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Abstract

In order to reduce the hydration heat of cement and thus to decrease the cracks of concrete caused by temperature strains, a large amount of fly ash has been used in concrete dams in China. This paper reported the effects of fly ash on the strength, deformation and durability of the concrete dam of Longtan in China. The results show that there is a relationship between the content of fly ash and the strength, or the deformation and durability of concrete. More than 50% fly ash may be used in the construction of large dam of Longtan.

Keywords: Fly ash; concrete dam; roller compacted concrete; deformation; durability

1. Introduction

Fly ash, an inorganic residue of coal burning thermal power plants is available in large quantities. The disposal of fly ash has been a problem in the world, and using fly ash in construction of dams is a way to recycle wastes. As a construction material, fly ash provides a cheap mineral resource, and may improve some properties of concrete, so it has been used widely in construction of dams, for example, Willow Creek Dam in America, Arabie Dam and Zaaihoek Dam in South Africa [1].

Due to the steady, rapid and continuous development of China economy, a great number of hydropower stations will be set up at the beginning of 21st century. At the same time, the situation of dams under construction may be improved further. Before the 1980s, China was distinguished only in the quantity of dams, and now dam's height increases rapidly. The well-known Three Gorges Project dam is the largest one in the world and a milestone of tremendous improvement of dam construction technology in China, in which only 30% fly ash has been used. Although the material qualities and temperature differences in the concrete were controlled strictly, superficial cracks were often found. Longtan dam (Hight=216.5 m with the first stage 192 m) will be the highest roller compacted concrete gravity dam in the world [2][3]. It will be a challenge to control cracks in the dam.

The roller compacted concrete (RCC) is often used in the construction of dams and pavements. RCC differs from conventional concrete (CC) not only as regards the placement method, but also its consistency and mixture [4]. It is an extremely dry concrete that is very difficult to compact by the normal methods for workable concrete. To reduce the risk of thermal cracking, these materials are usually characterized by the additions of a low cement dosage and large volume of mineral wastes, such as fly ash, and mineral slag. Utilization of fly ash in dam applications is feasible due to the availability of fly ash and its effect of reducing hydration heat of cement.

When adding a large volume of fly ash to RCC, the adiabatic temperature rise and strain have been reduced, but the strength and durability of RCC may be reduced at the same time [5]. The large volume fly ash and low cement content of RCC have two main consequences on its internal structure: the paste is normally less homogenous and the concrete contains a certain number of so-called compacted voids [6]. Due to the reasons of above, the permeability of RCC may be higher than that of conventional concrete, and the strength and durability may be reduced.

As the history of RCC is not long in the world, sufficient tests need to be made in the laboratory and in the field for the large volume applications of fly ash in dam construction. In order to improve the strength and durability of RCC, it is often to control the quality and content of fly ash and to entrain air [7]. Through the strength and durability test of concrete, we may estimate the success or failure of using fly ash in RCC dam construction.

2. Materials and methods

2.1 Materials

Fly ash, from Guizhou Province (Fa). Cement, China 52.5 medium heat Portland cement, from Guangxi Province, the mineral composition and strength of it as follows: C_3S, 50.77%; C_2S, 21.57%; C_3A, 3.06%; C_4AF, 16.28%; compressive strength: 3d, 30.4MPa; 7d, 44.0MPa; 28d, 60.2MPa. MgO-bearing expansive agent and retarded naphthalene water reducing agent were used in RCC. The chemical compositions of these materials and the physical property of fly ash are shown in Table 1 and 2, respectively.

The fine aggregate (fineness modulus of 2.5) had a well-graded size distribution and a well-rounded shape. Two types of coarse aggregate of a maximum size of 20 mm were used.

Table 1 Chemical composition of materials /%

Item	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	L.O.I	∑
Cement	20.90	4.57	5.35	60.91	3.81	2.59	1.48	99.61
Fly ash	46.53	27.69	16.52	2.56	1.45	0.80	3.82	98.57
Expansive agent	14.29	2.54	1.05	39.46	38.31	0.05	3.02	98.72

Table 2 Physical property of Fly ash

Loss /%	Water contain ratio /%	Residue sieve /%		SO_3 /%	Density /g/cm^3	Water requirement ratio /%
		45 μm	80 μm			
3.82	0.40	0.5	2.5	0.8	2.36	93.2

2.2 Methods

The concrete specimens used in this strength test were 100 × 100 × 100 mm, and the mix proportions of these specimens are shown in Table 3.

Table 3 Mix proportion of RCC / kg/m^3

Cement	Fa	Water	Expansion agent	Aggregate		Sand	Superplasticizer
				2.5~10 mm	10~20 mm		
200	0	96	16	635	803	720	1.4
140	60	96	16	635	803	720	1.4
100	100	96	16	635	803	720	1.4

The specimens were mixed and moulded by vibration with the following conditions: frequency 50Hz, surcharge mass 20kg. After being placed in a fog room (20℃, 90% RH) for 48 hours, the specimens were demoulded and cured in water at 20 ± 2℃ for 28 days, and then the strength and mass of specimens were measured.

The concrete specimens for expansions test were 75 × 75 × 280 mm. The specimens were demoulded and then cured in a fog room (20℃, 90% RH) for 48 hours, and the length of specimens (L0) were measured. After placing them in a fog room for 7, 14, 28, 60, 90, 120,150 and 180 days, the length of specimens (L1) were measured. The expansions of RCC may be determined.

Expansion (%) = $(L_1 - L_0) \times 100\% / L_0$

According to ASTM Standard C666 procedure "A" and the China National Standard SD 105-82, the freezing and thawing tests were carried out immediately. In a freezing and thawing unit, the freezing rate in this apparatus is approximately 4℃/h, all tests were continued for 300 cycles, then the strengths and mass losses of specimens were measured, the fly ash and the air void in the microstructure of RCC have been investigated by optical microscopy and scanning electron microscopy.

3. Results and discussions

3.1 Influence of fly ash content on the compressive strength of RCC

The effects of fly ash on the compressive strengths of RCC with 8% expansive agent are shown in Fig.1.When the content of fly ash varies from 0% to 30% and to 50%, the compressive strength of RCC in the curing time 7d are reduced obviously. However, there is slightly improvement for the compressive strength of RCC in the curing age of 28d. In the period of 90d, the compressive strength of RCC with 30% are almost equal to that of RCC without Fly ash, and the compressive strength of RCC with 50% are higher than that of RCC with 30% Fly ash and without fly ash. The results are shown that appropriate content and good quality fly ash replacing cement do not reduce, but may improve the compressive strength of RCC slightly in the later age.

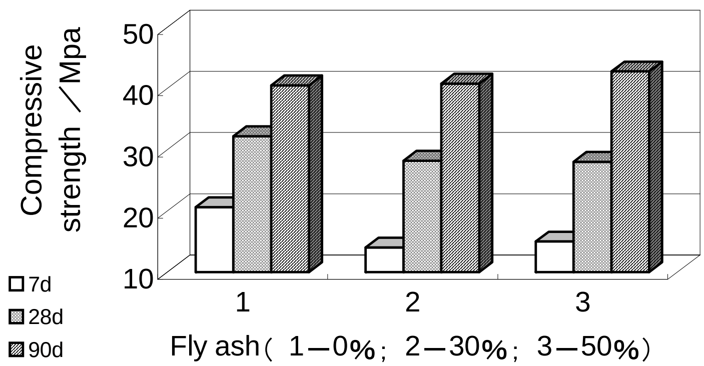


Fig.1 Influence of Fa on strength of RCC with 8% expansive agent

3.2 Influence of fly ash on the expansion of RCC

The expansion properties of RCC with 8% MgO type expansion agents and 0%, 30%, or 50% fly ash are studied respectively, and the results are shown in Fig.2.

Without fly ash, both the early shrinkage at 28d and later expansion at 90d of RCC with expansive agents are larger. When 30% and 50% cement were replaced by fly ash, the shrinkage in early period was reduced, and the larger expansion in later period was controlled. The deformation of RCC with 50% fly ash is lower than that with 30% fly ash. This result showed that the fly ash might decrease the deformation of RCC with expansive agent. Adding fly ash may reduce the cracks of concrete dam.

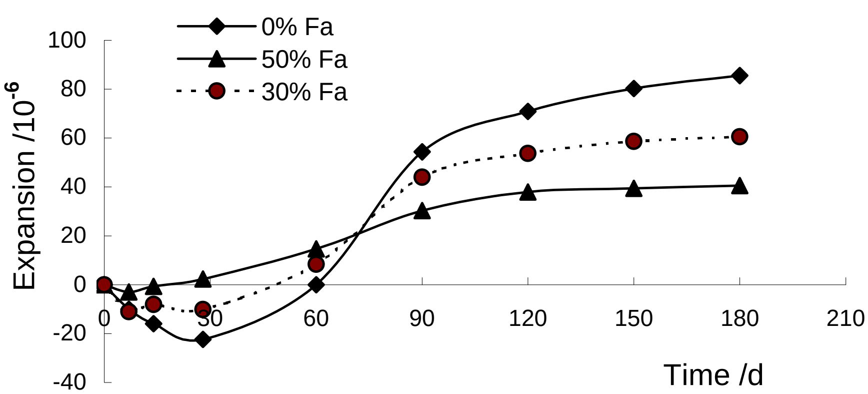


Fig. 2 Influence of Fa on the expansion of RCC with 8% expansive agent

3.3 Loss in strength and mass of RCC after 300 cycles

The results of the freezing and thawing tests carried out on the RCC are summarized in Fig. 3 and 4 where the strength and mass losses after 300 cycles are shown.

From Fig.3 and 4 it is can been seen that all RCC have not been damaged by the freezing and thawing cycles. When the content of fly ash increased from 0 to 30%, the strength and mass losses of RCC increased slightly. When from 30% to 50%, the strength and mass losses decreased, and lower than that of RCC without fly ash. All the strength and mass losses of RCC after 300 freezing and thawing cycles were far below 25% and 5% defined in ASTM. The results indicate that appropriate content of fly ash in RCC may exhibit good freezing and thawing resistance, thus improve the durability of concrete dam.

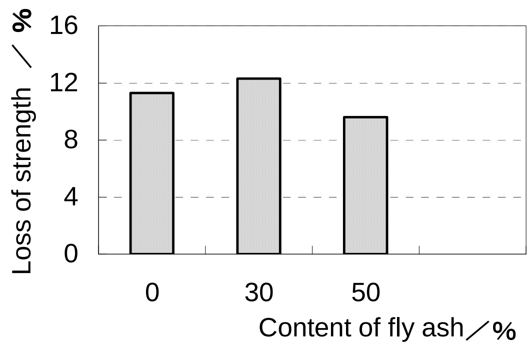


Fig. 3 Strength losses of RCC with Fa after frost

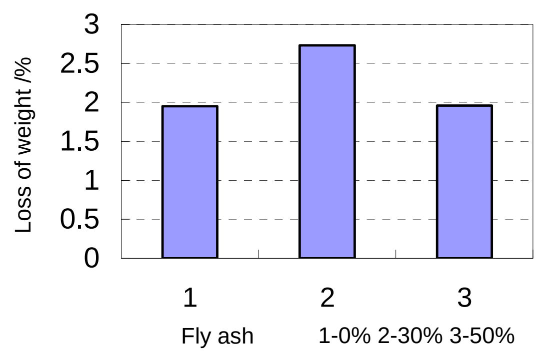


Fig. 4 Weight losses of RCC with Fa after frost

3.4 Observation on fly ash in RCC

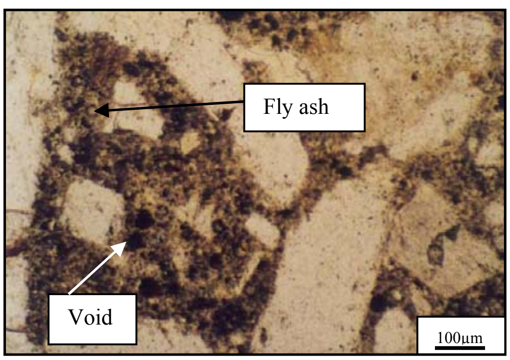


Fig. 5 Optical micrograph of RCC with 50% Fa

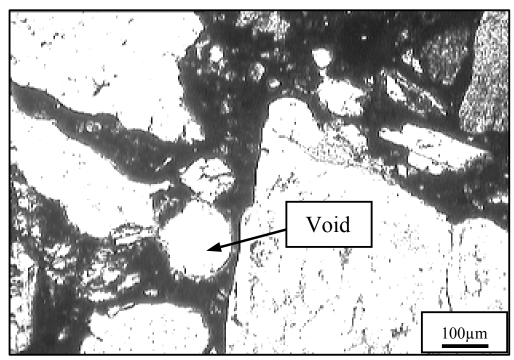
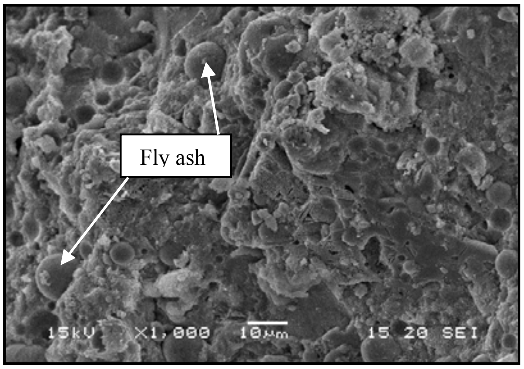


Fig. 6 Optical micrograph of RCC without Fa

Under the optical microscope, irregularly shaped compaction voids in RCC (Fig. 5) and reacted fly ash were observed. From Fig. 5, fly ash was filled into the interface between aggregate and mortar, and decreased the radius and amount of voids in RCC. The radius of voids in RCC with 50% fly ash was almost the half of that of RCC without fly ash. The lower the radius and amount of voids in RCC with 50% fly ash, the higher the density of the RCC. As the irregularly shaped compaction voids in RCC are not continuous and close to each other, the permeability of RCC with fly ash may be lower than that of conventional concrete. Due to the reasons of above, the compressive strength and durability of RCC with fly ash may be improved.

Under the scanning electron microscopy, the unreacted fly ash in RCC (in Fig.7) with 50% fly ash can be observed. The unreacted fly ash in RCC may be separated from mortar after frost (in Fig.8), and reduce the adherence between mortar and aggregate, thus the mechanical properties and durability of RCC with fly ash would decreased. With optimum content and quality of fly ash, water reducing agent and aggregate, under large vibratory rollers can make RCC pressed together. Thus the number of voids may be reduced and not to form continuous void network, and the resistance to freeze-thaw cycles will obviously be improved.



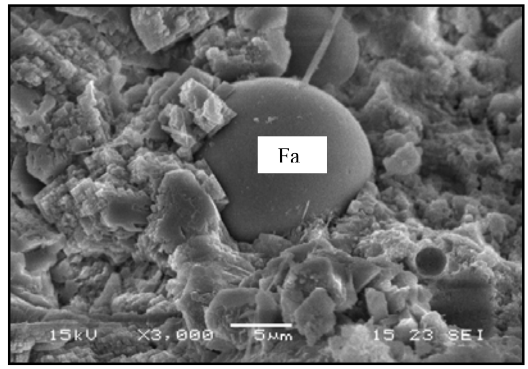


Fig. 7 Unreacted Fa in RCC observed by SEM Fig. 8 Fa apart from mortar in RCC after frost

4. Conclusions

When the content of fly ash increased from 0 to 30% and to 50%, the compressive strength of RCC are decreased before 7d and 28d, but the compressive strength of RCC with 50% fly ash are better than that of RCC with 30% fly ash or without fly ash slightly after 90d.

Fly ash may decrease the deformation of RCC, so reduce the cracks of concrete dam. At 50% fly ash addition, the shrinkage was reduced significantly and the expansion was increased slowly.

When the content of fly ash varies from 0 to 30% and to 50%, the strength and mass losses of RCC after 300 freezing and thawing cycles were below 25% and 5%. Appropriate content fly ash may exhibit good freezing and thawing resistance for RCC, and improve the durability of concrete dam.

Fly ash may fill into the interface of aggregate with the mortar, and improve the pore structure and density in RCC. Unreacted fly ash in RCC may be separated from mortar after frost, and decreased the mechanical properties and durability of RCC. The optimum content and quality of fly ash are two important factors in the construction of mass concrete dam.

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