% as the replacement rate of sericite increased. This means that the test range is within the effective range for far-infrared radiation in agreement with the previous research, which reported the effectiveness of far-infrared at or over the radiation ratio of 90%.

### 3.2.2 Negative ion emission test

The negative ion emission test first measures the number of ions inside the empty chamber of 1 m$^3$ and then takes the measurement of the number of negative ions emitted from the specimen inside the chamber. Thus, the latter measurement would include the number of negative ions inside the empty chamber. As seen in Fig. 11, while the standard (plain) concrete measured 79 negative ions per cm$^3$, the number of emitted negative ions increased to the maximum of 381 ions per cm$^3$ as the replacement rate of wood-pattern sandstone increased. The target negative ion emission was set at 200 ions per cm$^3$ in consideration of the street tree area or the garden city area. This target was met with 10% replacement rate of wood-pattern sandstone. Thus, it is determined that wood-pattern sandstone is effective in negative ion emission conducive to environmental functionality.

### 3.2.3 Electromagnetic wave shielding test

The electromagnetic wave shielding test involves measuring the electromagnetic wave (in unit of V/m) after the electromagnetic wave of 100 V/m generated from the electromagnetic wave source[4] passes through the concrete test specimen. As seen in Fig. 12, it was measured at 101 V/m for the case of standard (plain) concrete, reflecting that there was no shielding of the electromagnetic wave. However, this value was reduced to the fullest of 45.7 V/m as the replacement rate of carbon black for the concrete increased. Computing this shielding rate in relation to the plain concrete, it means 55% shielding rate for the electromagnetic wave when carbon black replaces the cement by 6% of the weight.

### 3.2.4 Antimicrobial (antifungal) test

Antimicrobial function test was carried out by culturing five kinds of microbes for four weeks, and then the degree of bacterial growth around the test specimen was visually inspected. The results shown in Fig. 13 indicate that both plain

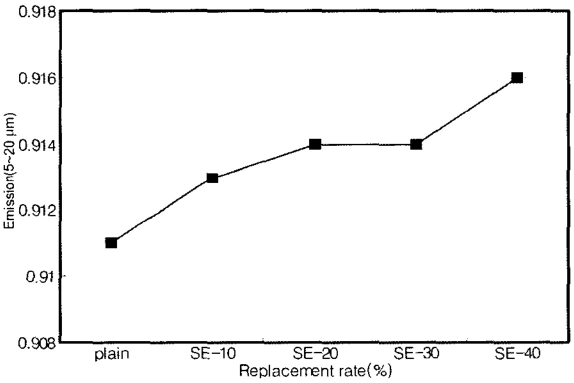


**Fig. 10** Emission rate of concrete with sericite relative to black body.

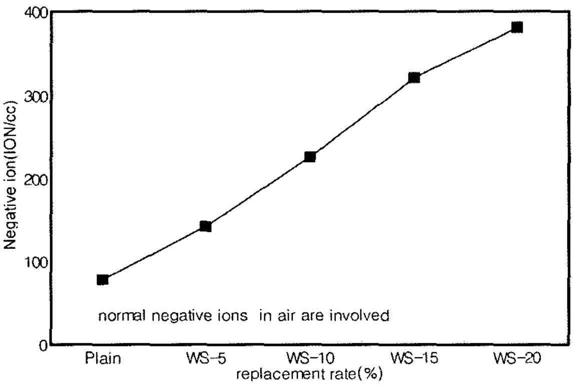


**Fig. 11** Number of negative ion emission from concrete mixed with wood-pattern sandstone.

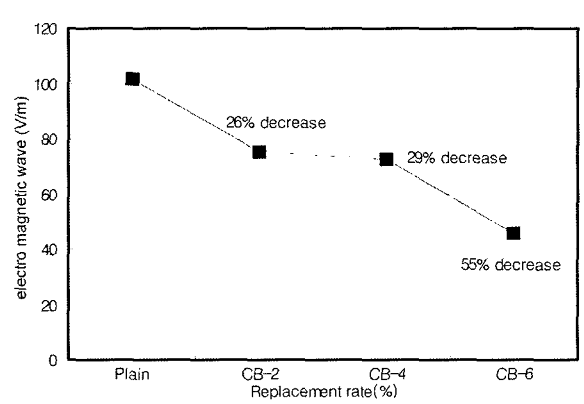
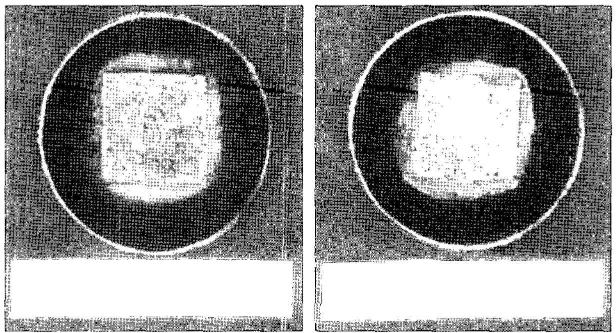
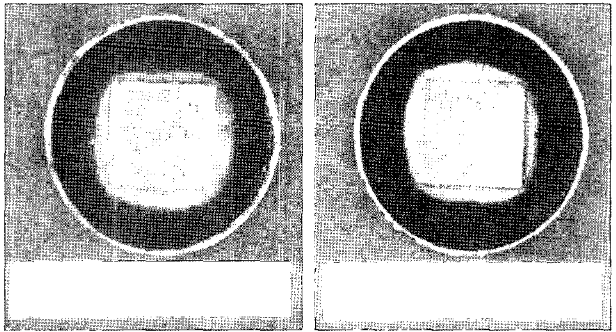


**Fig. 12** Electromagnetic wave shielding rate of concrete mixed with carbon black.



(a) Plain concrete

(b) Concrete in 1 kg/m$^3$ siver solution



(c) Concrete in 2 kg/m$^3$ silver solution

(d) Concrete in 3 kg/m$^3$ silver solution

**Fig. 13** Antimicrobial (antifungal) test result of the concrete treated with nano-metric silver solution.

concrete and concrete mixed with nano-metric silver solution did not exhibit apparent growth of the bacteria near the specimen. However, it was noted that, while the bacteria spread very close to the specimen of plain concrete, there was a definite borderline around the concrete specimen mixed with nano-metric silver solution, across which the bacteria could not infiltrate. Thus, it is believed that nano-metric silver solution possess some degree of effect to deter the infiltration of bacteria. The reason that bacteria did not grow in all cases is because concrete is of high alkaline to make it almost impossible for the bacteria to grow.[3] Thus, this experiment had the specimen subjected to 10% $CO_2$ gas treatment for a week to neutralize the high alkalinity. Nevertheless, it is believed that this neutral-ization method failed from the fact that plain concrete also had deterred the infiltration of the fungus. Therefore, it is construed that the antimicrobial (antifungal) function test of the concrete requires longer time for the neutralization to take effect.

## 4. Conclusions

The following conclusions are obtained from the result of experiments evaluating the basic performance property and functionality of the concrete mixed with functional materials.

1) The basic performance tests for slump, air content, and compressive strength of the test specimen by the controlled addition of the additives set the target ranges of $18 \pm 2.5$ cm for slump, $4.5 \pm 1.5\%$ for air content, and at or over 26.5 MPa for compressive strength. The four mixes, which satisfied these target ranges, were plain (standard) concrete mix and the concrete mixes with 6% carbon black, 10% sericite, and 1% nano-metric silver solution.

2) The result of far-infrared radiation test indicated that the plain concrete specimen exhibited 91.1% radiation energy compared to that of a black body. The concrete mixed with sericite showed the trend of increasing far-infrared radiation energy between 91.3% and 91.6% of a black body as the replacement rate of sericite increased from 10% to 40%. Thus, it is construed that sericite has some, but not markedly, positive effect on the far-infrared radiation.

3) The result of negative ion emission test revealed that plain concrete had 79 emitted negative ions per $cm^3$. The concrete replaced with wood-pattern sandstone showed the trend of increasing number of negative ion emissions from $142/cm^3$ to $381/cm^3$ as its replacement rate increased from 5% to 20%.

4) The result of electromagnetic wave shielding test indicated that the plain concrete exhibited 101.5 V/m of electromagnetic wave. The concrete replaced with carbon black manifested a decreasing trend from 75.2% to 45.7% compared to the baseline of 101.5 V/m as its replacement rate increased from 2% to 6%.

5) The result of antimicrobial (antifungal) function test revealed that all specimens of the plain concrete and the concrete replaced with 1~3% nano-metric silver solution deterred the infiltration of the fungus near the specimens, thus proving excellent antimicrobial capability. Nevertheless, it should be pointed out that, while the fungus infiltrated fairly near the specimen of plain concrete, the fungus could not grow past a certain distance near the specimen treated with nano-metric silver solution. Thus, it is anticipated that the distinction of antimicrobial capability between plain concrete and the concrete treated with nano-metric silver solution will become clearer as the test period is lengthened to a long-term.

6) The functional material the most appropriate for the use in concrete was found to be carbon black. Sericite and nano-metric silver solution showed only a minute increase in functionality of the concrete, making them somewhat inappropriate to apply to concrete. Additionally, although the concrete mixed with wood-pattern sandstone exhibited excellent functionality of negative ion emission, it also resulted in too low strength to make it a possible material for light-structure or to be used as product(non-structural concrete or factory product) only.

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