Activity Summary of the JSCE 264 Subcommittee – Recommendations for Design and Construction of Concrete Structures Containing High-volume Mineral Admixtures –

1. Introduction

Concrete is a primary material that plays an essential role in infrastructure development. In Japan, the production of one tonne of Portland cement consumes over 450kg of industrial byproducts and waste as raw materials and fuels; this gives concrete considerable environmental credentials. Besides, there is a long history of using industrial byproducts and waste, such as ground granulated blast furnace slag (GGBS) and fly ash, as admixtures and as ingredients in blended cement. Using them in this way has the benefit of reducing CO_2 emissions during the production of binder. Lately, the market share of such blended cement is growing. As a measure to further reduce CO_2 emissions, it has been proposed that mineral admixtures consisting of industrial byproducts and waste might be used at replacement ratios far above those stipulated by the Japanese Industrial Standards (JIS). Studies to investigate this proposal are under way.

Against this backdrop, the Concrete Committee of JSCE set up the Subcommittee for the Study of Design and Construction of Concrete Structures Containing High Admixture Ratios (Subcommittee 264) in April 2016. Chaired by Prof. Tetsuya Ishida of the University of Tokyo, the subcommittee compiled a set of design and construction guidelines based on the properties of concrete containing mineral admixtures at the high ratio of 70% (by mass) or more of total binders (Table 1). The standard compositions of the cement and admixtures discussed in these guidelines fall within the range of the trapezoid formed by vertices c-d-e-i in Fig. 1.

2. Properties of concrete with high ratios of mineral admixtures

This section summarizes the basic properties required of concrete with high mineral admixture ratios and the properties that are achievable when large amounts of admixtures are used. Particular properties requiring consideration in the design and construction processes when using high admixture ratios are also summarized.

Concerning the workability, material segregation resistance of concrete with high admixture ratios tends to be larger than that of normal concretes, if the slump and strength of these concretes are identical. Flowability is lower in the smaller slump value range, though this depends on the blend. Moreover, due to the smaller water-binder ratio and the larger unit powder volume, the fresh concrete is highly viscous. For this reason, the required pumping power is greater than for normal concretes and pumping performance might be reduced. This requires attention.

Because of the low content of Portland cement in the binder, setting of the concrete tends to be late. Particularly in cases where concrete is placed in cold weather, it is recommended that sufficient testing be carried out to determine a suitable time interval before casting additional concrete over already placed concrete.

The relationship between binder-water ratio and compressive strength of concrete with a high admixture ratio is linear.

Concerning the durability of concrete, frost resistance may be insufficient even with a water-binder ratio of 35% if the air content is as low as around 4.5%. Therefore, for applications where severe freeze-thaw action can be expected, an air content of about 6% is recommended. Resistance to the alkali-silica reaction is higher than with normal concrete because of the high proportion of admixture.

From the perspective of protection against reinforcing steel corrosion, the carbonation rate is three or more times as large as that of normal Portland cement concrete with the same water-binder ratio. On the other hand, resistance to chloride ion penetration can be considered higher than with normal concrete.

Autogenous shrinkage is greater than with concrete containing only Portland cement. It has been confirmed that dry shrinkage is reduced to about the same level as with normal concrete or slightly less after sufficient curing.

A reduction in environmental burdens can be anticipated from concrete with a high admixture ratio. Among other advantages, greenhouse gas emissions are reduced and fuel consumption is lower during cement production, the effective use of industrial byproducts is promoted, and natural resources are conserved.

3. Points to note in design and verification

As with normal concrete, the design of concretes with high admixture ratios should in principle be verified in compliance with the methods provided in Standard Specifications for Concrete Structures – Design –. Some of the characteristic values used in mixture design have not been fully verified because concrete with high admixture ratios has been available for only a few years. If judged necessary, such characteristics should in principle be verified through testing. Moreover, if the verification of properties relating to the long-term durability, etc., is considered lacking, design values should be set with a enough margin.

There is a general tendency for carbonation to progress readily in concrete with high admixture ratios, even in environments where carbonation is generally slow – including marine environments, such as the wave breaking area of the shore, and cold areas where anti-freezing agents are applied. This results in the combined action of carbonation and the chloride intrusion. In the case of an environment in which this combined action is anticipated, the guidelines require the carbonation depth of concrete to be verified by considering the remaining non-carbonated cover depth over the reinforcing steel. To determine the characteristic value of carbonation rate coefficient, α_k, it is recommended to carry out exposure testing under conditions equivalent to environmental conditions at the actual site. If test results are not available, it is permissible to use an estimated value of carbonation rate coefficient obtained according to JIS A 1153:2012 “Method of accelerated carbonation test for concrete.” If is not possible to perform the test, the effective water-binder ratio can be used to predict the characteristic value. The appendix of this recommendation provides examples of mix proportions of concrete in which the contribution of admixtures to the carbonation rate coefficient can be set to k=0.3.

Currently, no formulas are available for obtaining the characteristic value of chloride ion diffusion coefficient in concrete with high admixture ratios from the mix proportions, etc. Therefore, it is recommended to measure the distribution of chloride ion concentration in the concrete of an actual structure exposed to the same environmental actions as anticipated for the structure under study. The characteristic value of diffusion coefficient can then be obtained from the chloride ion distribution. If such data is unavailable, it is recommended to conduct immersion test according to "Test method for apparent diffusion coefficient of chloride ion in concrete by submergence in salt water" (JSCE-G 572-2013) to determine the characteristic value. Generally, as the rate of chloride ion intrusion into concrete with high admixture ratios is low, the immersion period should be at least a year.

4. Points to note in blend design, production and placement

In concrete with high admixture ratios, the water-binder ratio is lower and the unit powder volume is greater for a given strength than in normal concrete. Generally, however, from the perspective of materials and construction, such concrete can be treated as equivalent to normal concrete. Therefore, this section mentions only the points where particular attention is required.

Concerning the properties of the fresh concrete, as Fig. 2-B shows, under certain mix proportions, material segregation resistance can be greater than that of normal concrete with the same slump value and the flowability can be lower at small slump values. (Hereafter, this is expressed as a "high viscosity".) Moreover, a low content of Portland cement in the binder tends to delay the concrete setting. Attention must be paid to these unique characteristics during the production and placement of concrete. If, for example, normal concrete production and placement processes were to be used, the following problems might arise: insufficient mixing; decline of pumping performance; narrow propagation area of vibrators leading to inadequate compaction; and insufficient curing. Furthermore, the very small proportion of cement in concrete could increase errors in weighing cement.

The unit water volume should be as small as possible for concrete with high admixture ratios. However, with an extremely small water volume, viscosity rises too high. Moreover, in some cases there may be less leeway for adjusting the mix proportion to ensure proper workability and hardened properties than with normal concrete. This means that the types and quantities of chemical admixtures must be selected very carefully. It is also worth noting that, even though a higher slump may be set than for normal concrete, proper workability can still be obtained thanks to high viscosity and high material segregation resistance of high additive ratio concrete. Moreover, if the target slump value of the concrete just after the mixing is increased by considering the significant decline in slump expected during transportation, it is recommended that management of concrete production should include slump flow testing.

Table 1. Recommendations for Design and Construction of Concrete Structures Containing High Mineral Admixture Ratios

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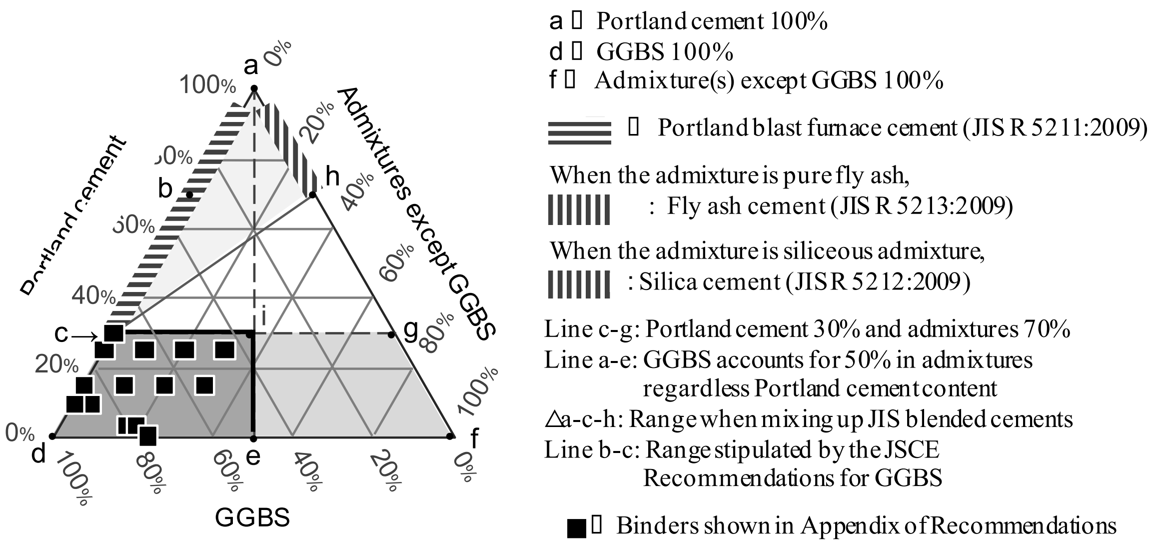

Fig. 1 Standard cement and admixture compositions of concretes with high admixture ratios

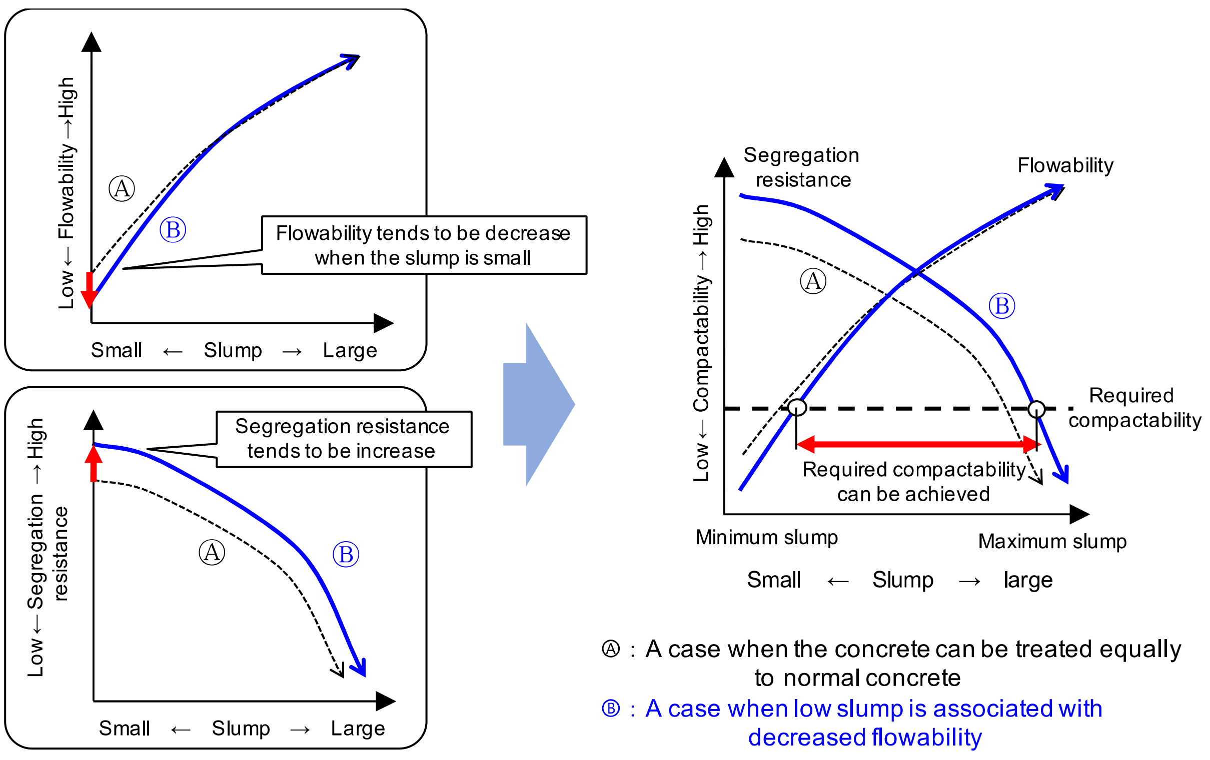

Fig. 2 Conceptual diagram of compactability of concrete with high admixture ratios