Asian Journal of Chemistry; Vol. 27, No. 11 (2015), 4207-4209

ASIAN JOURNAL OF CHEMISTRY

http://dx.doi.org/10.14233/ajchem.2015.19490

Strength Characteristics Based on Curing Method and Curing Time of Inorganic Binder Matrix of Ternary System†

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AJC-17436

This study investigated into cement substitutes using the industrial by-products and applied the blast furnace slag, red mud and silica fume and alkaline activator. In addition, experiments have been carried out by varying the curing method and curing times for preventing crack in matrix using industrial by-products. The results showed that no crack occurred in the matrix cured in water and that such matrix was found to have better strength than the air-dried matrix. Based on that, the experiment was performed to achieve economic efficiency through variation of curing time for water curing temperature. The results suggested that adequate strength was achieved when the water curing time was longer than 6 h at 80 °C.

Keywords: Silica fume, Blast furnace slag, Red mud, Water curing, Dry curing.

INTRODUCTION

The amount of CO_2 generated in the manufacturing process has been increasing every year, particularly in the case of Portland cement widely used at construction and civil engineering sites. Furthermore, CO_2 emissions 0.4 to 1.0 tons are emitted from the production of 1 ton cement, accounting for 7 % of CO_2 emissions worldwide[1,2]. Thus, researches have been conducted vigorously to reduce the amount of CO_2. Therefore, this study intended to examine the possibility of cement substitute based on inorganic binders using the alkaline stimulant and industrial by-products such as blast furnace slag, red mud, silica fume, *etc*., which can replace the cement. The crack that occurs in the process of air-dried curing decreases flexural strength.

By varying the curing method and curing time to prevent crack in inorganic binder matrix, the results obtained from the experiment can provide basic data for inorganic binder curing method.

EXPERIMENTAL

In this study, we selected W/B 31 %, CaO content 30 % and Si/Al 4 by using the optimal mixing time derived in the preceding experiment and added 400g inorganic binder such as blast furnace slag, red mud, silica fume, *etc*. and liquid alkaline stimulant of 50 g NaOH and 50 g Na_2SiO_3 which comes to a total of 100 g (Table-1). The curing conditions were defined in 3 levels, *i.e.*, the curing by air-dried temperature, curing by water temperature and curing based on variations of water curing time at 80 °C. The experiment was conducted at 2 levels covering the compressive strength and flexural strength, respectively. The experimental design is presented in Fig. 1[3].

TABLE-1
EXPERIMENTAL FACTOR AND LEVEL

Factor	Level	
W/B	0.31	1
Inorganic binder	Blast furnace slag, red mud, silica fume	1
Inorganic binder condition	CaO content 30 % Si/Al 4	1
Mixing condition	20, 30, 40, 50 (rpm) → each 90 seconds all 360 seconds	1
Test item	Compressive strength, flexural strength	2

Materials: In this study, the materials used were the blast furnace slag, silica fume and red mud. The chemical properties of the materials used are presented in Table-2.

Blast furnace slag: The blast furnace slag consists mainly of SiO_2, CaO, MgO and Al_2O_3. Type III blast furnace slag were used which had a density of 2.91 g/cm^3 and fineness of 4,464 cm^2/g.

†Presented at The 8th ICMMA-2014, held on 27-29 November 2014, Hoseo University, Chungnam, Republic of Korea

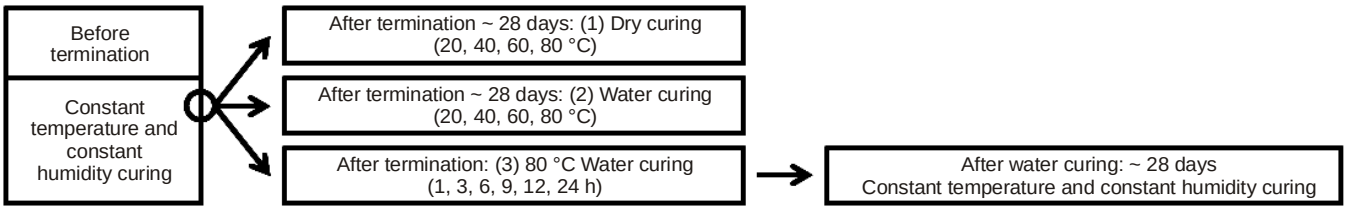

Fig. 1. Curing method

TABLE-2
CHEMICAL COMPONENT OF THE USING MATERIALS

Using materials	Chemical component (%)				
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO
Blast furnace slag	26.03	10.96	0.18	54.07	4.21
Silica fume	94.00	2.60	1.69	0.31	1.03
Red mud	14.20	25.12	25.12	13.99	0.40

Silica fume: The silica fume used in this study had a density of 2.18 g/cm^3 and fineness of 220,000 cm^2/g.

Red mud: The red mud consists mainly of Fe_2O_3 and Al_2O_3, contained Na_2O and has a density of 3.37 g/cm^3 and fineness of 3.483 cm^2/g.

Alkali accelerator: The alkaline activator used in this study was the liquid NaOH 33 % and Na_2SiO_3 which is the type I (38.5 %) conforming to KSM1415.

RESULTS AND DISCUSSION

Compressive strength and flexural strength by dry curing temperature: It was found that the compressive strength values increased as the curing temperature increased (Fig. 2). Meanwhile, high strength value was obtained after 3 days as the curing temperature increased. After 3 days, the improvement rate of strength was reduced. This is considered attributable to the fact that the compressive strength increased above a certain level due to the high temperature stimulation reaction in initial phase in case of high temperature curing and that the hydrate becomes densified significantly after 7 days and inhibits hydration reaction rate inside the matrix.

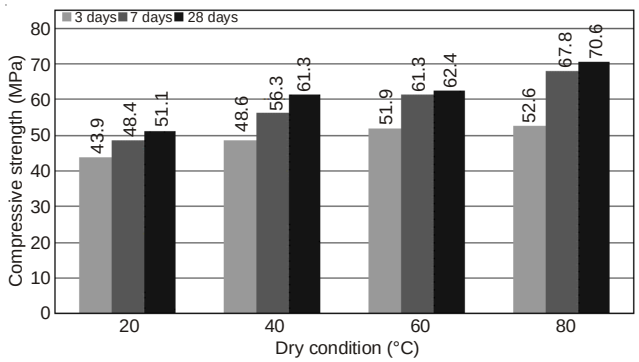

Fig. 2. Compressive strength by dry curing temperature

Meanwhile, the flexural strength value decreased as the curing temperature increased, which is attributed to the failure of normal hydration reaction due to the evaporation of water while being left in high temperature state and also attributed to the crack caused by the drying of ambient air surface that comes into contact with the test piece, thereby influencing the decrease in strength (Fig. 3). In relation to reverse phenomenon of compressive strength and flexural strength, the flexural strength can withstand upper compression caused by crack but cannot withstand lower-part tensile force due to the crack, thus reducing the flexural strength.

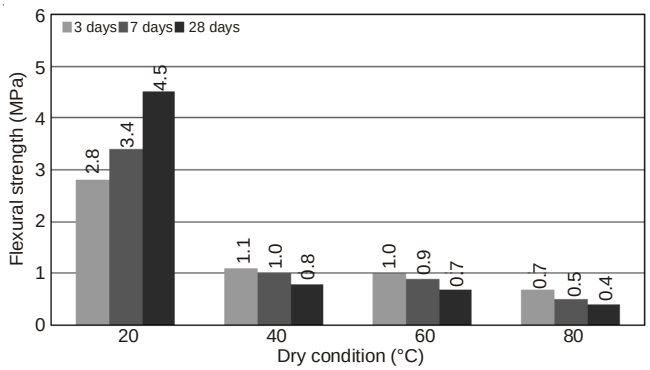

Fig. 3. Flexural strength by dry curing temperature

Compression strength and flexural strength by water curing temperature: The results of flexural strength and compressive strength by water curing temperature showed that flexural strength decreased when the air-dried curing was performed (Fig. 4).

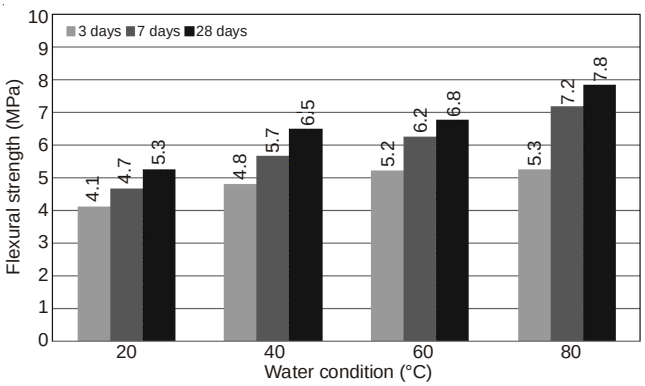

Fig. 4. Flexural strength by water curing temperature

However, compression strength and flexural strength tended to increase proportionally to the age in the case of water curing (Figs. 4 and 5). Unlike the air-dried curing, moisture was supplied adequately by water curing which allowed cracks to be controlled, thereby achieving higher strength value compared to that achievable by air-dried curing.

Figs. 6 and 7 show the cracks in air-dried curing matrix and water curing matrix. In the case of air-dried curing, the cracks inside the matrix could be viewed with the naked eye. By contrast, cracks do not occur in the matrix in the case of water curing. Thus, we further examined the characteristics based on the variation of time as the condition of water curing.

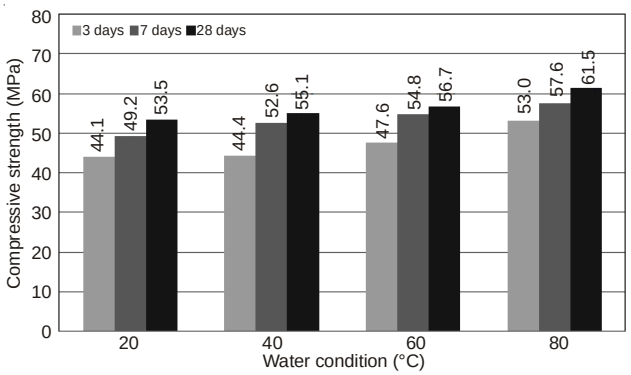

Fig. 5. Compressive strength by water curing temperature

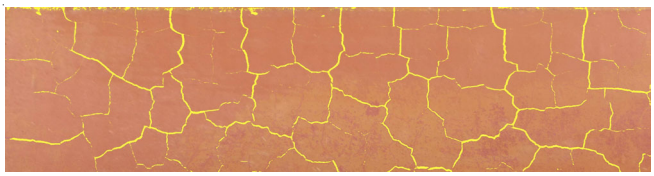

Fig. 6. Crack in matrix during the dry curing at 80 °C

Fig. 7. Matrix during the water curing at 80 °C

Compressive strength and flexural strength based on variation of water curing time at 80 °C: We measured the flexural strength and compressive strength based on variation of water curing time at 80 °C (Figs. 8 and 9). The results showed that the matrix exhibited lower strength than the matrix cured for 28 days. However, based on the economical effect of high temperature curing, the optimum curing time is considered to be 6 to 9 h in water curing at 80 °C.

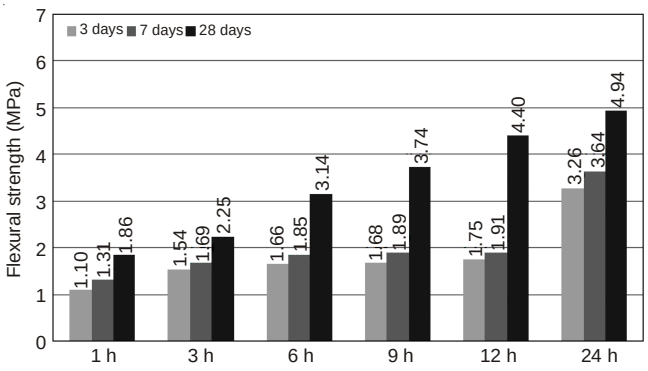

Fig. 8. Flexural strength based on variation of water curing time at 80 °C

Furthermore, the results of compressive strength suggested that the increase in strength slowed down as the age increased, which is considerate attributable to the fact that the strength performance rate, which was at an excellent level in early phase due to rapid progress of initial hydration, decreased as the age increased. Based on the measurement of flexural strength, it was found that the flexural strength of 3 MPa after 28 days showed difference from previous measurements. This degradation

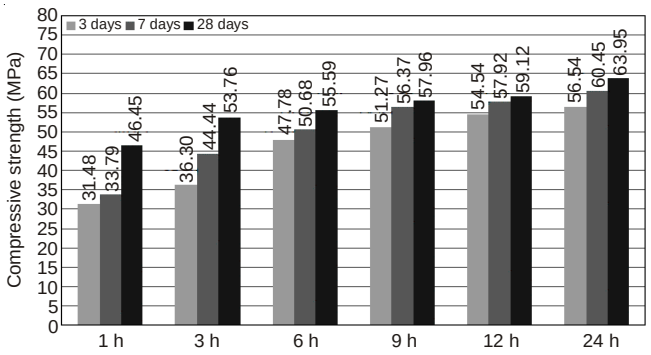

Fig. 9. Compressive strength based on variation of water curing time at 80 °C

of flexural strength was caused by the crack in the surface of test specimen while shifting the curing method from high-temperature water curing to constant temperature and constant humidity curing.

Conclusion

We measured the compressive strength and flexural compression based on the inorganic binder matrix curing method using the industrial by-products. The results are as follows:

• Based on the analysis of strength by air-dried curing temperature, it was found that the crack occurred at the surface when the curing was performed at temperatures over 40 °C. The compressive strength value was as high as 70.6 MPa in the case of air-dried curing at 80 °C while the flexural strength value decreased as the temperature increased and exhibited stable strength in the case of air-dried curing at 20 °C.

• Based on the analysis of strength characteristics by water curing temperature, it was found that the strength value increased as the temperature increased. However, the increase in strength slowed down. Compressive strength of 61.5 MPa and flexural strength of 7.8 MPa were manifested after 28 days.

• The test specimen cured at 80 °C for 28 days showed the most excellent results. However, optimum high-temperature water-curing time for compressive strength is considered to be 6 to 9 h based on economic aspects. The degradation of flexural strength was caused by the crack in the surface which results from the temperature difference while shifting the curing method from high-temperature water curing to constant temperature and constant humidity condition.

• This experiment was conducted with an aim to control the cracks and it could be found that the crack, cost-effectiveness and strength was improved by constant temperature and constant humidity curing which is preceded by the water curing.

ACKNOWLEDGEMENTS

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea Government (MEST) (No. 2012-001570).

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