SERIES TOPICS OF Fly Ash Concrete

2nd Topic: Newly Proposed Rational Mix Design

Fly ash has been extensively treated as a partial replacement of clinker-cement in industries and the conventional mix design method of normal concrete has been applied. In other words, the qualitative property of cement binder is thought to be changed in terms of heat generation, higher workability and long-term strength development. Within this scheme of design, logically, fly ash cannot be effectively used more than the cement content of standard conventional concrete mixtures.

However, fly ash can be also used as the part of fine aggregates to improve the grading of natural sand, especially the sea sand with a few amounts of fine particles. In fact, we encounter current shortage of aggregates with necessary and sufficient quality in Japan. In this case, engineers do not explicitly require the upgraded quality of hardened concrete mechanics. But, some of fly ash may work as a cementitious binder as well. It means that the concept of replacing sand with fly ash cannot fully utilize its performance as the binder. Both methods as stated above may function practically but hardly get hold of full performances of fly ash.

For effective use of various characters of fly ash as a binder and the mineral powder, the committee proposes the new mix design method. Here, fly ash is not treated as the part of clinker-based cement or the part of aggregates. It specifies fly ash as an independent constituent component of concrete mixture. The performance based design scheme is selected as the platform on which the strength of hardened fly ash concrete, workability before hardening and its durability related quality can be quantitatively assessed. To meet the challenge, the committee proposes the general water to cement-fly ash ratio model for engineering practice as,

$$\sigma_7 = 24.016\,(C/W + k\,F/W) - 16.756$$
$$\sigma_{28} = 28.933\,(C/W + k\,F/W) - 15.658$$
$$\sigma_{91} = 32.213\,(C/W + k\,F/W) - 13.910$$

where C, F, W are unit contents of cement, fly ash and water (weight/concrete volume),
σ_d is the compressive strength at d-days and the effectiveness factor “k” represents the contribution of fly ash on the strength development as shown in Figure 1.

Although fly ash produces less hardened hydrate at early ages, the long-term strength development is brought about due to lower rate of hydration. Thus, the effectiveness of fly ash can be utilized according to the design period when the strength is to be assured. In other words, at the early age, fly ash is not the part of cement and mostly acts as the agent to improve the workability. But, fly ash is quantitatively assessed as a major component of cementitious powders at the middle or older ages with regard to the parameter “k”. This sort of dynamism of fly ash in concrete mixture could not be evaluated in the former design scheme.

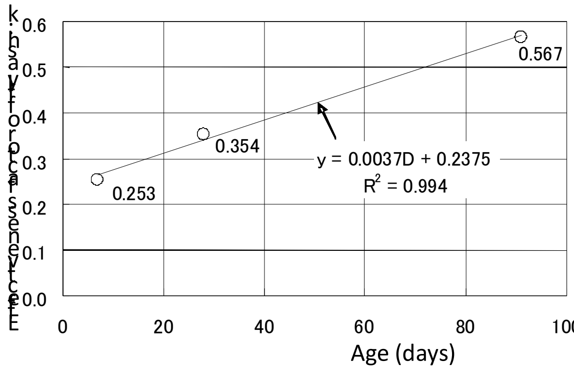

Figure 1 Effectiveness of fly ash on the strength development

We have the similar story on the workability assessment. Figure 2 shows three boundaries of workability limit states; overall consistency, segregation resistant limit state and excessive viscosity limit. These limit states has been specified for workability design method of conventional concrete. The committee verified the applicability to the fly ash concrete, and it was found that dosage of fly ash in mixture may fairly shift all limit states boundaries according to the particle shape and grading. In this framework, unit weight of powder materials is assigned as a governing factor. Thus, the effectiveness of both clinker-based cement and fly ash can be taken into account together and the quality of micro-particle features can be explicitly reflected on the practical design, which may realize more effective use of fly ash.

When we focus on the water content to produce the same consistency, fly ash may play an effective role for middle or large water to cement ratio as shown in Figure 3. This benefit can be automatically given by accepting the performance-based mix design in terms of entire powder content in the concrete composite mixture. The benefit of the reduced water content is furthermore evaluated in view of the volumetric stability and cracking risk assessment. These multiple profits can be considered in the new mix design.

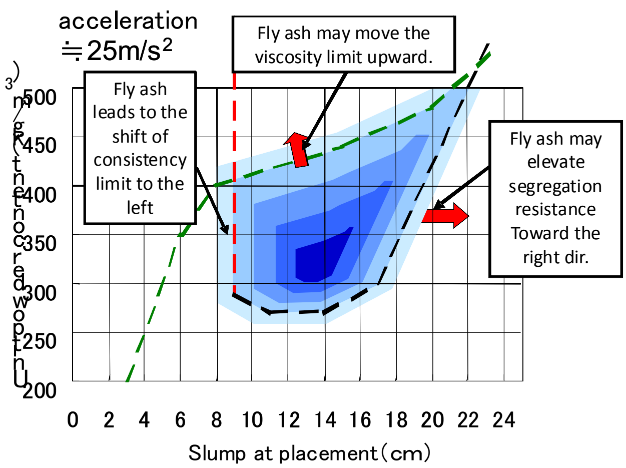

Figure 2 Trajectory of fresh concrete consistency and segregation resistance in practice.

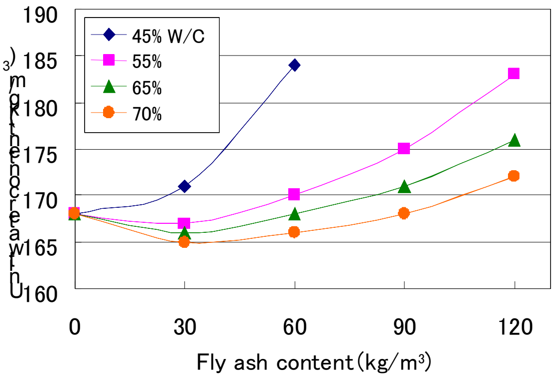

Figure 3 Water reduced by fly ash dosage

The higher performance of fly ash concrete against the alkali-aggregate reaction and cracking at early ages was investigated as well. This performance can be directly considered in the decision making process of mix design as well. These topics of interest will be discussed again in the forthcoming series.