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Effects of carbon additives on heat-transfer and mechanical properties of high early strength cement mortar

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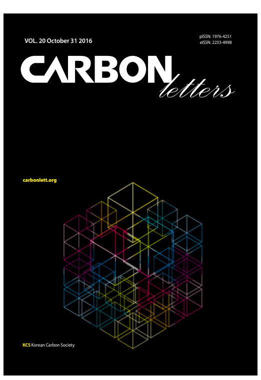

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The repair of mortar-based structures is critically important because mortar-based structures such as buildings, bridges, tunnels, highway and roads are inevitably degraded by deterioration or damage. To save expense during construction and to avoid traffic congestion during repair work, it is very important to reduce construction time as much as possible. In order to reduce construction time, therefore, the setting time of mortars has to be shortened. The mortars which have short setting times are called high early strength cement mortars. These high early strength cement mortars usually have a short working time of under 40 min and a compressive strength of over 24 MPa [1].

During the winter, mortar-based structures such as tunnels, bridges and roads typically use geothermal heat or internal heaters to protect them from freezing [2]. To use a heat source efficiently, the heat-transfer properties of the mortars are important. However, mortars have low heat-transfer properties because mortars are generally nonconductors. Therefore, it is necessary to improve the heat-transfer properties of mortars [3-7].

Carbon materials such as carbon fibers, carbon blacks, carbon nanotubes and graphites usually have high thermal conductivity [8-10]. Consequently, there have been a wide number of studies that have explored carbon material reinforced composites, or reinforced concretes, to improve their thermal conductivity and mechanical properties. In particular, carbon blacks and carbon fibers are usually used as an additive to improve thermal properties as well as strength properties [11-14].

To prevent mortar-based structures from freezing in the winter, mortars have to transfer heat efficiently from the heat source, such as geothermal heat or internal heater. In this study, to improve the heat-transfer properties of mortars for repair work, the effect of carbon black and carbon fibers on the heat-transfer properties of high early strength cement mortars was investigated.

High early strength cement (Jeong Woo Materials Co., Seoul, Korea) was used as a binder for the mortar. Sand was also used for the mortar, and its density and fineness modulus were 2.65 g/cm^3 and 2.70, respectively. Carbon black (Chezacarb AC-60; Unipetrol RPA, Litvinov, Czech Republic) and carbon fiber (T700SC; Toray Co., Tokyo, Japan) were used as an additive; the bulk density and specific surface area of the carbon black was 0.12 g/cm^3 and 800 m^2/g, and the bulk density and tensile strength of the carbon fiber was 1.8 g/cm^3 and 3.70 GPa, respectively.

Table 1 shows the composition (wt%) of the materials added to the mortar. The weight ratio of binder and sand was 1:3 and that of binder and water was 1:1. The additives were 2 wt% of the binder [15]. The mixing method for the mortar was conducted by the ISO 679 method. A mixture of cement and additive in water was mixed for 30 s at 140 ± 5 rpm, and followed by mixing with the added sand mixture under the same conditions. Then, the mixture, which included cement, additive, water and sand, was mixed for 30 s at 285 ± 10 rpm, and the mixture was mixed for 60 s, and at the same rpm for 90 s, for better dispersion in the mortar.

Plain mortar, which is just high early strength cement mortar, was denoted as HESM-P, and the high early strength cement mortars with added carbon black or carbon fiber were denoted as HESM-CB and HESM-CF, respectively. Also, the high early strength cement mor-

Table 1. The composition (wt%) of the materials added to the mortar

	Cement (wt%)	Carbon black (wt%)	Carbon fiber (wt%)	Sand (wt%)	Water (wt%)
HESM-P	50	0	0	37.5	50
HESM-CB	49	1	0		
HESM-CF	49	0	1		
HESM-CBCF	49	0.5	0.5		

HESM-P, high early strength cement mortar; HESM-CB, high early strength cement mortars with added carbon black; HESM-CF, high early strength cement mortars with added carbon fiber; HESM-CBCF, high early strength cement mortars with both added carbon black and carbon fiber.

Table 2. The density, flow and setting time of the prepared mortars

	HESM-P	HESM-CB	HESM-CF	HESM-CBCF
Slurry density (g/cm^3)	2.15	2.04	1.93	1.95
Dry density (g/cm^3)	2.03	1.80	1.81	1.81
Flow (mm)	176	150	148	153
Initial setting time (min)	30	33	35	32
Final setting time (min)	45	48	50	45

HESM-P, high early strength cement mortar; HESM-CB, high early strength cement mortars with added carbon black; HESM-CF, high early strength cement mortars with added carbon fiber; HESM-CBCF, high early strength cement mortars with both added carbon black and carbon fiber.

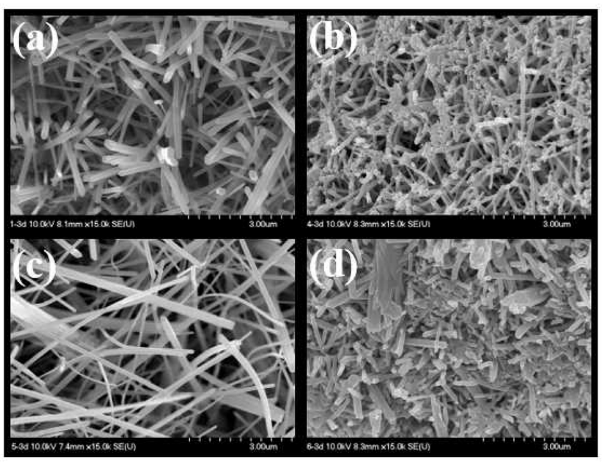

Fig. 1. Scanning electron microscopy images of the prepared mortars: (a) high early strength cement mortar (HESM-P), (b) high early strength cement mortars with added carbon black (HESM-CB), (c) high early strength cement mortars with added carbon fiber (HESM-CF), and (d) high early strength cement mortars with both added carbon black and carbon fiber (HESM-CBCF).

tars with both added carbon black and carbon fiber (1:1 weight ratio) were denoted as HESM-CBCF. Pre-curing was conducted at a temperature of 20°C ± 2°C and humidity of 65% ± 10% in air for a day. Then, wet-curing was conducted at 20°C ± 1°C for 28 days.

Scanning electron microscopy (SEM; JSM-7000F, JEOL, Tokyo, Japan) was used to investigate the morphologies of the prepared mortars. To investigate the density, flow and setting time of the carbon additive added mortars, KS F 2409, KS L 5105, and ISO 9597 methods were used, respectively. To characterize the compressive strength and flexural strength of the mortars, the ISO 679 method was used. The heat-transfer properties of the prepared mortars were measured at 100°C for 40 min using a hot-plate.

Fig. 1 presents the SEM images of the pristine mortars and the mortars with added carbon additives. Fiber-shaped cement can be seen in all of the samples, and carbon fiber can be seen in HESM-CF and HESM-CFCB.

Table 2 shows the density, flow and setting time of the prepared mortars. The slurry and dry density of the prepared mortars with carbon additives decreased, compared to those of HESM-P. This is because the density of carbon black and carbon fiber is much lower than that of the cement. The flow of the prepared mortars with carbon additives decreased 13.1%–15.9% compared to that of HESM-P, and in particular, the flow of HESM-CF was the lowest. This is because the carbon black and the carbon fiber act as a cross-linker in the mortar slurry.

The initial and final setting times of the prepared mortars with carbon additives increased compared to those of HESM-P, but the initial setting time of all the samples was under 35 min. In general, the initial setting time of high early strength cement is under 40 min. Thus, the setting time of the prepared mortars is within the range expected for general high early strength cement mortar.

Fig. 2 shows the compressive strength and flexural strength of the prepared mortars at the age of 1, 7 and 28 d. A minor increase in compressive and flexural strength of the prepared mortars was observed on day 1, and it increased in the order of HESM-P, HESM-CB, HESM-CF and HESM-CBCF. These results can be interpreted to mean that the carbon additives improved the mechanical properties of the mortars [16]. At the age of 28 d, the compressive and flexural strength of the HESM-CF,

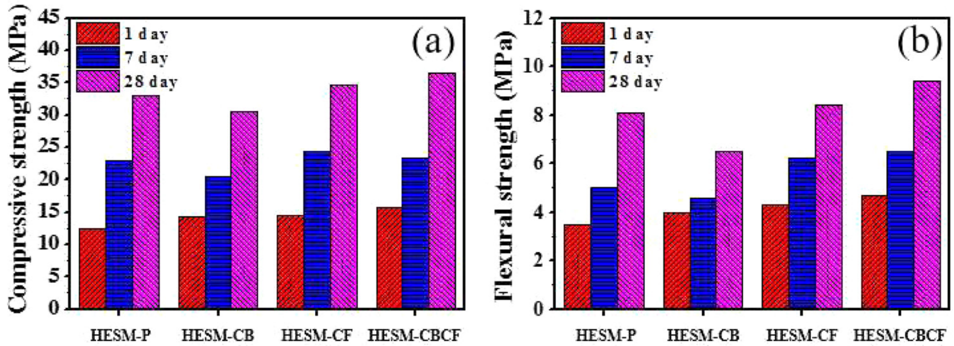

Fig. 2. The strength properties of the prepared mortars over time: (a) compressive strength and (b) flexural strength.

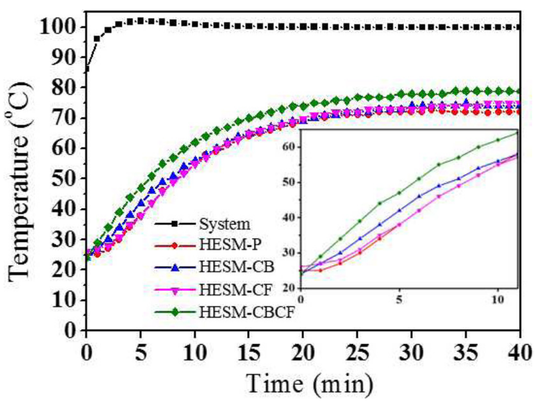

Fig. 3. Heat-transfer properties of the prepared mortars.

HESM-CBCF increased compared to those of HESM-P, whereas those of HESM-CB decreased. Because carbon black adsorbs a fraction of water during the mixing procedure due to its large specific surface area (>800 m^2/g), it tends to decrease the water/cement ratio [17]. Generally, if the water/cement ratio is lower than the optimized ratio, the reaction rate of hydration decreases. This results in a decrease in mechanical properties.

Fig. 3 shows the heat-transfer properties of the prepared mortars, and the slope is proportional to the value of the heat-transfer properties. In the initial step, which is under 10 min, the slope of HESM-CBCF is the steepest, and that of HESM-CB is the next steepest. Meanwhile, the slopes of HESM-P and HESM-CF are almost the same tendency, and they are lower than that of HESM-CB. In addition, the slope of HESM-CB is steeper than that of HESM-P and HESM-CF.

After 30 min, the slopes of all the samples is almost zero and does not change much. In this range, the temperature of the prepared mortars with carbon additives is higher than that of HESM-P. Specifically, the temperature of HESM-CBCF was the highest at 80°C, whereas that of other mortars was under 75°C. Carbon black can help to improve heat-transfer properties, and carbon fibers can act as bridges across carbon black particles [16,18]. Thus, the bridge-connecting effects of carbon fiber and carbon black has the effect of improving the heat-transfer properties of the mortars (HESM-CBCF).

In conclusion, high early strength cement mortar with added carbon black and carbon fiber was prepared to investigate the effect of those additives on the mortars' heat-transfer properties. The carbon black in the mortars was effective at improving heat-transfer properties. When a mixture of both carbon black and carbon fiber was added to the mortars the heat-transfer properties increased, compared to that of the mortars with only carbon black added.

This can be interpreted to mean that the carbon fiber acts as a bridge, linking carbon black particles, and thus increases the heat transfer capacity. Furthermore, the strength properties of the mortars were improved by the mixture of carbon black and carbon fiber due to the effect of bridging between the carbon black and carbon fiber. Thus, high early strength cement mortar with a mixture of added carbon black and carbon fiber can be used for repair work when higher heat-transfer properties are required.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

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