- Technical Paper -

PROPERTIES OF MORTAR INCORPORATING SPENT COFFEE GROUNDS COATED WITH WATER REPELLENT

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ABSTRACT

As the amount of spent coffee grounds(SCG) generated after manufacturing coffee increases, a treatment plan is needed. Therefore, this study examined the properties of mortars incorporating SCG with and without water repellent coating. Results showed, the compressive strength, density and absorption ratio of a mortar incorporating water-repellent coated spent coffee grounds were improved. However, additional research is needed to reduce the W/B due to the separation of the surface layer and the deep layer of the test specimen and the destruction of the specimen.

Keywords: spent coffee grounds, water repellent, mortar, compressive strength, absorption ratio

1. INTRODUCTION

Disposal of domestic waste and industrial by-products is one of the serious social problems, and recycling can play an important role in solving national issues such as depletion of natural resources, greenhouse gas problems, and climate change. In this regard, Kajiwara, N., Uehara, T. and Saito, K. used rice hull ash, an industrial by-product, to examine the characteristics of concrete and its applicability as a concrete admixture[1]. Domestic waste includes various things such as food waste and clothing that we commonly encounter. Among them, spent coffee grounds (SCG), a part of food waste, is increasing every year[2]. SCG is a by-product left over from making coffee, and is often referred to as ‘spent coffee grounds’. In addition, about 15g of coffee beans are used to make a cup of Americano, of which only 0.03g (0.2%) of the coffee beans are eaten and 14.97g (99.8%) of the coffee beans are discharged as SCG. Methods for treating emitted SCG include recycling, landfill, and incineration. However, if SCG cannot be recycled, enormous social costs are incurred and discarded. To recycle SCG as a construction building material, a number of studies have been conducted on mixing SCG with cement or developing geopolymers[3-12].

Kua et al. verified that undried SCG has low utility as a resource that can replace coarse soil similar to existing fine aggregate [9]. In addition, Arulrajah et al. also found that SCG as a building material is highly organic and has a high moisture content of 125 to 130 (%) in undried SCG, which affects strength and requires appropriate treatment if mixed with cement[8].

In order to improve the usability of SCG, Charai et al. used SCG that had been dried (65 °C to 75 °C) to improve thermal insulation properties for secondary products such as wall screeds or bond coatings. In addition, because SCG has a fine porous structure, it is effective in thermal conductivity and acoustic insulation. The dried SCG was replaced by up to 40% of the cement weight and the thermophysical properties were examined. As a result, as the replacement ratio of SCG increased, the thermal conductivity decreased, resulting in excellent thermophysical properties. In addition, studies also showed the SCG can be potentially used as a replacement of up to 30% of the cement weight, however, further research is required[4].

Na, S., Lee, S. and Youn, S. studied the compressive strength characteristics of mortar by using SCG that had undergone a high-temperature drying process (100 ℃). As a result, the compressive strength decreased with the addition of 5% or more of SCG relative to the cement weight. In addition, as the highest compressive strength was derived from 1% of SCG relative to the cement weight, it was concluded that the SCG addition rate above the critical value could hinder cement hydration due to lack of moisture inside the cement[3].

Choi et al. induced the hydration reaction of cement using SCG_Ash through a high-temperature carbonization (800 ℃) process, and as a result, more hydration products were produced than SCG dried at high temperature, and the compressive strength was also improved. However, this process has the potential to hinder carbon neutrality, which is being promoted globally, due to carbon emissions from incineration. Therefore, in order to reduce carbon emissions, treatment through a method other than the high-temperature carbonization method is required[12].

Typically for the materials with high absorption ratio, a water repellent is used to reduce or block water absorption. Water repellents are divided into penetration

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type water repellents and film type water repellents. The penetrating water repellent agent penetrates the inside of the material and hardens to exhibit a water repellent effect. The film-type water repellent is hardened by water-repellent coating the surface of the material to show a water repellent effect. In addition, the film-type water repellent agent not only has a superior water-repellent effect than the penetrating-type water repellent agent, but also has an excellent anti-fouling effect on the inside.

In this regard, Lee, B. J., Kim, K. H. and Kim, Y. Y. examined the effect of the type of water-repellent coating material and application method on the absorption ratio of recycled fine aggregate in waste concrete. For this purpose, four types of water repellents were used. Among them, the effect of the water repellent consisting mainly of acrylic resin was excellent. Based on this, the recycled fine aggregate in waste concrete was water-repellent coated, and a test matrix was fabricated and the compressive strength was measured. As a result of the study, the compressive strength of the specimen using the water-repellent coated recycled fine aggregate in waste concrete was higher than that of the specimen using the water-repellent uncoated recycled fine aggregate in waste concrete[13]. However, there is no study using SCG as a water-repellent coating. Therefore, it is suggested that the SCG can be used as a building material if the surface of SCG having a high moisture content is water-repellent coated and used.

This study aims to examine the properties of mortar replaced for Coated Spent Coffee Grounds (C-SCG) whose surface is water-repellent coated using a water repellent instead of carbonization.

2. EXPERIMENTAL PLAN AND METHOD

2.1 Outline

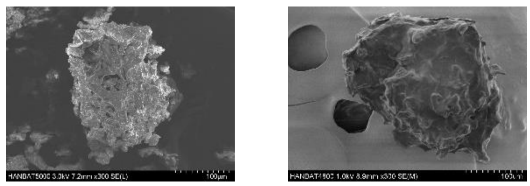
In order to examine the effects of water-repellents on mortar containing SCG with and without water-repellent coating, the ranges of W/B, SCG, and C-SCG replacement rates were selected as shown in Table 1 in accordance to the previous studies [12]. These parameters were set as a result of preliminary experiment showed that the mixing of composites with binder to fine aggregate ratio of 1:1, was not possible when the W/B was lower than 50% at the replacement rate of SCG of 12% or above. SCG used as a cement binder was dried at 50 ℃ for 5 days under similar conditions to the SCG used in previous studies [8,9,11]. This is to minimize the change and loss of excessive mass due to ignition loss of organic particles of SCG in the standard 100 ℃ drying process [8]. In addition, the reason why SCG is used as a cement substitute rather than fine aggregate is that some particles of spent coffee grounds mix with water to become coffee water, making it impossible to use it as fine aggregate.

Table 1 Experimental factors and levels

Experimental factors	Experimental levels	
Binder	SCG,OPC	C-SCG,OPC
Water repellent	-	Acrylic resin
Replacement ratio of SCG or C-SCG (%)	0, 3, 6, 9, 12	0, 3, 6, ,9, 12
Curing condition	Water curing	Water curing
Experimental items	Flow table, Compressive strength, Density, Absorption ratio	

2.2 Materials

For the synthesis of mortar, A ordinary portland cement (OPC) with a density of 3.15 g/cm^3 and a fineness of 3,200 cm^2 /g was used. SCG was collected from domestic coffee shops regardless of the type of beans and dried at 50 °C for 5 days as suggested in previous studies [8,9,11]. C-SCG was prepared by water-repellent coating of dried SCG. As shown in Table 2, the chemical composition of SCG consists mostly of potassium oxide and calcium oxide. C-SCG was used by coating the surface of dried SCG with a water repellent mainly composed of acrylic to prevent absorption of blended water by the dried SCG. The specific gravity of the water repellent used is 1.00 to 1.02, the viscosity is 30 cps, the color is milky white, and the drying time is 25 to 45 min (based on 20 ℃). The bulk densities of dried SCG and C-SCG are 0.42 g/cm^3 and 0.47 g/cm^3, respectively. The specific surface area of SCG is 0.157 m^2/g. The particle size distribution is mostly composed of 0.15 to 0.6 (mm), as the residual amount is 11% on a 0.15mm sieve, 18.2% on a 0.3mm sieve, and 66.2% on a 0.6mm sieve. This is similar to most previous studies[5, 8, 9, 10, 11]. In addition, the SEM images (Fig.1) shows a significant difference between dried SCG and water-repellent coated C-SCG as the surface pores of C-SCG were significantly reduced compared to SCG. Fine aggregate with a density of 2.51 g/cm^3 and a fineness modulus of 2.61 was used.



(a) SCG (b) C-SCG

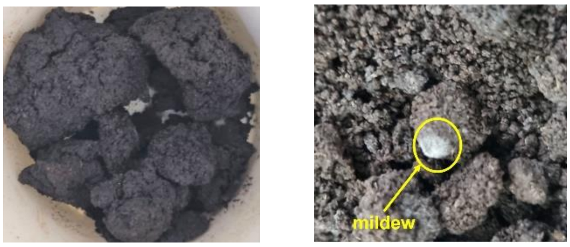
Fig.1 SEM image

Table 2 Chemical composition of SCG

Chemical composition (%)	SCG
K_2O	41.90
CaO	25.70
SO_3	13.00
P_2O_5	7.66
MgO	5.65
SiO_2	1.41
Fe_2O_3	1.36
Al_2O_3	0.49

2.3 Samples Synthesis Method

As mentioned in section 2.2, C-SCG is prepared by adding an acrylic water repellent to dried SCG. In order to select the optimal amount of water repellency, 80g, 120g, and 160g of acrylic water repellent were added per 100 g of SCG. As a result, when 160g of water repellent was used, excessive aggregation and mildew of C-SCG were confirmed as shown in Fig.2. On the other hand, when 80g, and 120g of acrylic water repellent were used, mildew and excessive agglomeration were not identified. Therefore, the appropriate amount of water repellent added was selected as 120g, which can maximize the amount of water repellent added and does not cause mildew or excessive aggregation. Finally, the C-SCG sample was prepared by adding about 120g of acrylic water repellent per 100g of SCG dried at 50 °C for 5 days. Afterwards, as shown in Fig.3, C-SCG was spread evenly on a wide flat plate and dried for more than 24 hours (temperature 20±2℃, humidity 60±5%). For the preparation of the specimen, the mortar replaced with SCG and the mortar replaced with C-SCG were prepared by weight mixing in consideration of the density of each raw material. Therefore, the mixture was designed as shown in Table 3 to examine the properties of the mortar containing dried SCG and water-repellent coated SCG (C-SCG).



(a) Clumping (b) Mildew

Fig.2 Clumping and mildew of C-SCG

(a) Material preparation (b) Mixing

(c) Sample dispersion (d) Dry

Fig.3 Manufacturing process of C-SCG

Table 3 Mix proportion of SCG and C-SCG mortar

Unit weight (kg)				
Type (SCG, C-SCG)	Water	Cement	SCG C-SCG	Fine aggregate
Plain	546.50	1,093.00	0.00	1,093.00
3%	546.50	1,060.21	32.79	1,093.00
6%	546.50	1,027.42	65.58	1,093.00
9%	546.50	994.63	98.37	1,093.00
12%	546.50	961.84	131.16	1,093.00

2.4 Experimental Method

The flow table was measured by lifting the mold filled with mortar by using equipment suggested by ASTM C 230 and referring to ASTM C 1437. For compressive strength, a samples were prepared using 40x40x160 (mm) mold in accordance with ISO 679 and cured in water. Then, the compressive strength was measured on the 28th day of age. For density and absorption ratio, water curing was performed for 28 days after preparing a test matrix using a 50x50x50 (mm) mold. Thereafter, the mass and density (wet state) of the specimen cured in water for 28 days were measured according to JIS A 1161. After the measurement, the specimen was dried in a dryer until it reached a certain mass, and the density (dry state) and absorption ratio were measured.

3. RESULTS AND DISCUSION

3.1 Flow Table

When the replacement ratio of SCG was increased from 0, to 12 (%), the flow table decreased from 155, to 87 (mm) as shown in Table 4, which is about 43% compared to Plain sample (SCG 0%). It is believed to be associated to absorption of blending water by dried SCG which in the composites.

C-SCG on the other hand increased the flow table from 155 to 250 (mm) as the amount of C-SCG was increased from 0 to 12 (%). Interestingly, this increase is about 61% compared to Plain (C-SCG 0%) sample. This is because the surface of C-SCG was coated with a water repellent and did not absorb the mixing water. In addition, it is considered that as the replacement ratio of C-SCG as a cement substitute increases, the amount of cement capable of absorbing the mixing water decreases and surplus water exists. Therefore, the flow table of the mortar in the presence or absence of the water-repellent coating of the spent coffee grounds showed a clear tendency to increase in the mortar using C-SCG compared to the mortar using SCG. However, flow table control requires readjustment of W/B because the blending water is excessively present the composites.

Table 4 Flow table

Type	mm	Type	mm
Plain	155	Plain	155
SCG 3%	114	C-SCG 3%	181
SCG 6%	97	C-SCG 6%	192
SCG 9%	95	C-SCG 9%	230
SCG 12%	87	C-SCG 12%	Above 250

3.2 Compressive Strength

The compressive strength when SCG was replaced was measured as 39.87, 32.10, 0.65, 1.11, and 1.67 (MPa), respectively, as shown in Fig.4, when the replacement ratio of SCG was 0, 3, 6, 9, and 12 (%). That is, the compressive strength decreased up to 6% at the replacement ratio of SCG, and the compressive strength increased slightly at the replacement ratio of SCG at 9%. However, the increase in compressive strength was insignificant, and it is judged that the compressive strength was actually developed up to 3% of the replacement ratio of SCG. In addition, when the replacement ratio of SCG was 3%, the compressive strength was developed up to about 80% compared to Plain (SCG 0%). However, the replacement ratio of SCG of 6, 9, and 12 (%) showed compressive strength of about 1 to 4 (%) compared to Plain. As shown in Fig.5, the specimens replaced with SCG up to 3% were close to the color of cement, similar to Plain with developed compressive strength. However, the colors of the test specimens with SCG replacement ratios of 6%, 9%, and 12%, which did not develop compressive strength, were similar to those of the SCG samples. Therefore, it can be seen as the same as the compressive strength result of the mortar replaced with SCG. It is believed that the cause of this strength loss is that chemical components containing organic impurities interfere with cement hydration, even though the spent coffee grounds have gone through a drying process. In addition, similar to previous studies, it is thought that SCG absorbed mixing water and hindered the cement hydration reaction due to insufficient moisture required for cement hydration [3].

In the case of substituting C-SCG, excessive mixing water was mixed during the production of the test specimen, and after the specimen was cured in water, surface separation and destruction were identified in all specimens replaced with C-SCG except for the plain specimen, as shown in Fig.6. Accordingly, it was judged that the compressive strength would be similar to that of mortar replaced with SCG. However, when the replacement ratio of C-SCG were 0, 3, 6, 9, and 12 (%), they were measured as 39.87, 35.19, 23.25, 0.67, and 0.93 (MPa), respectively, as shown in Fig.7. Compared to Plain (C-SCG 0%), as the compressive strength of C-SCG replacement ratio of 3 and 6 (%) was developed up to about 88 and 58 (%), it was improved compared to mortar replaced with SCG. It is considered that in the same W/B, as the surface of C-SCG is coated, the mixing water necessary for the cement hydration reaction is not absorbed and does not affect it, so that the hydration product is formed tightly inside. However, when the C-SCG replacement ratio is 9 or 12 (%), it is judged that the compressive strength was not developed due to the small amount of hydration product inside as the amount of cement required for the hydration reaction decreased in a state where the mixing water remained excessive. In addition to this, it is also determined that the compressive strength was not developed due to lack of moisture due to bleeding. Also, as shown in Fig.5, it can be seen that the internal colors of the specimens with C-SCG replacement ratios of 3% and 6% are similar to those of Plain with developed compressive strength. However, the color of the specimens with 9% and 12% C-SCG replacement ratios, which did not develop compressive strength, was similar to that of the C-SCG samples. This can be seen as the same as the compressive strength result, so the hydration reaction was judged by the appearance. Therefore, based on this, the compressive strength of the mortar was improved when C-SCG was used. However, due to excessive mixing, it is necessary to reduce the W/B so that the specimen surface is free of defects as shown in Fig.6.

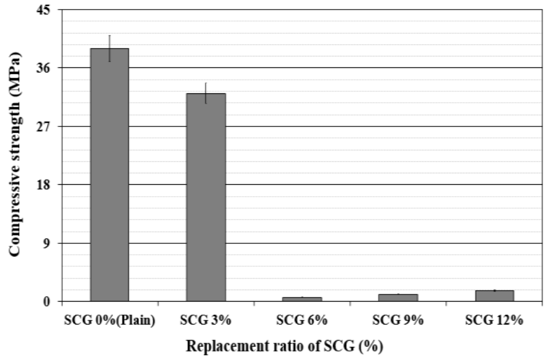
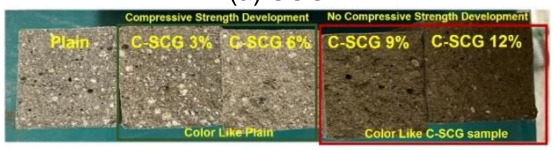


Fig.4 Compressive strength (SCG)

(a) SCG



(b) C-SCG

Fig.5 Internal state of specimens


(a) Surface destruction (b) Surface separation

Fig.6 Changes in the surface state of specimen (C-SCG)

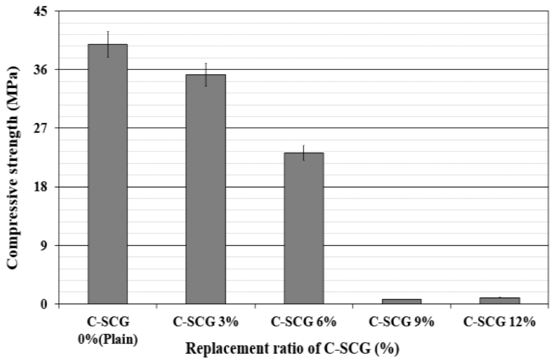


Fig.7 Compressive strength (C-SCG)

3.3 Density and Absorption Ratio

The wet density of the SCG-replaced mortar was 2.10, 2.01, 1.98, 1.99, and 1.98 (g/cm^3) from Plain, as shown in Fig.8. The dry state density was 1.92, 1.81, 1.66, 1.68, and 1.64 (g/cm^3) from Plain. In addition, the difference between the wet density of SCG replacement ratio of 0, 3, 6, 9, and 12 (%) and the dry density was 9.43, 9.95, 16.16, 15.57, 17.17 (%), and the replacement ratio of SCG ranged from 6% appeared distinctly. Absorption ratios were 9.42, 10.07, 16.04, 15.64, and 16.80 (%) from Plain. Similar to the density, there was no significant difference from Plain until the SCG replacement ratio was 3%, and there was a clear difference from Plain from the SCG replacement ratio of 6%. In addition, the increase in absorption ratio of SCG replacement ratio 3, 6, 9, and 12 (%) compared to Plain was 6.90, 70.27, 66.02, and 78.34 (%), and the absorption ratio increased rapidly from 6%. This is considered to be because there were more voids than hydration products inside the test specimen compared to Plain, moisture was filled in the voids, and moisture evaporated during drying. That is, the compressive strength was developed up to 3% of SCG replacement ratio, and the result is the same as the result of not developed compressive strength from 6% of SCG replacement ratio.

The wet density of the mortar replaced with C-SCG slightly decreased from Plain to 2.12, 2.05, 2.05, 1.96, and 1.88 (g/cm^3) as shown in Fig.9, but the decrease was insignificant. The dry state density decreased from Plain to 1.92, 1.83, 1.79, 1.60, and 1.50 (g/cm^3). In addition, the difference between the density in the wet state and the density in the dry state at the replacement ratio of C-SCG of 0, 3, 6, 9, and 12 (%) was 9.43, 10.73, 12.68, 18.36, and 21.11 (%), which was evident from 9%. Absorption ratios were 9.42, 10.69, 12.39, 18.37, 21.04 (%) from Plain, and, similar to density, a clear difference compared to Plain was observed from 9% of C-SCG replacement ratio. The increase in absorption ratio of C-SCG replacement ratio 3, 6, 9, and 12 (%) compared to Plain increased rapidly from 9% to 13.48, 31.52, 95.01, and 123.30 (%). This is the same as the result in which the compressive strength was developed up to 6% of the C-SCG replacement ratio and the compressive strength was not developed from 9%. In addition, the absorption ratio using C-SCG gradually increased compared to SCG. However, the absorption ratios of 9 and 12 (%) replacement ratio of C-SCG were derived higher than those when SCG was used. This is because in the range of 9% and 12% replacement ratio of C-SCG, which has not developed compressive strength, the specimen was destroyed and the surface of the specimen was separated as shown in Fig.6. That is, in the process of measuring the absorption ratio of the specimen replaced with C-SCG, the weight of the specimen decreased due to the destruction and surface separation of specimen, thereby influencing the higher absorption ratio to be derived.

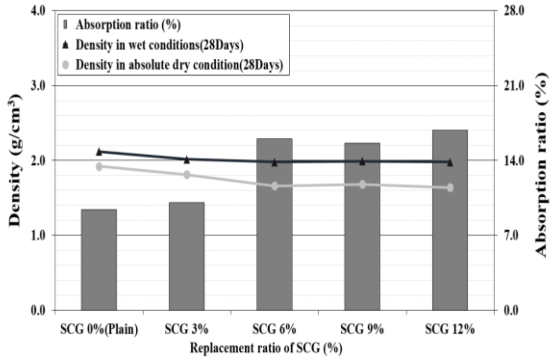


Fig.8 Density and absorption ratio (SCG)

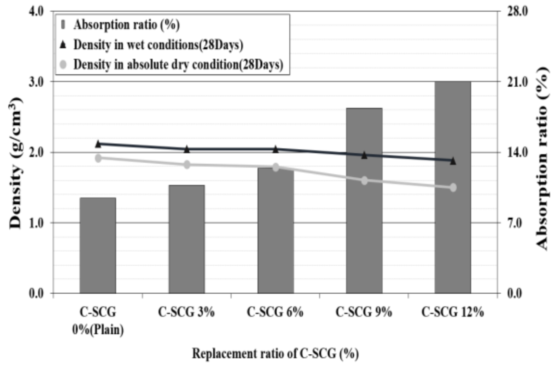


Fig.9 Density and absorption ratio (C-SCG)

4. CONCLUSIONS

In this study, the results of examining the physical properties of mortar replaced with C-SCG coated with water repellent are as follows.

(1) The flow table of SCG-replaced mortar decreased as the SCG-replaced ratio increased. Whereas, the flow table of the mortar replaced with C-SCG increased as the replacement ratio of C-SCG increased, but W/B needs to be readjusted because the mixing water is excessive. This is because the surface of C-SCG was coated with a water repellent and did not absorb the mixing water. In addition, as the replacement ratio of C-SCG, a cement substitute, increases, the amount of cement capable of absorbing the mixing water decreases, indicating that excess water exists.

(2) The compressive strength of mortars replaced with SCG decreased as the replacement ratio of SCG increased. Also, the compressive strength of mortars replaced with C-SCG decreased as the replacement ratio of C-SCG increased. However, the mortar with 6% C-SCG improved the compressive strength compared to the mortar with 6% SCG. It is considered that in the same W/B, as the surface of C-SCG is coated, the mixing water necessary for the cement hydration reaction is not absorbed and does not affect it, so that the hydration product is formed tightly inside.

(3) Density and absorption ratio were improved in mortars replaced with C-SCG compared to mortars replaced with SCG. In addition, based on the replacement ratio of SCG of 6%, the density of the

replacement ratio of C-SCG of 6% was high and the absorption ratio was derived low.

Therefore, based on the experimental results of this study, when the replacement ratio of C-SCG was used up to 6%, the compressive strength, density and absorption ratio performance was improved, confirming the possibility of using a water repellent coated SCG. However, additional research is needed on the properties of the mortar with reduced W/B due to the separation and destruction of the specimen surface.

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REFERENCES

[1] Kajiwara, N., Uehara, T. and Saito, K., "Characteristics of concrete mixed with unground rice husk ash," JCI., Vol.28, Jan.2017, pp.1-13.

[2] Nam, G., Kim, M. S. and Ahn, J. W., "Analyses for current research status for the coffee by-product and for status of coffee wastes in seoul," Journal of Energy Engineering., Vol.26, Dec. 2017, pp.14-22.

[3] Na, S., Lee, S. and Youn, S., "Experiment on activated carbon manufactured from waste coffee grounds on the compressive strength of cement mortars," Symmetry., Vol.13, Apr. 2021, pp.619-627.

[4] Charai, M. et al., "Thermophysical characteristics of cement-based mortar incorporating spent coffee grounds," Materials Today: Proceedings., Vol.57, Mar. 2022, pp.867-870.

[5] Le, T. T. et al., "Strength characteristics of spent coffee grounds and oyster shells cemented with GGBS-based alkaline-activated materials," Construction and Building Materials., Vol.267, Jan. 2021, pp.120986.

[6] Yun, B. Y. et al., "Circular reutilization of coffee waste for sound absorbing panels: A perspective on material recycling," Environmental research., Vol.184, May. 2020, pp.109281.

[7] Mierzwiński, D. et al., "Effect of coffee grounds addition on efflorescence in fly ash-based geopolymer," In IOP Conference Series: Materials Science and Engineering., Vol.416, Sep. 2018, pp.012035.

[8] Arulrajah, A. et al., "Compressive strength and microstructural properties of spent coffee grounds-bagasse ash based geopolymers with slag supplements," Journal of cleaner production., Vol.162, Sep. 2017, pp.1491-1501.

[9] Kua, T. A. et al., "Stiffness and deformation properties of spent coffee grounds based geopolymers," Construction and Building Materials., Vol.138, May. 2017, pp.79-87.

[10] Suksiripattanapong, C. et al., "Strength and microstructure properties of spent coffee grounds stabilized with rice husk ash and slag geopolymers," Construction and Building Materials., Vol.146, Aug. 2017, pp.312-320.

[11] Kua, T. A. et al., "Strength assessment of spent coffee grounds-geopolymer cement utilizing slag and fly ash precursors," Construction and Building Materials., Vol.115, Jul. 2016, pp.565-575.

[12] Choi, Y. S. et al., "Hydration Reaction and Strength Characteristics of Cement Mortar Mixed with Spent Coffee Ground," Journal of the Korean Recycled Construction Resources Institute., Vol.10, Mar. 2022, pp.15-22.

[13] Lee, B. J., Kim, K. H. and Kim, Y. Y., "Effects of Coating Materials and Application Methods on the Absorption Rate of Fine Aggregate Recycled from Waste Concrete," Journal of the Korea Concrete Institute., Vol.33, Jun. 2021, pp.307-314.