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Sustainability study of mix design of high-strength concrete based on fly ash

Junhao Ma

Leeds Joint School, Southwest Jiaotong University, Chengdu, Sichuan Province, China, 611756

cn20j2m@leeds.ac.uk

Abstract. Concrete is the most widely used building material in the construction of buildings, bridges, highways, and other infrastructure. With the spread of environmental preservation ideas and technological improvement, high-strength concrete materials and their sustainable hybrid design methods have been developed. A sustainable mix design approach for high-strength concrete (HSC) is critical for the construction industry as it is one of the major emitters of CO_2 emissions worldwide. Fly ash concrete is an environmentally friendly, economical and sustainable building material. This paper analyzes the sustainable mixed design method of fly ash concrete by combining past scholars' research and practical experience. By analyzing the properties of fly ash, theoretical principles, and some sustainable mixed design methods, the properties (such as durability, compressive strength, etc.) of fly ash HSC are studied. It is found that the properties of fly ash HSC and traditional HSC are similar or even stronger in some aspects, which has a good improvement on the compatibility and durability of concrete. In the future, with the progress of science and technology, people will further study fly ash and HSC, and the application of fly ash in HSC will certainly get greater development, and achieve green development and sustainable development while meeting the strength of concrete.

Keywords: high strength concrete, fly ash, sustainability, mix design, construction.

1. Introduction

As an important part of some engineering, HSC determines the manufacturing cost and engineering quality of civil construction. Traditional concrete wastes resources and pollutes the environment in order to fulfill the demands for high strength, which is counterproductive to the sustainable growth of the civil engineering industry [1]. With the spread of environmental preservation ideas and technological improvement, in the past two decades, the development and application of HSC have greatly developed. The process involved is a combination of improved compaction using special additives, improved aggregate matrix bonding and reduced porosity. It is necessary to use supplementary cementing material to replace a large amount of cement in concrete structures, and the most effective supplementary cementing material in the world is fly ash [2]. Fly ash concrete, as an environmentally friendly and economical building material, has a wide range of application prospects. With the continuous improvement of concrete performance requirements in the construction industry, the research and application of fly ash concrete have received more and more attention. As an active admixture, fly ash plays an important role in concrete, which can not only improve the strength and durability of concrete,

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but also reduce the waste of resources and protect the environment in civil engineering [3]. Therefore, it is very important to find a more effective and sustainable mixture design method for fly ash HSC. The main topic of this paper is to study the properties of existing fly ash concrete and evaluate the benefits of some sustainable mixing methods for fly ash concrete. By deeply studying the properties of fly ash and some mixed design methods, the performance of fly ash HSC can be further improved, and its role in engineering is to be more energy-saving, more environmental-friendly and more efficient.

2. Fly ash high strength concrete

2.1. Source of fly ash

The primary solid waste released by coal-fired power stations is fly ash. Fly ash emissions from coal-fired power plants rise yearly as a result of the growth of the electric power sector. If fly ash is not treated, it will damage the air and water supplies, imperil the environment and the harmful compounds therein, hurt people and other living things. Nowadays, the resource utilization of fly ash has become the guiding ideology for people to deal with fly ash, and fly ash concrete is one of the main achievements.

2.2. Theoretical principle of application of fly ash in high strength concrete

Fly ash is an important cement blending material. Its chemical and physical properties have a very important effect on the performance of concrete [4]. In terms of chemical properties, silicic acid and alumina are the main active ingredients of fly ash, which can participate in the hydration reaction to produce compounds such as calcium silicate and calcium aluminum silicate with gelling effects. These compounds can fill the microscopic pores in concrete, improve the compactness of concrete, and make the strength of concrete significantly increase in the later stage to form HSC [5]. In terms of physical properties, the density of fly ash is also one of the important factors affecting its application in concrete. With an average density of 2.159/cm^3, a lower density can improve its dispersion and stability in concrete, thereby improving its strength and durability.

2.3. Improve the gelation efficiency of fly ash

The gelation efficiency of fly ash is a very important factor affecting the performance of fly ash concrete. Gelation efficiency refers to the ability of fly ash to chemically react with water and cement in concrete to form hydration products, which directly affect the strength and durability of concrete. In order to improve the gelation efficiency of fly ash, there are the following methods: (1) Use appropriate fly ash. Different sources, various processing technologies, and multiple chemical compositions and physical properties of fly ash will affect the gelation efficiency. Therefore, when preparing fly ash concrete, the appropriate fly ash should be selected according to the requirements of concrete and the characteristics of fly ash. (2) Optimize the mix ratio, which means that under the premise of ensuring that the performance of the concrete meets the requirements, by adjusting the water-cement ratio, water-binder ratio, fly ash content and other parameters, to maximize the gelation efficiency of the fly ash. (3) Use active agents. The active agent can promote the chemical reaction between cement clinker and fly ash, improve its reactivity, accelerate the hydration reaction speed of cement, and increase the number of hydration products [6]. (4) Mechanical activation technology, which is an important fly ash utilization technology, changes the particle structure and form of fly ash through physical action, increases its activity, and improves its utilization efficiency, such as high-energy ball milling. (5) Thermal activation technology, also known as high-temperature calcination technology for fly ash, is based on the principle of enhancing the activity of fly ash by calcining it. The thermally activated fly ash has higher reactivity and gelation activity, which can be used to produce concrete with higher strength and performance.

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3. High strength high-volume fly ash concrete

3.1. Feature

In recent years, the application of fly ash in concrete has been widely concerned.. According to the research and discovery of Kate and Thakare, the workability of HSC will be improved with the increase of fly ash content, and slump loss will be reduced on average by the incorporation of fly ash. And the addition of fly ash not only increases the compressive strength of concrete, but also reduces the dry shrinkage of concrete [7]. In addition, when the content exceeds 50%, its physical and mechanical properties and durability are revolutionary improved. For the sake of distinction, Professor Mehta, a famous concrete expert, calls concrete with a fly ash content of more than 50% as high-volume fly ash concrete (HVFAC) [8]. HVFAC not only saves cement and optimizes the performance of concrete, but also saves energy and reduces emissions of greenhouse gas such as carbon dioxide. Because of its green energy saving advantages and sustainable development potential, HVFAC is favored and valued by the industry [9].

3.2. Optimizing particle size method of cementitious material for high strength HVFAC

HVFAC has the disadvantages of low early strength, slow setting, and a long duration of strength growth, which makes it difficult to meet the requirements of fast construction speed and a short construction period in modern construction. In order to make high-strength HVFAC better applied in engineering, improve the early performance of HVFAC, reduce the production cost of concrete, and avoid the occurrence of side effects, Tong and Shen conducted research on optimizing the particle size of fly ash and cement, and found that the specific surface area of cement mainly affects the early strength of mortar. The specific surface area of fly ash mainly affects the later strength of mortar. Compared with the specific surface area of cement and fly ash, the effect of fly ash content on the strength of mortar is the most significant. The results show that HVFAC at an early age can be prepared by increasing the specific surface area of cement and decreasing the specific surface area of fly ash [9].

4. Fly Ash HSC with incorporation of silica nanoparticles (SNPs)

Nanotechnology is a development area in the field of construction, and SNPs are frequently used in concrete. Because it has excellent performance, it can increase the early strength of concrete. Due to the additional C-S-H gel formation and filler effect, SNPs can also improve the later age strength of concrete, reduce segregation and bleeding, and shorten the setting time [10-11]. According to Palla, Karade, et al., the use of SNPs in fly ash concrete (40% displacement) can optimize the performance of high strength sustainable concrete. The incorporation of SNPs into the mixture can shorten the duration of the dormant period and increase the hydration rate. The initial setting time and final setting time of concrete also reduce with the addition in SNP content. The study also showed that the optimal content of SNPs decreased as the decrease in the w/b ratio. The ideal content of SNPs particles was 1%, 2%, and 3%, respectively, with w/b ratios of 0.23, 0.25, and 0.33. SNP particles also densify the interface between the matrix and the sand particles. Therefore, after adding SNPs, ITZ is densified, and there is no CH crystal at the interface between aggregates and matrix. The early compressive strength of fly ash concrete is significantly improved. The initial strength increases (at 3 days) for adding 0.5% and 2% SNPs were 27.7% and 61.1%, respectively. At 28 d compressive strength, compared with the condition without adding SNPs, when the addition of SNPs is 2%, the compressive strength of concrete increases by about 30%, and the sustainable HSC with 66 MPa compressive strength is obtained. It is indicated that by optimizing SNPs content and w/b ratio, sustainable HSC can be obtained with a high volume of FA [12].

5. Fly Ash HSC with incorporation of effective microorganism (EM)

Recently, effective microorganisms (EMs) have begun to be used in the construction industry. Effective microorganisms (EMs) are a group of beneficial microorganisms (divided into viruses, fungi, and bacteria) [13]. It is a non-toxic and environmentally friendly material with a low price [14]. It can be

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used as a novel self-healing and biological concrete material [15]. EMs can improve the workability, strength and durability of concrete, which is constantly studied in the construction field and has found a number of structural applications [16]. In the experiments of Fahim Huseien, Hussein Joudah et al., it was proved that 10% of FA and EM is the best mix in the mixed design of EMs, fly ash and concrete, which was more than 30% higher than the early compressive strength of conventional concrete in the experiment. And durability in harsh environments has been improved. It was proven that the presence of EM is helpful to decrease the heat hydration and water loss of fly ash concrete, so as to enhance the early compressive strength, and enhance the resistance to sulfuric acid attack and durability. Therefore, 10% FA and EM mixed into concrete improves its performance and ensures high strength while protecting the environment and helping to reduce global warming.

6. Conclusion

The study on sustainable mixing design method of fly ash in high strength concrete is not only the need to improve the performance of concrete, but also by the desire to save energy and reduce emissions, as well as to preserve the environment and promote sustainable development. Based on the properties of fly ash and some mixed design methods, we can see that when Optimizing particle size method is used in fly ash concrete, adding SNPs and EMs can improve the performance of fly ash concrete and can be used to prepare sustainable HSC. It is believed that in the future, with the further study of fly ash and HSC, fly ash will be more widely used in the development of sustainable HSC.

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