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STUDY ON THE INFLUENCE OF CURING TEMPERATURE ON MECHANICAL PROPERTIES OF MODIFIED FLY ASH MORTAR

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Using fly ash as an admixture for concrete can contribute to environmental load reduction and concrete quality improvement. However, as the quality of fly ash fluctuates depending on the ash source, quality stabilization is required. It was proved that concrete with fly ash of Japanese Industrial Standardized class II has different strength properties depending on curing temperature, but it is not obvious whether concrete with modified fly ash by flotation method has similar properties. In this study, the influence was examined on the mechanical properties when changing the curing temperature of mortar using fly ash modified by the flotation technique. The sealing curing was set to 5°C, 20°C, 40°C and 60°C. Also, after 7 days, 5°C, 40°C and 60°C, is changed to 20°C and compression strength and static elasticity coefficient were measured. The value of compressive strength and static elastic modulus showed that mortar using modified fly ash had the same characteristics as mortar with ordinary fly ash. Because it was represented by one strength compressive estimation curve regardless of the curing temperature, it became clear that compressive strength can be evaluated by roughly using accumulated temperature as an indicator.

Keywords: Flotation method, Curing method, Compressive strength, Cumulative temperature, Static modulus of elasticity.

1 INTRODUCTION

Fly ash (FA), which is an industrial by-product of coal-fired power plants, can be used as an admixture for concrete, helping to reduce environmental load and improve concrete quality. However, because the quality depends on the ash source, quality stabilization of FA is required. Therefore, we used the flotation method, which has been used to remove the unburned carbon in FA (Takasu *et al*. 2014), to improve the quality of FA by modifying the ignition loss so that the FA conforms to Japanese Industrial Standards (JIS) class I. The strength properties of concrete containing JIS class II FA depend on curing temperature (Watanabe and Suda 2007). However, it is unclear what effect FA modified by the flotation method has on concrete properties. In this study, we examined the effect of FA modified by the flotation method on the mechanical properties of concrete cured at various temperatures.

2 SUMMARY OF THE EXPERIMENT

We made modified FA with the unburned carbon removed by the flotation method. In this method, kerosene was used as a collector for unburned carbon and pine oil was used as a foaming agent. FA containing a large amount of unburned carbon was eliminated with air bubbles. The FA before modification did not meet the JIS. However, the modified FA had a density, ignition loss, and specific surface area conforming to JIS class I.

Table 1 shows the materials and Table 2 shows the mix proportions used in this study. Ordinary Portland cement (OPC) and sea sand as the fine aggregate were used. The mix proportions in Table 2 exclude the coarse aggregate. In all mix proportions, the water/cement ratio was 50% and the FA replaced the fine aggregate. The unmodified FA had a density of 50 g/m3, whereas the modified FA had densities of 50, 100, and 150 kg/m^3.

Table 1. The materials.

Material	Sign	Type	Physical properties
Cement	C	Ordinary Portland cement	Density: 3.16g/cm^3
Admixture	FA	Fly ash(unmodified)	Density: 2.10g/cm^3
			Specific surface area: 3890cm^2/g
			Loss on Ig: 11.95%
		Fly ash(modified)	Density: 2.10g/cm^3
			Specific surface area: 3610cm^2/g
			Loss on Ig: 1.23%
Water	W	Tap water	—
Fine aggregate	S	Sea sand	Density in sarface-dry:2.74g/cm^3
			Water absorption rate:1.26%
			Solid content rate:62.4%

Table 2. The mix proportions.

Sign	W/C (%)	Unit Weight(kg/m^3)				
		W	C	FA	S	G
FA50	**50.0**	**180**	**360**	**50**	**744**	~~**949**~~
FA100	**50.0**	**180**	**360**	**100**	**718**	~~**915**~~
FA150	**50.0**	**180**	**360**	**150**	**692**	~~**882**~~

Table 3 shows the curing method. Three curing conditions were used: underwater curing, air curing, and sealing curing. The underwater curing and air curing were performed at 20°C. Sealing curing was carried out in a chamber in which the temperature was set to 5, 20, 40, or 60°C. Some of the specimens cured at 5, 40, and 60°C were then cured at 20°C after 7 days. The specimens were prepared by mixing cement, tap water, and FA for 30 s in a mortar mixer, and then sea sand was added and mixed for 4 to 5 min. The amount of air-entraining agent added was adjusted, and the target air amount was set to 6.7 ± 1.0%. We used a plastic cylindrical mold of ϕ50 × 100 mm to produce specimens for the compressive strength test. We immediately stored the underwater curing and air curing test specimens in a curing room at a temperature of 20 ± 1°C. The specimens were removed from the mold after 1 day and transferred to the curing conditions. The sealing cured specimens were cured in a chamber at each temperature.

Table 3. Curing condition.

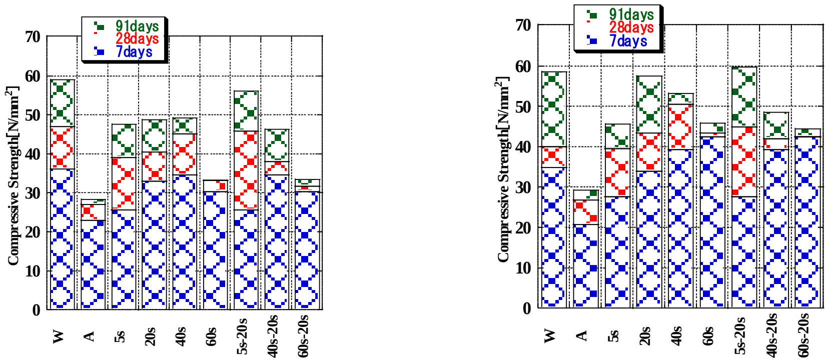
Sign	Curing temprtuer（℃）		Curing method
	Before 7days	After7days	
5s-20s	5	20	Seal
40s-20s	40	20	
60s-20s	60	20	
5s	5		
20s	20		
40s	40		
60s	60		
W	20		Under water
A	20		Air

The compressive strength was measured in accordance with JIS A 1108 "Method of Test for Compressive Strength to Concrete" and the static modulus elasticity was measured in accordance with JIS A 1149 "Method of Test for Static Modulus Elasticity". The compressive strength was tested after 7, 28, and 91 days of aging.

3 RESULTS AND CONSIDERATION

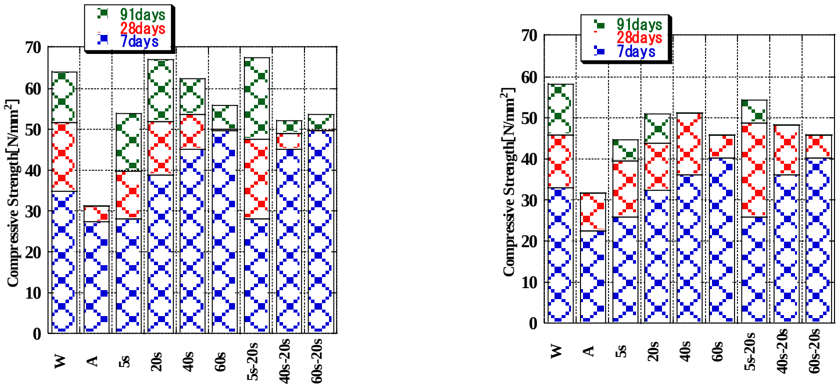
3.1 Compressive Strength

Figure 1 shows the compressive strength for each replacement rate. For underwater curing, all the specimens showed increased compressive strength. The compressive strengths of the other curing conditions for the modified FA 10% and the modified FA 15% specimens were higher than those of the underwater curing specimens. Focusing only on the sealing curing, the compressive strength at 7 days of age tended to be lower as the curing temperature was lower in the specimen. Focusing on compressive strength increase by age, 60s hardly increased. These results confirmed that continuing high-temperature curing did not increase the compressive strength. The compressive strength increased with the FA replacement rate. This result confirmed that the modified FA increased the compressive strength. The specimen containing unmodified FA 5% was compared with that containing modified FA 5%. For A, 40s and 60s of, no increase in compressive strength for unmodified FA was confirmed at 91 days compared with 28 days. The compressive strength of 60s modified FA specimens did not increase, whereas that of A, 40s, increased. These results indicated that modified FA increased the compressive strength more than unmodified FA. The compressive strengths of the samples cured under these conditions at 91 days were similar. For all replacement rates, the compressive strength at 91 days increased as the curing temperature decreased. These results confirmed that the difference in the initial curing temperature strongly affected the subsequent strength increase. We compared the unmodified and modified FA 5% 40s-20s and 60s-20s specimens. The modified 5% FA specimens showed a large increase in compressive strength from 7 to 28 days, whereas the modified FA 5% showed a large increase in compressive strength from 28 to 91 days. In addition, the increase in compressive strength increased with the rate of FA replacement.



(a)Modified FA5%.

(b)Modified FA10%.



(c)Modified FA15%.

(d)Unmodified FA5%.

Figure 1. The compressive strength for each replacement rate.

Figure 2. shows the relationship between compressive strength and cumulative temperature. The cumulative temperature is used for the strength prediction equation for normal strength concrete. The cumulative temperature is expressed by equation (1).

$$\sum_{\theta}^{t}(\theta+10)\times\Delta t \tag{1}$$

M: Cumulative strength (℃・day), Δt: Time（day）, θ : Δt temperature during time(℃)

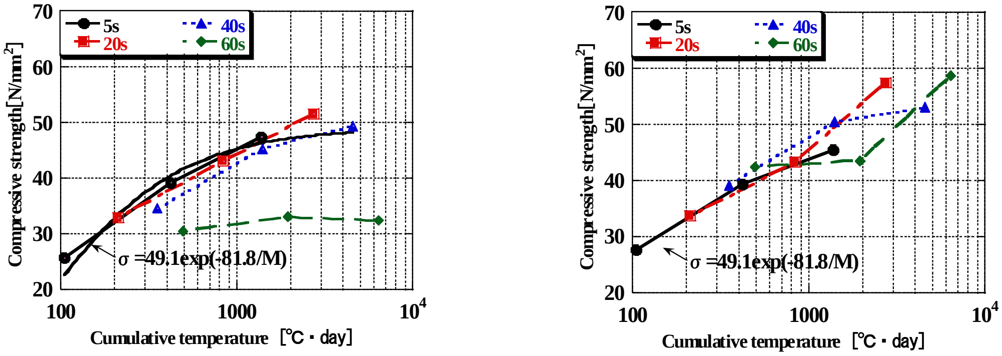
However, the relationship between cumulative temperature and compressive strength depends on cement type, fineness of powder, and mix proportions. Therefore, we predicted compressive strength using exponential function (2), which is a growth curve.

$$F = a \times exp\left(-\frac{b}{M}\right) \tag{2}$$

F: Compressive strength（N/mm^2） a,b: Experiment coefficient,

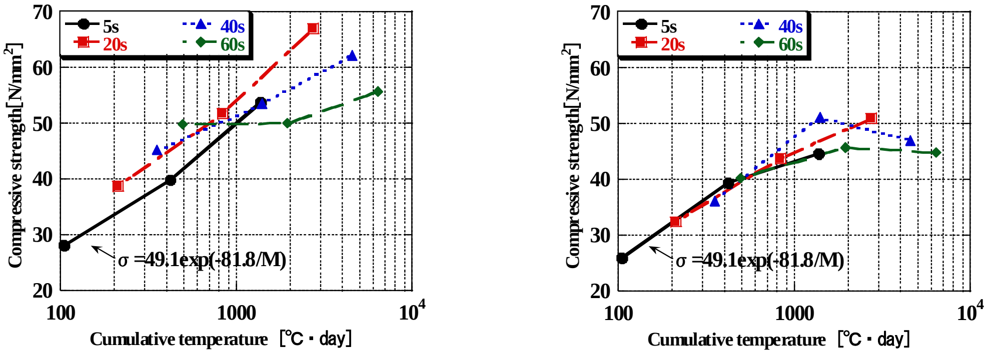
M: Cumulative strength (℃・day)

The experimental values in previous work tended to vary from the strength prediction curve for small amounts of cement (Mizobuchi *et al.* 2012). However, in this work, it was possible to secure at least some minimum amount of cement because it was part of the fine aggregate. Therefore, the experimental values generally followed the compressive strength prediction curve. In addition, the experimental coefficient, a, increased as the FA replacement rate increased, and the value of the strength prediction equation also increased. This result demonstrated that the strength increase with the FA replacement rate could be expressed by the strength prediction equation using the cumulative temperature even when modified FA was used. Therefore, one strength prediction curve was used for all curing temperatures.



(a) Modified FA5%.

(b) Modified FA10%.



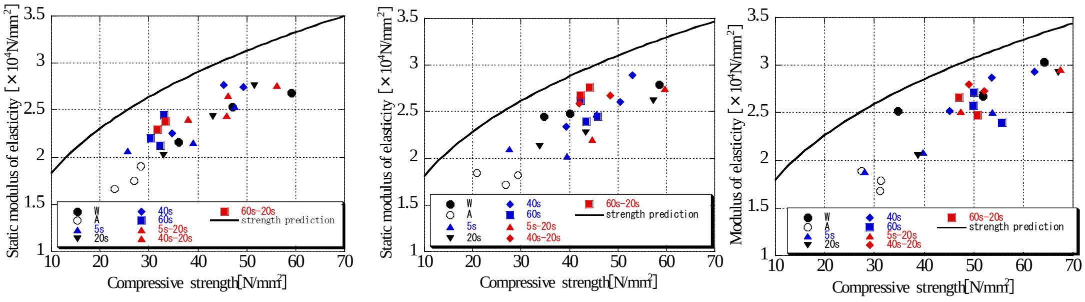
(c) Modified FA15%.

(d) Unmodified FA5%.

Figure 2. The relationship between compressive strength and cumulative temperature.

3.2 Static Modulus of Elasticity

Figure 3 shows the relationship between the static modulus of elasticity and compressive strength. The experimental values were distributed below those calculated with the Architectural Institute of Japan standard for structural calculation of reinforced concrete structures equation (The new RC equation) because the experiment was conducted with mortar. The experimental values followed the new RC equation; therefore, the new RC equation was suitable for describing the distribution of values, even for different curing temperatures. The distribution of the experimental values of the modified FA 15% specimens was wide because of the increase in compressive strength due to the increase in the FA replacement rate. These results showed that the static modulus of elasticity could be expressed in relation to compressive strength even for different curing temperatures.



(a) Modified FA5%. (b) Modified FA10%. (c) Modified FA15%

Figure 3. The relationship between the static modulus of elasticity and compressive strength.

4 CONCLUSION

The findings obtained in this research are shown below.

(1) In mortar using modified FA, compressive strength at initial hardening increases with higher curing temperature, but it can not be expected to increase long-term compressive strength. The lower the initial curing temperature, the greater the improvement in long - term compressive strength

(2) In mortar using modified FA, compressive strength also increases as FA replacement rate increases in any curing condition. Moreover, in the specimens given the temperature change, the strength increase rate increased as the replacement rate of FA increased.

(3) In addition, the experimental coefficient, a, increased as the FA replacement rate increased, and the value of the strength prediction equation also increased. This result demonstrated that the strength increase with the FA replacement rate could be expressed by the strength prediction equation using the cumulative temperature even when modified FA was used.

(4) In mortar using modified FA, static modulus of elasticity could be expressed in relation to compressive strength even for different curing temperatures.

Acknowledgments

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