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Reaction Characteristics of Blast Furnace Slag-Based Non-Cement Paste Using Alkali Accelerator and Red Mud†

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This study involved to examine the strength properties and reactions of non-cement paste that used the blast furnace slag from steel manufacturing and red mud, the by-products. It was found that KOH, NaOH and $Ca(OH)_2$ stimulated the blast furnace slag particles and created the C-S-H (calcium silicate) hydrate, *etc*., resulting in the hardening of non-cement paste. The results of compressive strength test suggested that both KOH and NaOH exhibited a tendency that compressive strength decreased as the replacement rate of red mud increased. In addition, the test specimen added with $Ca(OH)_2$ showed the increased strength proportionally to the replacement rate, but showed much lower strength compared to that of KOH and NaOH.

Keywords: Blast furnace slag, Alkali accelerator, Red mud, SEM-EDS, Non-cement.

INTRODUCTION

The manufacture and production of cement involve the use of fossil fuels, which is the main cause of CO_2 generation. For example, CO_2 emissions occur during the process of making cement (CaO) with limestone ($CaCO_3$) and in this process, massive amount of CO_2 is generated, again when fossil fuel is burned to supply the heat required in this process[1,2].

One of the solutions is to produce a non-cement paste which is based on the blast furnace slag. Blast furnace slag is advantageous for long-term strength due to its latent hydraulic property, but is difficult to secure the strength of early age. Such blast furnace slag destroys and stimulates the film of blast furnace slag particles which cause latent hydraulic property by using the alkali accelerator.

However, there has been no research that concluded clearly about the compatibility based on the type of alkali accelerator and blast furnace slag[3,4]. Therefore, this study intended to produce the matrix based on blast furnace slag by using the KOH, NaOH, $Ca(OH)_2$, the alkali accelerators.

EXPERIMENTAL

The blast furnace slag (BFS) used in this experiment has the density of 2.91 g/cm^3, fineness of 4,464 cm^2/g. Its chemical composition, it SiO_2 and CaO which comprises 35.08 and 41.10 %, respectively. The red mud (RM) has the density of 3.37 g/cm^3 and fineness of 3,483 cm^2/g. Its chemical composition, is with 25.14 %, Al_2O_3 with 33.30 %, Fe_2O_3 and with 8.30 % of Na_2O the alkaline component (Table-1).

This study is conducted in order to produce the non-cement paste (NCP) based on blast furnace slag. The W/B was fixed at 0.45 and the KOH, NaOH, $Ca(OH)_2$ were used as alkali accelerator. In addition, 10 % by weight of binder was added.

Furthermore, it was cured at the humidity of 80 ± 5 % and temperature of 20 ± 2 ºC by substituting with 0, 10, 20, 30 (wt. %), *etc*., in blast furnace slag to reduce the consumption of alkali accelerator. For the test items, scanning electronic microscope (SEM) imaging, EDS analysis were conducted and compressive strength were measured. The factor and level of this experiment are presented in Table-2.

SEM imaging and EDS analysis were conducted on the 28th day in order to observe the microstructure and chemical composition of each non-cement paste. Moreover, the test specimen was produced with 40 mm × 40 mm × 160 mm mold in accordance with the cement strength test method (KS L ISO 679) to measure the compressive strength by age.

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TABLE-1
CHEMICAL COMPONENT OF USING MATERIALS

Materials	Chemical components (%)							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	TiO_2
Blast furnace slag	35.08	13.87	0.52	41.10	3.60	2.36	–	1.20
Red mud	12.00	25.14	33.30	2.50	0.20	0.30	8.30	–

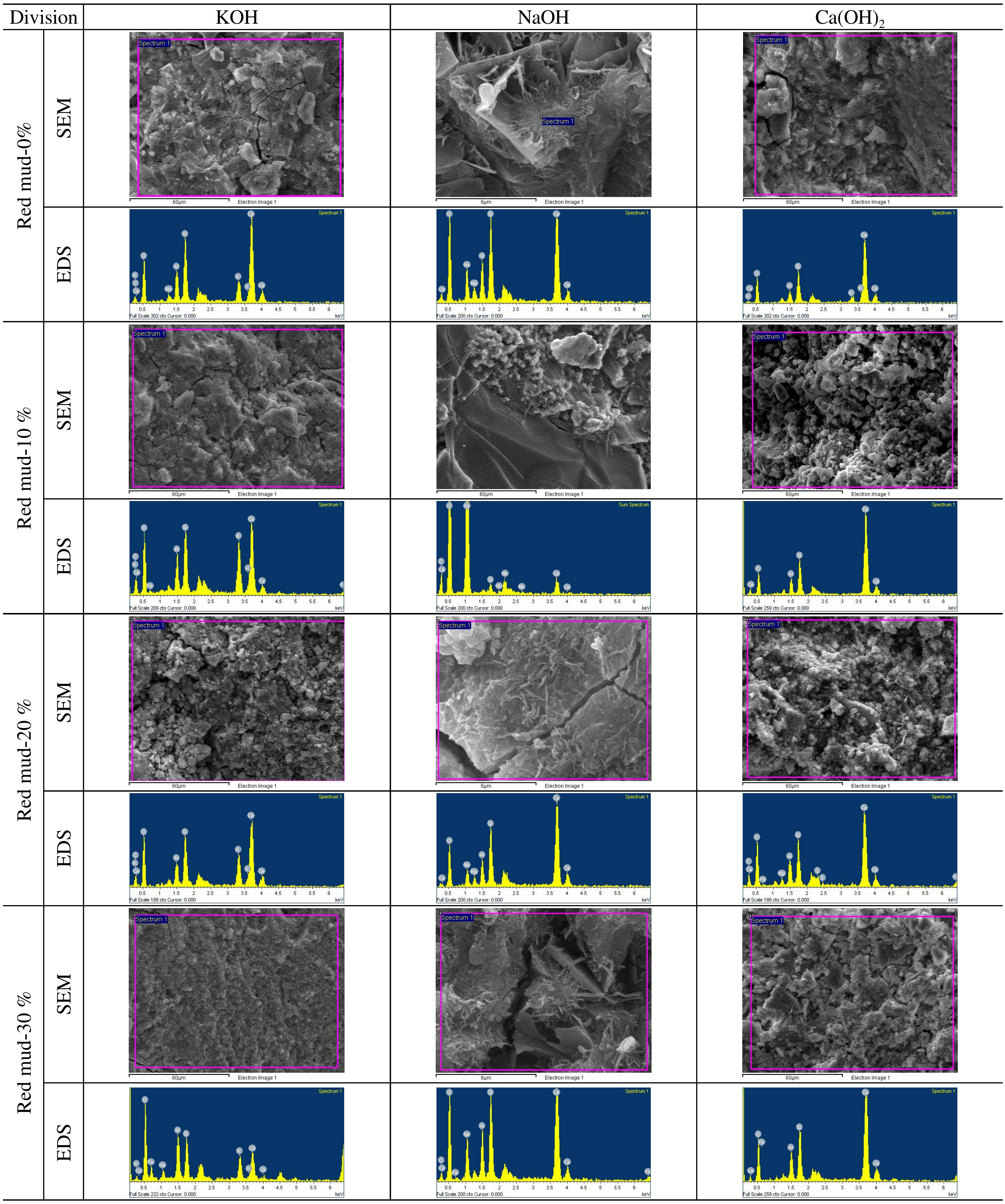

Fig. 1. SEM-EDS in the 28 days

TABLE-2
EXPERIMENTAL FACTORS AND LEVELS

Factors	Levels
Binder type	BFS, RM
Alkali accelerator	NaOH, KOH, $Ca(OH)_2$
Addition ratio of alkali accelerator	10 (wt. %)
Replacement rate of red mud	0, 10, 20, 30 (wt. %)
Curing condition	Relative humidity (80 ± 5) %, temp. (20±2) ºC
W/B	0.45
Test items	SEM-EDS, XRD, compressive strength

RESULTS AND DISCUSSION

SEM-EDS: The results of SEM imaging and EDS analysis suggested that the glassy film of BFS particles were destroyed by KOH, NaOH, $Ca(OH)_2$, the alkali accelerators, leading to the elution of the components necessary for hydration reaction, such as SiO_2, CaO, which were contained in BFS particle and resultantly, BFS-based NCP was hardened (Fig. 1).

For the NCP added with KOH, there was a slight difference in size and compactness, depending on the replacement rate of red mud. However, all NCPs massed and microcrack was observed between the crystals. That is attributed to the fact that the expandable hydrated product was created by K^+, although the strength would be increased by the formation of compact structure as a result of reaction through KOH between water and components that were contained in BFS.

The NCP added with NaOH also formed the compact structure in the same way as when the KOH was added. The 2-dimensional netlike C-S-H hydrate was observed in the test specimen that did not substitute the red mud.

Furthermore, the test specimen that substituted the 20 and 30 % showed the layered product and Na phase which were different from those of the test specimen that did not substitute the red mud. Microcrack was observed in the surface of test specimen.

Massiveness similar to that of KOH was observed in NCP which was added with $Ca(OH)_2$. However, there was no formation of the structure with compactness greater that of the test specimen which had been added with KOH. The low reactivity of $Ca(OH)_2$ prevented the complete hardening of the material even in the 28 days and therefore, long-term observation would be necessary.

Compressive strength: The results of compressive strength test showed that the compressive strength diminished in the test specimen added with both KOH and NaOH as the replacement rate of red mud increased. For the NCP added with KOH and NaOH, the test specimen that did not substitute the red mud exhibited the highest strength in the 28th day. The NCP added with KO and NaO showed the decreasing strength as the replacement rate of red mud increased. That is considered to be attributable to the crack caused by red mud.

Besides, the substitution of red mud resulted in the reduction of the amount of BFS that plays a key role in the strength development and furthermore, all alkaline components required for activation of BFS were supplied from the alkali accelerator prior to the elution of Na_2O contained in red mud. Therefore, the Na^+ in red mud which was not involved in hydration reaction remained inside the test specimen and became a factor that decreased the strength over the long-term.

Meanwhile, the NCP test specimen added with $Ca(OH)_2$ showed the increased strength as the replacement rate increased, but exhibited noticeably lower strength compared to that of KOH and NaOH. That is attributed to low reactivity of $Ca(OH)_2$, leading to the lower strength compared to NCP which used the KOH and NaOH, as it was mentioned about the results of SEM imaging. As a result, the Na^+ contained in red mud was consumed to activate the BFS and therefore, the strength increased, depending on the replacement rate of red mud (Fig. 2).

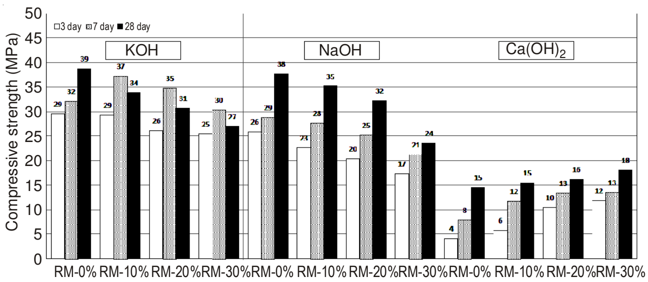

Fig. 2. Compressive strength

Conclusion

In this study, an experiment was conducted to produce the matrix based on the blast furnace slag by using the BFS, KOH, NaOH, $Ca(OH)_2$ which are the alkaline accelerator and red mud which contains the alkaline component and the following conclusion was reached: All of the KOH, NaOH, $Ca(OH)_2$, the alkali accelerators used in this experiment, destroyed the film of BFS particles, leading to the elution of components that were contained in BFS, thus stimulating the hydration reaction. C-S-H hydrate was found to have been formed in NCP. NCP which used both KOH and NaOH showed the decreasing strength as the replacement rate of red mud increased. Meanwhile, $Ca(OH)_2$ exhibited the increasing strength, but the strength was significantly low. Thus, it is considered that red mud may replace the alkali accelerator if the consumption of both KOH and NaOH is reduced, as well as $Ca(OH)_2$ and proper amount of red mud is used.

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