

## **Influence of Fly Ash on Strength Development of Concrete and its Temperature Dependence**

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### **1 Introduction**

In recent years, in Japan, fly ash (FA) has been often used as a mineral admixture of concrete from the viewpoint of effective use of industrial waste and reduction of carbon dioxide (CO<sub>2</sub>) emissions. The use of FA as an admixture in concrete is said to be effective in improving concrete performance such as workability of concrete, reducing thermal cracks, development of long-term strength, and suppressing salt damage and alkali-silica reaction. The pozzolanic reaction peculiar to FA is activated beneficially to develop the strength of concrete as the curing temperature increases. On the contrary, when the curing temperature is low, the strength enhancement due to the pozzolanic reaction does not progress and the expected effect may not be obtained. Therefore, in order to make full use of the effect of fly ash used in place of cement, we obtained basic data on the mechanical properties of cement types with curing temperatures.

### **2 Experimental Plans**

The curing temperatures in the experiment were set as 5, 10, 20 and 30°C, and the specimens were divided into two groups; the three different specimens of the first group were composed of normal Portland cement (N), medium heat Portland cement (M), and low heat Portland cement (L) without FA, and the three specimens of the second group used the same kinds of cement with 30% of the cement being replaced by FA. Under these conditions, the specimens were subjected to the experiments of strength development (only in the case of N included 15% replacement by FA). For comparison, the specimen using blast furnace cement B was experimented. The FA used for this project was FA type II of JIS A 6201, with constant water to binder ratio (W/B) of 45%. The target slump 60 minutes after mixing was set at  $18.0 \pm 2.5$ cm, and the target content of air at  $5.5 \pm 1.5$ %. Referring to the test mixing, the rates of addition of AE water reducing agent (AD) and AE agent (AE) were determined. Specimens were taken after confirming at a fresh concrete test that the concrete satisfied the targets of the

slump and air content 60 minutes after mixing. Then, after curing for 24 hours in the initial curing room at a temperature of  $20 \pm 2^\circ\text{C}$  and relative humidity of 95% or more, the specimens were removed from the formwork. Prior to tests of hardened concrete specimens, they were cured in water under a predetermined temperature condition until reaching a determined age.

### 3 Experimental Results and Conclusion

The experimental results obtained are as shown below:

(1) In the mix proportions (blending) of N, M, L and BB, the higher the temperature, the faster the strength developed. However, strength increase slowed down early and reached a peak. On the other hand, the mix proportions (blending) using FA steadily developed long-term strength regardless of the difference in binder and curing temperature, exceeding the long-term strengths of N and M. Especially N15 — a mix proportion of N with 15% replacement by FA — did not peak even at about  $80 \text{ N/mm}^2$  of compressive strength which is 1.3 times N's peak of  $60 \text{ N/mm}^2$ , and we learned that FA substitution has a high impact on the compressive strength.

(2) In the mix proportions (blending) using N, M, L, and BB, it was shown that the strength increased highly correlated with the temperature adjusted concrete age (in logarithm) up to the moment its strength rate slowed down. On the other hand, the mix proportions (blending) using FA developed the strength for a long span of time, keeping a close correlation with the temperature adjusted concrete age.

(3) It was found that for the mix proportions (blending) using FA, the lower the initial strength of the base cement or the higher the replacement rate of FA, the slower the strength development. Moreover, it was found that they demonstrate the characteristics of strength development which correspond to those of the base cement. The mix proportion (blending) using the binder with a slower initial strength development tended to result in the larger strength.

(4) Regardless of the use of FA, the relationship between compressive strength and static Young's modulus and the relationship between compressive strength and dynamic Young's modulus were constant. The dynamic Young's modulus demonstrated a larger value than the static Young's modulus, and this trend was more conspicuous at young ages.

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