A STUDY ON THE ENHANCEMENT OF DURABILITY PERFORMANCE OF FACED SLAB CONCRETE IN CFRD

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Abstract

The main purpose of this research was to enhance the durability in both the design and construction of dams. Especially, in case of rockfill dams, the durability of face slab concrete in a concrete-faced rockfill dam(CFRD) is achieved by optimizing the fly ash replacement for cement and application of PVA(Poly Vinyl Alcohol) fibre. The effect on durability corresponding to the increasing replacement of fly ash and application of PVA fibre was evaluated, and the optimum value of fly ash replacement and fibre application was recommended. The results show that 15% of fly ash replacement and 0.9kg/m^3 of PVA fibre application were found to be an optimum level and demonstrated excellent performance in durability.

1. Introduction

Dams are permanent structures that must be made from highly durable concrete. However, since they are mass concrete structures that are constructed in one continuous build using large amounts of concrete, they have a high risk of cracking due to both the effects of hydration heat produced while the concrete hardens and the very large surface area of the structures. Examination of the causes of cracks in dam concrete has revealed that plastic shrinkage cracking results from the rapid evaporation of moisture due to hydration heat in the initial stage of hardening. Plastic shrinkage cracking in concrete is affected by environmental conditions such as temperature, relative humidity and wind speed, as well as factors such as the internal concrete temperature and bleeding. At the time of concrete pouring, loss of moisture due to foundational or moulding material and the internal loss of water due to surface evaporation during the hydration period provide, to a certain degree, initial stage binding of the concrete surface, and thereby make the occurrence of plastic shrinkage cracking possible. When a crack, either internal or external, occurs in dam concrete, the water permeability increases and causes the durability of the structure to deteriorate. This may have a serious impact on safety of dams. Durability rapidly deteriorates under environmental conditions such as repeated freezing and thawing in winter, abrasion from flowing water and repeated drying and wetting from the increase and decrease of water volume in the summer.

The major causes of damage are freezing, water penetration, degradation and erosion. Therefore, the durability of dam concrete must be enhanced. During the initial stage of hardening, the compressive strength of fly ash concrete is lower than that of ordinary Portland cement (OPC) concrete because the strength of fly ash concrete develops slowly [1–3]. There is a need to determine the appropriate amount of fly ash to be added to face slab concrete in order to improve the durability of a CFRD. As face slab concrete is mass concrete with large sectional areas, doing the pouring all at once is, however, impossible. One must ensure that the initial strength of the previously poured concrete is sufficient to support the new concrete. Therefore, the constructability of a dam must be considered along with its durability. The main purpose of this study was to establish the most effective mixing ratio of fly ash that provides the best economical efficiency and long-term durability for face slab concrete used in CFRDs. The existing test results described above suggest that the appropriate level of fly ash was in the range of 0–25%. In addition, they also suggest that the poly vinyl alcohol fibre has a hydrophilic property, a good resistance of crack occurrence, and a number of good results of durability tests of concrete. Thus, this study also evaluated the improved crack control and durability that resulted when poly vinyl alcohol fibres were added to the fly ash concrete.

2. Experimental Program

2.1 Mixing Ratio of Dam Concrete

A total of six different mixtures were produced. Table 1 shows the mixing ratios of fly ash and poly vinyl alcohol fibre in the concrete that were considered in the tests. The fly ash was used to retard the hydration heat and thereby control the heat-induced temperature cracks. The amount of fly ash ranged from 0 to 20% of cement by weight. This range was selected by considering the required initial-stage work strength of the face concrete and the desired economic efficiency and constructability of the face slab. A 0.1% poly vinyl alcohol fibre mixture was used to control plastic shrinkage cracking.

Table 1. Mixing Ratio of dam concrete

f_{ck} (MPa)	kg/m^3						
	W	C	F/A	S	G	AD	PVA
24	154	328.0	0.0	748	1,036	1.48	0.0
24	154	328.0	0.0	748	1,036	1.48	0.9
24	154	278.8	49.2	748	1,036	1.48	0.0
24	154	278.8	49.2	748	1,036	1.48	0.9
24	154	262.4	65.6	748	1,036	1.48	0.0
24	154	262.4	65.6	748	1,036	1.48	0.9

2.2 Test Methods and Procedure

The main objective of this study was to assess and improve the long-term durability of face slab concrete in CFRD. To evaluate the long-term durability of face slab concrete, accelerated aging tests were conducted in a laboratory to simulate long-term field exposure conditions. Accelerated aging conditions were examined through compressive strength, flexural strength, plastic shrinkage, adiabatic temperature rise, chloride ion resistance, abrasion resistance, and repeated freezing and thawing tests.

2.3 Compressive strength test

Compressive strength tests were used to evaluate the dam concrete in accordance with the ASTM C 39-96 standard [4]. Cylindrical specimens of diameter 150mm and 300mm height were initially cured for one day, and then cured in water at 23 ± 2°C. Each test was performed on three specimens after 91 days of curing.

2.4 Flexural strength test

Flexural strength tests were carried out according to the ASTM C 78 standard [5]. These were repeated twice for two samples taken from dam concrete after 91 days of curing.

2.5 Plastic shrinkage test

The conventional experimental method for measuring the plastic shrinkage of concrete is to observe the process followed by any crack formed due to plastic shrinkage by providing a constraint so that the restraint stress in the concrete is affected by any variation in the constraint, configuration, material or environment when the concrete is actually cast. We therefore conducted tests in accordance with the experimental method used in existing studies to evaluate the plastic shrinkage of dam concrete (Fig. 1). The tests were conducted by observing the crack area when a specimen surface was exposed to wind at 4.0–4.6 m/s at a temperature of 28°C and a relative humidity of 35%. Each test was repeated twice.

Fig. 1. Experimental apparatus for crack due to plastic shrinkage

2.6 Adiabatic temperature rise test

The rise of internal temperature due to heat of hydration of concrete, which varied with fly ash replacement, was estimated, and the effect of adiabatic temperature rise of concrete was analyzed. In this study, concrete calorimeter was used, and the values were measured per 30 min for 14 days just after placement.

2.7 Chloride ion penetration

This test was carried out according to the ASTM C 1202-97 standard [6] to measure the quantity of chloride ion penetration. The amount of chloride ions that penetrated the specimen after 6h was measured using an electrical indicator. The specimens were water-cured for 91 days.

2.8 Abrasion resistance

This test was used to evaluate the change in abrasion resistance caused by adding fly ash and poly vinyl alcohol fibre to the cement mixture. The tests were performed according to the ASTM C 779-95 standard [7], following Procedure B using dressing wheels. The 300mm × 300mm × 150mm specimens were water-cured for 91 days. The speed of revolution of the dressing wheels was 56 rpm. The depth of abrasion in each specimen was measured after exposure to the abrasive force for 30 and 60 min.

2.9 Repeated freezing and thawing

This test was used to investigate any possible degradation of the cement-based material exposed to repeated freezing and thawing cycles. The freezing of water in the mortar capillary pores causes an internal pressure that leads to cracking and the deterioration of the concrete. This is because the water volume increases when it turns to ice, creating an expansion pressure that can exceed the tensile strength of the concrete. This test was used to analyse the effect of fly ash and poly vinyl alcohol fibre on the resistance of concrete to specific cycles of freezing and thawing. It was carried out according to the ASTM C 666-92 standard [8]. The dynamic modulus of elasticity of each specimen after 300 cycles was used as the durability factor.

3. Experimental results

3.1 Compressive strength test

The compressive strengths measured in specimens cured for 91 days are shown Fig. 2. The results indicated that the long-term strength of fly ash concrete was better than that of OPC when the fly ash content was 20% at 91 days [Fig. 2 shows that the strength improves for all tested levels of fly ash.]. The compressive strength of the poly vinyl alcohol fibre-reinforced concrete was slightly higher than that of other concrete, but the difference was small. At day 91, all fly ash mixtures showed an increase in strength.

3.2 Flexural strength test

The flexural strength test results are shown in Fig. 3. The long-term strength of fly ash concrete was better than that of OPC, when 20% fly ash was used. The flexural strength of the poly vinyl alcohol fibre-reinforced concrete was slightly higher than that of other concrete, but the difference was small.

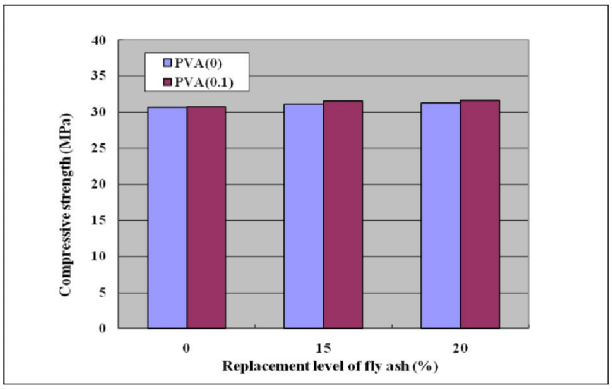

Fig. 2. Results of compressive strength test

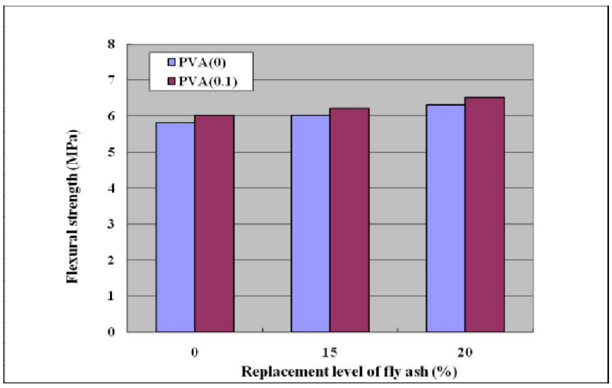

Fig. 3. Results of flexural strength test

3.3 Plastic shrinkage test

The results of the plastic shrinkage test are shown in Fig. 4. The substitution of fly ash in the concrete reduced the plastic shrinkage, with the greatest effect observed for the 15% fly ash content. The amount of plastic shrinkage due to the addition of poly vinyl alcohol fibres was considerably less than that of other concrete.

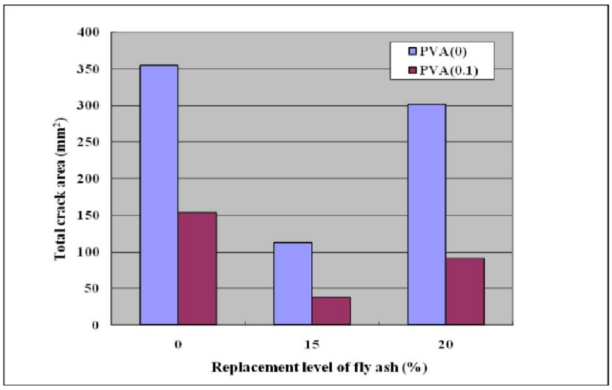

Fig. 4. Results of plastic shrinkage test

3.4 Adiabatic temperature rise test

The results of the adiabatic temperature rise test are shown in Fig.5 and Fig. 6. Fig. 5 shows the change of value of adiabatic temperature rise in varying fly ash replacement. The substitution of fly ash in the concrete reduced the value of adiabatic temperature rise, with the greatest effect observed for the 20% fly ash content.

Fig. 6 shows the change of reaction rate and the reaction rate decreased in varying fly ash replacement. The reaction rate decreased because fly ash restrained or retarded temporarily reaction of hydration, and as the amount of fly ash replacement was increased, this tendency was more apparent. The amount of reaction rate due to the addition of poly vinyl alcohol fibres was slightly more than that of other concrete. The values of adiabatic temperature rise and reaction rate obtained through this test will be applied to analyze the possibility of crack development due to thermal stress.

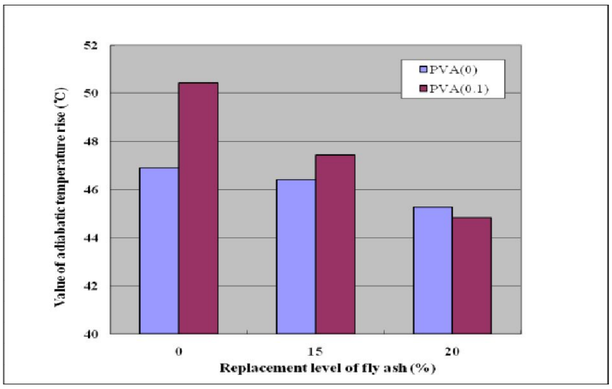

Fig. 5. Results of adiabatic temperature test

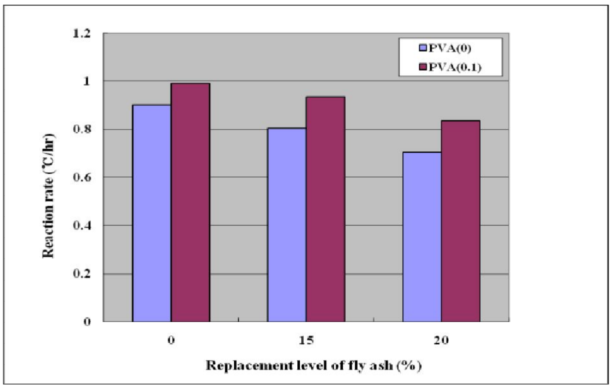

Fig. 6. Results of reaction rate test

3.5 Chloride ion penetration

The quantity of electric charge passing through the concrete was used to estimate its permeability characteristics, but not to obtain an exact coefficient of permeability. Specimens were water-cured for 91 days. The results are shown in Fig. 7. The long-term permeability resistance was most effective when the fly ash content was 20%. Generally, when fly ash and blast furnace slag are added to concrete, the texture of the concrete becomes denser and the permeability becomes lower. Our test results were in agreement with this general tendency. The quantity of electric charge passing through the poly vinyl alcohol fibre-reinforced concrete was less than that passing through the concrete without fibre.

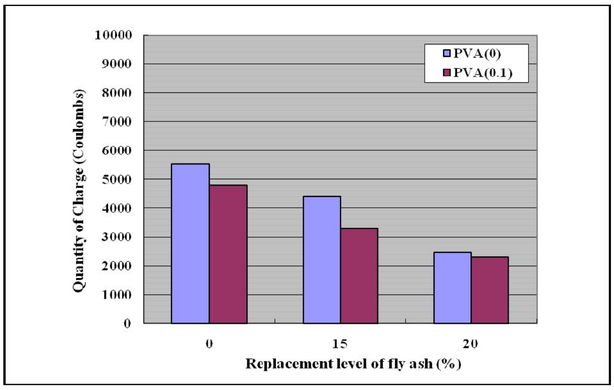

Fig. 7. Results of chloride ion penetration test

3.6 Abrasion resistance

The results of the abrasion resistance test are shown in Fig. 8. For the 30min tests, the abrasion resistance increased with the fly ash content. The abrasion resistance of the specimens cured for 91days was greatest when the fly ash content was 20%. In general, when fly ash is added to concrete the water repellence and durability increases, the present experiments were in agreement with this general tendency. The abrasion resistance of the poly vinyl alcohol fibre-reinforced concrete was only slightly better than that of the concrete without fibre.

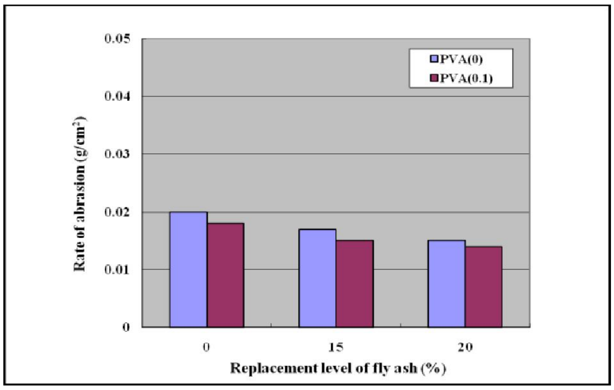

Fig. 8. Results of abrasion resistance test

3.7 Repeated freezing and thawing test

The repeated freezing and thawing test was conducted for 300 cycles. The average relative dynamic moduli of elasticity of the specimens during the test are shown in Fig. 9. The results obtained after the 300th cycle were taken as the durability factors. The freezing and thawing resistance bettered slightly as the amount of fly ash increased. The addition of poly vinyl alcohol fibre also increased the resistance. In this test, the freezing and thawing resistance was greatest when the 20% fly ash was added to the concrete with fibre.

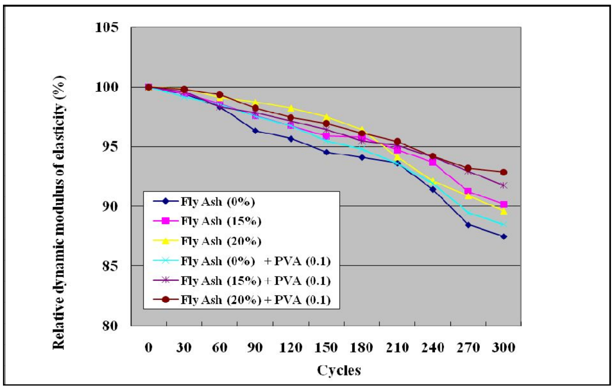

Fig. 9. Results of relative dynamic modulus of elasticity for each cycle

4. Conclusions

The following conclusions were obtained from this study.

(1) The amount of plastic shrinkage was least when the fly ash content was 15%. The addition of poly vinyl alcohol fibre reduced the plastic shrinkage considerably.
(2) The substitution of fly ash in the concrete reduced the value of adiabatic temperature rise, with the greatest effect observed for the 20% fly ash content. The amount of reaction rate due to the addition of poly vinyl alcohol fibre was slightly more than that of other concrete.
(3) The chloride penetration test showed that the specimens with 20% fly ash had the best long-term permeability resistance. The addition of poly vinyl alcohol fibre improved the permeability resistance slightly.
(4) The abrasion resistance of the specimens was greatest when the fly ash content was 20%. The abrasion resistance of the poly vinyl alcohol fibre-reinforced concrete was only slightly better than that of the concrete without fibre.
(5) The freezing and thawing resistance bettered

slightly as the amount of fly ash increased. The addition of poly vinyl alcohol fibre also increased the resistance. In this test, the freezing and thawing resistance was greatest when the 20% fly ash was added to the concrete with fibre.

On the basis of the above results, we conclude that the optimal durability and economical efficiency of dam concrete can be obtained when the fly ash content is 15% and the poly vinyl alcohol fibre content is 0.1%. Therefore, this is recommended as the most effective mixing ratio for face slab concrete in CFRDs.

References

[1] Lee, C. Y., Lee, I. D., Kim, K. W. and Bae, S. Y., "Resistance of freeze-thaw and strength development of recycled concrete", *Journal of Korea Concrete Institute*, Vol.10, No. 4, pp 163-169, 1998.

[2] A. M. Neville "*Properties of Concrete*", 4th edition, Addison Wesley Longman Limited, 1995.

[3] Naik, Tarun R., Singh, Shiw. and Bruce, Ramme., "Mechanical properties and durability of concrete made with blended fly ash", *ACI Materials Journal*, Vol.95, No. 4, pp 454-462, 1995.

[4] AMERICAN SOCIETY FOR TESTING AND MATERIALS. *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*. American Society for Testing and Materials, West Conshohocken, PA, USA, 1996, ASTM C 39-96.

[5] AMERICAN SOCIETY FOR TESTING AND MATERIALS. *Standard Test Method for Flexural Strength of Concrete.* American Society for Testing and Materials, West Conshohocken, PA, USA, 1994, ASTM C 78.

[6] AMERICAN SOCIETY FOR TESTING AND MATERIALS. *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*. American Society for Testing and Materials, West Conshohocken, PA, USA, 1997, ASTM C 1202-97.

[7] AMERICAN SOCIETY FOR TESTING AND MATERIALS. *Standard Test Method for Abrasion Resistance of Horizontal Concrete Surfaces*. American Society for Testing and Materials, West Conshohocken, PA, UA, 1995, ASTM C 779-95.

[8] AMERICAN SOCIETY FOR TESTING AND MATERIALS. *Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing*. American Society for Testing and Materials, West Conshohocken, PA, USA, 1992, ASTM C 666-92.