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Effects of High-volume Fly Ash on the Properties of Roller Compacted Concrete: A Review

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Abstract: *Roller compacted concrete (RCC) is a kind of dry and water-poor concrete, which has the advantage of less water consumption, fast construction speed using roller compaction machine compaction and low cost. RCC is often used in water conservancy projects. This paper outlines the effects of fly ash on the impact of compacted concrete in terms of compressive properties, flexural properties, dynamic modulus of elasticity, impermeability performance and crack resistance based on the working mechanism of fly ash in concrete. In a certain range, the performance of RCC is improved with the increase of fly ash content. Finally, this paper puts forward some suggestions for the further research of RCC.*

Keywords: *Roller compacted concrete; High volume fly ash; Mechanical properties; Durability*

1. Introduction

Roller compacted concrete (RCC) is widely used because of its low water consumption, fast construction speed and low cost, especially in water conservancy projects.

As an important mineral admixture of concrete, fly ash plays an important role in filling and activation of concrete, and has an important influence on the performance of concrete [1]. The incorporation of fly ash can reduce the gap among particles in concrete, reduce the porosity of concrete and increase the structural density, thus significantly improving the compressive properties, flexural properties, frost resistance and crack resistance of concrete. When the content of fly ash is 65-75%, the impermeability grade can reach more than B7[2]. In addition, fly ash can give good fluidity to concrete because of its ball effect and weak water absorption. Using a large amount of fly ash in roller compacted concrete can not only reduce the amount of cement and carbon emissions, but also improve the performance of concrete and make full use of the activity of fly ash, which has high economic and environmental benefits [2]. Therefore, this paper summarizes the effect of large amount of fly ash on the performance of roller compacted concrete, which will help to improve the utilization rate of fly ash [3].

2. Effect of fly ash on the mechanical properties of compacted concrete

2.1. Compressive properties

Some scholars have found that the strength of RCC decreased with the increase of the amount of fly ash in a parabolic trend. Li et al. found that 75% of the fly ash content was the turning point in the decline of concrete strength [4]. When the fly ash is less than 75%, the strength of crushed concrete decreases more slowly, while when the admixture is higher than 75%, the strength begins to decrease significantly. At the same time, Zhao et al. found that the cement activity was much greater than that of fly ash. The early age compressive strength of large volume fly ash-RCC was mainly due to cement hydration [5]. In the middle and late stages, the compressive strength of concrete is composed of both cement hydration and the secondary hydration of fly ash. In the early age, the strength of concrete decrease with the increase of content of fly ash, this is because of the decrease of amount of cement [2]. In the middle and later stage, the pozzolanic reaction occurs between fly ash and cement hydration products, which increases the strength of concrete. However, the development of strength still cannot make up for the decrease of strength due to the decrease of cement content. As a result, the larger the fly ash content is, the lower the compressive strength of concrete is [3]. This also explains the turning point of fly ash content mentioned above. Overall, it can be concluded that fly ash has the highest contribution at the content of 75% from the view of RCC strength [6].

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2.2. Flexural properties

Some scholars have found that there is a certain link between the flexural strength and compressive strength of RCC with different content of fly ash [7]. Li et al. found that the development trend of flexural properties of RCC with large amounts of fly ash was similar to the development of compressive strength. For instance, the compressive strength and flexural strength of concrete with low water to binder ratio are higher, which is because reducing the water-binder ratio increases the content of hydration products and reduces the porosity of concrete [4]. Ruan et al. found that the water-cement ratio and the amount of cementitious material have more obvious effects on the porosity of RCC with high content of fly ash [8]. As a result, the compressive strength of the concrete can be greatly improved in the early stage. At low water to binder ratio, the concrete can obtain high compressive and flexural strengths in all periods. However, Liu et al. also found that due to the presence of micro-aggregate effect, the micro-beads and debris of very small particle size in fly ash can be equivalent to unhydrated cement particles in RCC [4]. The strength values of all ages of RCC increase with the increase of fly ash under the condition that the amount of cement and water consumption are basically the same [9].

2.3. Dynamic elastic modulus

The compressive and tensile moduli of high-volume fly ash RCC increased with the increase of compressive and tensile strength of concrete. Liu et al. found that the ultimate tensile value of concrete was improved with the increase of the amount of fly ash under the condition of the same cement content. Moreover, the tensile value of concrete increases rapidly with the increase of curing age. In the case of high-volume fly ash RCC, the water consumption of the RCC was significantly reduced with the increase of the maximum size of the coarse aggregate, which slightly increased the ultimate tensile value of RCC [8].

Ai et al. found that the quality and admixture of fly ash was not significant for the increase in modulus of elasticity in the large volume fly ash-RCC [9]. It was also reported that the growth of modulus of elasticity in relation to strength in large volume fly ash concrete [4]. In addition, the elastic modulus of fly ash concrete was higher than that of normal concrete at similar strength. This is due to the unhydrated fly ash particles act as fine aggregates and inhibit the deformation of the concrete. Moreover, Liu et al. regressed the experimental data and obtained the following relationship between the elastic modulus E_h and the compressive strength f_{cu}:

$$E_h = 6.3\sqrt{f_{cu}} \tag{1}$$

The regression curve derived from this equation is in basic agreement with the experimental data.

3. The effects of fly ash on the performance on RCC

Some studies have shown that fly ash can improve some of the durability of concrete, e.g., fly ash can significantly improve the frost resistance of concrete, its resistance to carbonation and its resistance to corrosion of reinforcing steel. In the following section, this paper will analyse the effects of fly ash on the RCC in terms of its impermeability, frost resistance and crack resistance.

3.1. Permeability resistance

There exists a close link between the impermeability of large volume fly ash-RCC and its durability, which will directly affect the performance of concrete resistance to freezing and thawing, corrosion of reinforcing steel, carbonation and salt erosion. Impermeability is an important indicator of the durability of concrete. Ai et al. found that when fly ash is mixed into concrete, chemically stable mullite and quartz can play a microaggregate role [10]. As a result, the incorporation of fly ash can improve the uniformity of hardened concrete. Then the pores and capillaries in the concrete were gradually filled and refined. Consequently, the structural strength and impermeability of the paste are significantly improved. The potentially active aluminosilicate vitreous body will play the role of a cementing material to optimise the microstructure of the concrete, which in turn enhances the impermeability of the concrete.

Dong et al. found that the fly ash content of concrete cannot exceed 50% at a water to binder ratio of 0.50 when the impermeability grade of concrete is W8. If the water to binder ratio is 0.55, only the roller compacted concrete with 40% fly ash can meet the impermeability requirements. Li et al. reported that the high content of fly ash has an obvious effect on the impermeability of RCC. When the fly content is

65-75%, the impermeability grade of concrete can reach more than B7, while the impermeability of roller compacted concrete decreases sharply when the fly content increases from 75% to 85%. This indicates that the effects of fly ash content on impermeability is more obvious than mechanical properties [11]. Therefore, fly ash as an economic admixture, it is appropriate to use its "water-binder ratio effect" to compensate and improve the impermeability. However, it is more important to select the best dosage of fly ash admixture [12].

3.2. Frost resistance

Dong et al. found that the quality loss of roller compacted concrete with more than 60% fly ash increased significantly in the process of freezing and thawing. Ai 's group found that fly ash incorporated into concrete affects the degree of hydration of cement, the pore structure of concrete and the effect of air-entraining agents. As a result, it has an effect on the frost resistance of concrete [9]. The effects of fly ash on frost resistance of roller compacted concrete was still controversial. Some studies reported that the frost resistance of fly ash concrete was better than or close to that of normal concrete. On the other hand, some studies have come to the exact opposite conclusions. With the same air content and compressive strength, the frost resistance of fly ash RCC mainly depends on the quality of fly ash and its dosage. Du et al. found that an increase in the amount of fly ash admixture would worsen the frost resistance of concrete, which is consistent with the findings of Ai et al [7]. At the same time, Du et al. also found that the maximum amount of fly ash within 60% of RCC can still meet the specification requirements in water conservancy projects. They also found that the strength and frost resistance of RCC are not fully correlated. The initial strength and fly ash content would jointly affect the frost resistance of the RCC in the case of a short curing age. Liu et al. argue that RCC with high content of fly ash has higher frost resistance, which is due to the increase of the amount of fly ash, the decrease of water to binder ratio, the increase of concrete compactness (apparent density) and the increase of strength of each age [13].

3.3. Anti-cracking performance

Nowadays, the rapid construction technology of RCC is mostly used in the construction of large hydropower stations at home and abroad. Considering the technical characteristics of dam construction materials with high content of fly ash and low amount of cementitious materials, the crack resistance of RCC is of great significance to ensure the long-term safe operation of water conservancy projects. Lin et al. have studied the layered RCC, in which the crack resistance parameters of RCC can be calculated by the following formula [14].

$$\phi = \frac{\varepsilon_P R_l}{aTE} \tag{2}$$

They found that the tensile strength of RCC layer increased with the increase of total cementitious materials. In addition, the adiabatic temperature rise value of RCC was significantly reduced and the crack resistance of RCC was enhanced. Moreover, they cleared that the layer must be treated effectively to improve the crack resistance of RCC layer after the final setting of RCC.

4. Conclusions

The main conclusions of this paper are as follows.

(1) In terms of compressive strength, the strength of RCC decreases with the increase of fly ash in a parabolic trend, and the fly ash has the highest contribution strength for RCC at about 75%.

(2) In terms of flexural strength, the development trend of flexural properties of the large amount of fly ash in RCC is similar to the development of compressive strength. The strength values of RCC at all ages increase with the increase of fly ash amount.

(3) In terms of dynamic elastic modulus, the compressive elastic modulus and tensile elastic modulus of RCC with high content of fly ash increase with the increase of compressive strength and tensile strength.

(4) In terms of impermeability and frost resistance, the impermeability and frost resistance of concrete with large amount of fly ash increase with the increase of concrete compactness (apparent density) and strength.

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(5) In terms of crack resistance, the tensile strength of RCC layer increases with the increase of total cementitious materials composed of cement and fly ash. The adiabatic temperature rise value of RCC is also significantly reduced and the crack resistance of RCC is enhanced.

Overall, there have been some studies on the effects of fly ash content on the performance of RCC. However, it should be mentioned that there are few studies on different activation methods and activation combinations of fly ash in the utilization of RCC, which need to be further studied.

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