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Effect of Calcium Compounds on Mechanical Properties of Eco-friendly Non-cement Mortar

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Abstract. Improvement in the mechanical properties of non-cement mortars using ASTM Class C fly ash (FA) containing high amounts of CaO produced from a fluidized bed-type boiler and blast furnace slag (BS) was studied. This type of FA has been used to carbonate non-cement mortar under supercritical conditions for CO_2 fixation, because such mortars cannot be recycled and easily reclaimed owing to the presence of high amounts of CaO that may adversely affect their eco-friendliness because of the high volume expansibility of CaO. Because a substantial increase in the compressive strength was observed for the specimen containing 20% FA, two types of Ca compounds—CaO and $Ca(OH)_2$—were added to the BS specimens to investigate the effects of Ca compounds on the mechanical properties of non-cement mortar specimens. Three types of curing methods—room temperature, room temperature with hermetic sealing, and high temperature with hermetic sealing—were used and the specimens were aged for 3, 7, and 28 days. Because both CaO and $Ca(OH)_2$ enhance the compressive strength at the concentration corresponding to that in the FA, it is speculated that the amorphous materials in the BS is destroyed without adding any acid or reagents because of the increase in pH by the Ca compound present in the specimen. An increase in the specimen pH may affect the strength improvement because of ion elution and curing reaction. It is concluded that enhancement in the mechanical property by the addition of 20% FA to BS can be explained from the results obtained by adding Ca compounds.

Introduction

Global warming caused by CO_2 has become a serious environmental problem that needs to be solved. In particular, the amount of CO_2 produced while manufacturing Portland cement, used in most buildings and civil constructions, is increasing every year. Approximately 0.4–1.0 ton of CO_2 was produced during the production of 1 ton of cement [1]. Significant research is focused on reducing CO_2 production and identifying substitute materials for cement with the view to protect the environment [2,3].

Attempts to increase the utilization of fly ash (FA), a by-product of thermal power generation, to partially replace cement in concrete are gathering momentum. However, most of the FA generated is being currently dumped in landfills, harming the environment [4].

Ash from power plants is generally classified as bottom ash and FA. FA is generated particularly from fluidized bed-type boilers and contains high levels of CaO used for the desulfurization of exhaust gases from the boiler. This type of FA, classified as ASTM Class C FA, cannot be recycled and easily reclaimed because of the high content of alkali-earth metal oxides such as CaO and MgO. These oxides have high volume expansibility that may adversely affect their eco-friendliness [5,6]. Therefore, a suitable method for recycling this type of FA is urgently required, especially because in Korea the number of fluidized bed-type boilers have increased recently [7].

In this study, we investigate the mechanical properties of non-cement mortars containing FA and blast furnace slag (BS). The amorphous film of the BS decomposed by pH caused by FA addition leads to the formation of high-compressive-strength mortar. Additionally, mortar was synthesized by adding CaO and $Ca(OH)_2$ to confirm the effect of the Ca component of the FA. In the case of mortar synthesized using CaO and $Ca(OH)_2$ reagents, it was cured hermetically at room temperature and high temperature, in addition to being subjected to room-temperature curing for a day.

Experimental Procedures

Materials. The FA used can be classified as ASTM Class C FA, whose chemical composition is shown in Table 1. The FA mainly consists of 41.25 wt% and 29.32 wt% CaO and SiO_2, respectively. Because the FA used in this study came from a fluidized bed-type boiler, it contains greater quantities of CaO than normal FA. In addition, mortars with added CaO and $Ca(OH)_2$ were synthesized to confirm the effect of the Ca component of the FA.

Table 1. Elemental composition of fly ash and blast furnace slag expressed in oxide forms (wt%).

	Ig. Loss	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	ZrO_2	P_2O_5	Cr_2O_3	MnO	SO_3	Total
FA	1.94	29.32	5.34	9.46	41.25	7.33	0.16	0.84	0.50					3.81	100
BS		36.35	13.39	0.31	44.08	4.49	0.08	0.44	0.48		0.02		0.27		99.92

Mixture ratios and experimental methods. The mixture ratios and water content are shown in Table 2. The mixture ratio of BS to FA varied from 100:0 to 0:100. The mortar mixture was filled in a cubic mold ($50 \times 50 \times 50$ mm^3), and then tapped and pressed 20–30 times with a compaction tool for removing voids and air from the mixture. After aging for 24 h, the specimens were aged for 3, 14, and 28 days at room temperature in air. In the case of the mortar synthesized with the added reagents, room-temperature hermetic curing and high-temperature (60 °C) curing, besides room-temperature curing for a day, were performed. The mechanical properties of the samples were analyzed by measuring their compressive strength.

Table 2. Mixture proportions of mortars (g).

<table>
<tr><th>Symbol</th><th>Fly ash</th><th>Blast furnace slag</th><th>Distilled water</th></tr>
<tr><td>F100B0*</td><td>600</td><td>0</td><td>236</td></tr>
<tr><td>F80B20</td><td>480</td><td>120</td><td>212</td></tr>
<tr><td>F60B40</td><td>360</td><td>240</td><td>206</td></tr>
<tr><td>F40B60</td><td>240</td><td>360</td><td>190</td></tr>
<tr><td>F20B80</td><td>120</td><td>480</td><td>180</td></tr>
<tr><td>F0B100</td><td>0</td><td>600</td><td>162</td></tr>
<tr><td>with added CaO</td><td rowspan="2">49.2</td><td rowspan="2">480</td><td rowspan="2">158</td></tr>
<tr><td>with added $Ca(OH)_2$</td></tr>
</table>

Results and Discussions

Fly ash addition. The compressive strength of the specimens as a function of FA and BS composition ratio and aging time is shown in Fig 1. For the 3-, 7-, and 28-day specimens, higher compressive strength was obtained as the FA content decreased, except for F0B100. The higher BS content accelerates the hardening reaction (geopolymer reaction) because of greater availability of alumino-silicate minerals. In the case of the F0B100 specimen, the compressive strength cannot be measured because the absence of FA results in no alkalinity, which is required to dissolve the alumino-silicates in the BS. This shows that 20 wt% of FA is sufficient to synthesize non-cement mortar, because it is sufficient to maintain the required pH for synthesizing non-cement mortars.

The pH values of the specimens synthesized using distilled water are shown in Fig. 2. The pH of FA and hydrated FA containing 20 wt% slurry were maintained at ~12.6 and 12.2, respectively. The high alkalinity of these slurries makes F20B80 achieve the maximum compressive strength (26 MPa). In contrast, the strength decreased as the FA content was increased. The pH increased with an increase in the FA content; however, it is speculated that the amount of the sources for non-cement mortars supplied by the BS would be reduced on decreasing the content of BS.

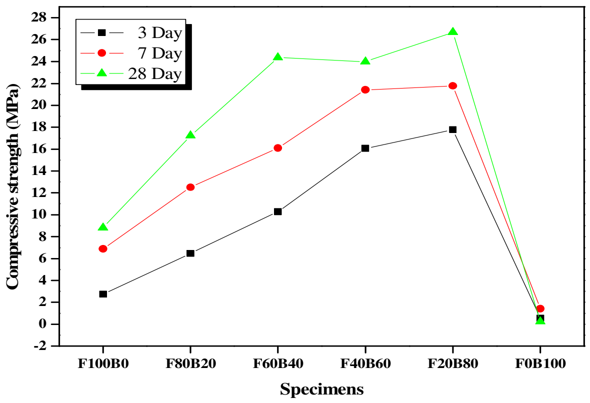


Fig. 1. Compressive strength of non-cement mortars made with distilled water.

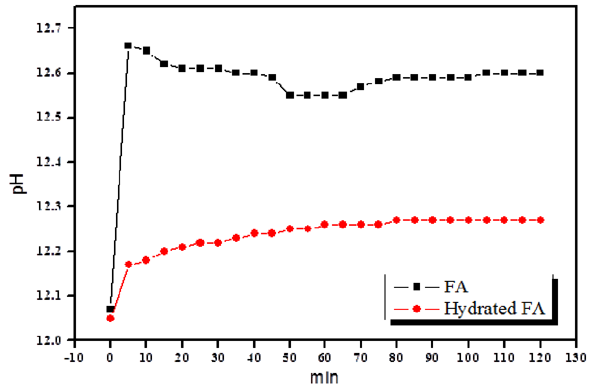
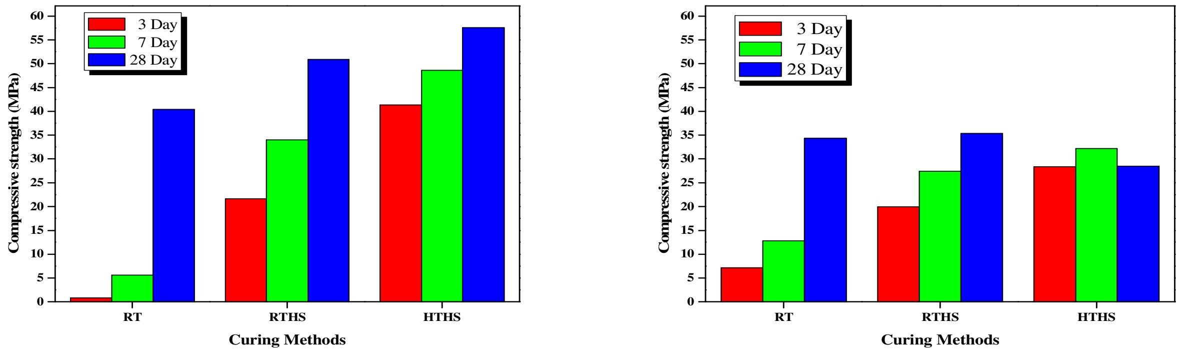


Fig. 2. pH as a function of mixing time of distilled water with fly ash.

CaO and $Ca(OH)_2$ addition. Fig. 3 shows the compressive strength of mortars with the addition of CaO and $Ca(OH)_2$. Compared to the mortar with FA, the mortar with CaO and $Ca(OH)_2$ showed a relatively higher strength. In the case of the mortar with CaO, when cured at high temperature, compressive strength on day 28 is ~57 MPa; a highest strength of ~50 MPa was obtained for the sample cured at room temperature with hermetic sealing.



(a) (b)

Fig. 3. Compressive strength of CaO and $Ca(OH)_2$ added mortars (RT: curing at room temperature, RTHS: curing at room temperature with hermetic sealing, HTHS: curing at high temperature with hermetic sealing). (a) CaO addition and (b) $Ca(OH)_2$ addition

It was determined that the compressive strength in the early stage of curing at room temperature with hermetic sealing was higher than that for curing at room temperature without hermetic sealing, because the hermetic condition promotes the reaction, which suppresses the evaporation of the specimen moisture for both CaO and $Ca(OH)_2$ addition. In the case of $Ca(OH)_2$ addition, the compressive strength was lower than that of the CaO mortars (Fig. 3), but higher than that of the mortars with only FA. If hydrated CaO, i.e., $Ca(OH)_2$, was used, it causes volume expansion in the specimens, which generates more cracks and voids inside the specimens. Hence, the CaO reacts with the moisture present inside the mortar to produce $Ca(OH)_2$, which again reacts with the moisture to make the specimen alkaline and generate additional pozzolanic reaction, resulting in a higher compressive strength.

The compressive strength of the specimens containing CaO cured at high temperature with hermetic sealing for 28 days was highest of all. It is important to note that the effect of high temperature and hermetic sealing was only seen in the case of CaO addition. This means that hydrated CaO cannot play an effective role as an activator or provide additional hardening sources.

Fig. 4 shows the fractured sections of mortars for different curing methods and reagent addition. From the figure, it is confirmed that the mortar with CaO has a more elaborate structure than the mortar with $Ca(OH)_2$. This is in good agreement with the compressive strength data shown in Fig. 3.

					
RT	RTHS	HTHS	RT	RTHS	HTHS
CaO addition			$Ca(OH)_2$ addition		

Fig. 4. Fracture section of mortars for each curing method and reagent addition.

Conclusion

When only distilled water is added to non-cement mortar, the resulting high pH of the FA enhanced the reactivity of the BS; consequently, the compressive strength of the specimens also increased. The pH increase caused by the addition of only 20 wt% FA was sufficient to synthesize non-cement mortar with a maximum compressive strength of 26 MPa. In the case of the mortar with CaO, the values of compressive strength after 28 days of curing at high temperature with hermetic sealing and curing at room temperature with hermetic sealing were 57 and 50 MPa, respectively.

From the results of both CaO and $Ca(OH)_2$ additions, it is speculated that the amorphous materials in the BS is destroyed without adding any acid or reagents because of the increase in the pH caused by the Ca component of the specimen, which can be incorporated by adding FA to BS. Therefore, it was confirmed that the presence of Ca in FA affects the mechanical strength of non-cement mortars.

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