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THE EFFECT OF MINERAL ADMIXTURES IN SELF-COMPACTING CONCRETE

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ABSTRACT
With the advancement and progression of modern concrete techniques the focus is no longer limited to achieving high strength, but increasingly emphasises workability, volume stability, and durability, etc. In the field of high-performance concrete, self-compacting concrete represents one of the most significant breakthroughs in recent decades. However, the large quantity of cement required in its preparation not only raises costs and pollutes the environment but also negatively impacts concrete quality. Combining self-compacting concrete with mineral admixtures can address environmental pollution, reduce costs, and enhance performance. Based on this, the article explores the current research and development of different mineral admixtures in self-compacting concrete, summarises and evaluates existing findings, and identifies current research limitations and future directions. The results of this study can provide important references for the formulation and development of self-compacting concrete.

Keywords:
Self-compacting concrete, mineral admixture, research status, development

INTRODUCTION

In the last few years, with the high-speed improvement of the global economy, the urban population has continued to grow and available construction land is severely limited. With the advancement of building techniques, high position buildings and long-span bridges have become increasingly popular, and the requirement for high durability and strength of concrete building structures is growing (Kong & Norul, 2023). Therefore, the concrete industry will also face more technological innovation and progression opportunities. Improving the quality and performance of concrete, and promoting its high-performance, multifunctional, and sustainable development are inevitable trends in the enhancement of concrete methodologies (Kong & Norul, 2025). Self-compacting concrete has emerged in response to these developments.

Self-compacting concrete represents a significant advancement in high-performance concrete (HPC) research in recent decades, owing to its advantages in increasing productivity, improving the working environment, and decreasing construction duration. Therefore, to date, research and progression on mineral admixtures for self-compacting concrete have continued and gradually become a major focus of study both domestically and internationally. This is also an important progression path for future building materials.

SELF COMPACTING CONCRETE

Self-compacting concrete exhibits superior performance compared to conventional concrete. However, self-compacting concrete necessitates a greater quantity of cementitious materials to achieve high fluidity and mitigate segregation and bleeding during transport and placement. Utilising a single type of cement adversely affects concrete quality, resulting in increased early hydration exotherm, greater contraction of the hardened concrete, and a propensity for drying and shrinkage cracks, which undermines the long-term durability and volumetric stability of the concrete (Wang et al., 2024).

Furthermore, the high energy consumption and emissions associated with cement production not only raise the cost of self-compacting concrete but also contribute substantially to carbon dioxide emissions, exacerbating environmental challenges and hindering the advancement of sustainable concrete development. Simultaneously, the swift advancement of industrial technology and population growth have led to a year-on-year increase in industrial waste, resulting in significant accumulation characterised by diverse types and complex mineral and chemical compositions. This accumulation not only pollutes the atmosphere, soil, and water resources, occupying substantial land, but also endangers ecosystems and human health (Liu et al., 2019).

A multitude of studies have demonstrated that incorporating industrial waste to partially substitute cement in self-compacting concrete can mitigate environmental pollution from industrial waste, facilitate energy conservation and emission reduction, and promote resource reutilisation. Furthermore, it can lower concrete costs, and more importantly, the incorporation of industrial waste substantially influences the efficacy of self-compacting concrete by filling the spaces within the paste, diminishing its water consumption, and enhancing both water secretion and overall segregation of the concrete. The water secretion and segregation of self-compacting concrete are improved, enhancing its overall performance which makes the quality and use of concrete more reliable and convenient. Consequently, to concurrently advance the eco-friendly development of the social economy and satisfy the requirement for high powder content in self-compacting concrete, auxiliary cementitious materials exhibiting volcanic ash properties are typically used to partially substitute cement in the formulation of self-compacting concrete (Xiong, 2023).

THE IMPORTANCE OF MINERAL ADMIXTURES IN SELF-COMPACTING CONCRETE

Self-compacting concrete exhibits superior performance compared to conventional concrete. However, the substantial quantity of cement required in its formulation not only elevates costs but also amplifies its carbon footprint (Sun, 2021). Studies indicate that utilising industrial waste as mineral admixtures in self-compacting concrete might mitigate secondary environmental contamination, decrease concrete costs, and enhance the diverse properties of self-compacting concrete.

Regarding the application of mineral admixtures in self-compacting concrete, the objective is to investigate the effective utilisation of industrial waste in the formulation of high-performance self-compacting concrete. This study will offer reference and technical assistance for the formulation of high-performance concrete, the construction, and the safe operation of associated projects, which holds substantial practical value for the sustainable advancement of the concrete industry.

RESEARCH STATUS AND DEVELOPMENT OF MINERAL ADMIXTURES IN SELF-COMPACTING CONCRETE

The active influence of mineral admixtures on the properties of self-compacting concrete has perpetuated ongoing study and advancements in this area. The commonly used mineral admixtures for self-compacting concrete currently include industrial waste such as fly ash (Zhang &Wang, 2024), slag powder (Gan et al., 2023), silica fume (Xu et al., 2024), rice husk ash (Huang, 2021), limestone powder (Wang, 2021), etc. In the last few years, natural volcanic ash materials have also been studied and applied in self-compacting concrete (Gong et al., 2024), however, due to the different types of admixtures, the effects on the performance of concrete are also different. Currently, research on self-compacting concrete with mineral admixtures is still in its infancy, and new problems are constantly being discovered during the research process, which urgently need to be solved by researchers.

FLY ASH

Fly ash enhances the workability and strength of concrete when used as an additive. Nonetheless, varying grades of fly ash exhibit substantial disparities in phase composition, chemical composition, microstructure, and both chemical and physical properties. Consequently, the influence on the performance of self-compacting concrete exhibits significant variability.

Concerning the impact of fly ash content on the efficacy of self-compacting concrete, Ye (2022) investigated the impact of fly ash content on the workability, mechanical properties, and impermeability of self-compacting concrete, as well as its thermodynamic properties via thermogravimetric analysis. Similarly, Zhang and Wang (2024) investigated the impact of varying fly ash dosages on the impermeability and mechanical qualities of self-compacting concrete. The research results all indicate that the addition of fly ash can effectively improve the workability and impermeability of self-compacting concrete; Under the conditions of a curing age of 7 days and 28 days, the compressive strength of concrete specimens decreases as fly ash content increases; When the fly ash content is 20%, self-compacting concrete has the optimal performance. However, the above research on the prediction model of the performance of fly ash self-compacting concrete is insufficient, as it only considers dosage while ignoring the influence of various factors such as fly ash quality and admixture types, and the types of performance studied are not comprehensive enough.

Furthermore, as public awareness of environmental conservation grows, recycled coarse aggregate self-compacting concrete has emerged as a prominent research focus in recent years. Zheng (2024) and Dong et al. (2023) used recycled concrete aggregates instead of natural aggregates and industrial waste instead of cement to prepare eco-friendly recycled self-compacting concrete. The influence of different water cement ratios, replacement rates of recycled coarse aggregates, and mineral admixtures on the performance of recycled self-compacting concrete was analysed. It is believed that the addition of mineral admixtures can compensate for the adverse effects of recycled coarse aggregates (Li & Norul, 2025) and effectively improve the workability and mechanical properties of recycled self-compacting concrete.

MINERAL POWDER

As one of the common mineral admixtures, mineral powder not only has a lower cost than cement, but also meets the national standards for waste utilisation. Additionally, mineral powder exerts a lubricating influence on concrete mixtures, significantly enhancing their fluidity. The particle size of mineral powder is smaller than that of cement, allowing it to efficiently occupy the voids between cement particles, hence reducing porosity in concrete and enhancing its compactness and homogeneity. Consequently, the investigation of the impact of mineral powder on the efficacy of self-compacting concrete has consistently been a focal point of interest for researchers.

In terms of work performance, Gan et al. (2023) analysed the effects of different dosages of mineral powder on the flowability and anti-segregation of concrete using slump tests, sieve analysis tests, and V-funnel tests. It has been proven that mineral powder is beneficial for improving the flowability of self-compacting concrete mixtures. Reddy et al. (2020) found that when no more than 40% mineral powder is added, the filling capacity and gap permeability of self-compacting concrete augment with an increase in mineral powder content, however, the anti-segregation performance diminishes.

Conversely, certain academics assert a contrasting perspective: Ofuyatan et al. (2020) observed that when the mineral powder concentration rose from 0% to 30%, the slump expansion of self-compacting concrete diminished from 590mm to 560mm, but the T500 transit time escalated from 5.65s to 6.05s. Secondly, mechanical properties are also a focus of research for many scholars at home and abroad. Ahmad et al. (2020) found that when the water cement ratio is 0.40, using 10%, 20%, and 30% mineral powder as substitutes for cement slurry can increase the compressive strength of self-compacting concrete by 4%, 18.4%, and 19.8%, respectively. Esfahani et al. (2021) found that when the water cement ratio was 0.35, using mineral powder instead of 15%, 30%, 45%, and 60% cement slurry increased the compressive strength by 18.7%, 22.7%, 13.2%, and 11.2%, respectively. This is because using mineral powder instead of cement slurry can reduce the pores between cement matrix, effectively improve the microstructure of concrete, and thus enhance the compressive strength of concrete. Tadi &Rao (2022) showed that when the mineral powder content increased from 0% to 60%, the compressive strength of self-compacting concrete increased by 4% to 14.4%. Prasanna et al. (2021) also found that replacing 0%-80% of cement with mineral powder resulted in a maximum 28 day compressive strength at a mineral powder content of 20%, with an increase of 4%. But when the amount of mineral powder exceeds 20%, the 28 day compressive strength decreases with the increase of mineral powder content, with a maximum decrease of 22%. Selvarani &Preethi (2021) also obtained the same result, that when the added mineral powder exceeds a certain critical point, the compressive strength gradually decreases.

For the study of mineral powder and other mineral admixtures, Liu (2019) selected fly ash and slag powder as admixtures for self-compacting concrete, and studied the influence of different dosages, grades, and forms of admixtures on the performance of self-compacting concrete. Single or compound admixtures of fly ash and slag powder were carried out, focusing on the workability, strength, drying shrinkage, and hydration products of self-compacting concrete. The economic benefits of self-compacting concrete with single or compound admixtures were also analysed.

In the following research, the types and amounts of mineral admixtures can be increased, and other properties of self-compacting concrete can be further studied. Similarly, Zhou et al. (2020) also believed that fly ash and mineral powder have high economic and social benefits. Based on C30 self-compacting concrete, a mix design was carried out, and fly ash and mineral powder were used to replace cement. The study investigated the effects of single addition of fly coal (0-40%), single addition of mineral powder (0-40%), and combined addition of 40% mineral powder and fly ash on the workability of self-compacting concrete. This article mainly studies mineral admixtures with a dosage of 0-40%, and no research has been conducted on admixtures with a dosage higher than 40%. Further research is needed to investigate the impact of larger dosages on self-compacting concrete.

Due to the large amount of self-compacting concrete binder and low water cement ratio, shrinkage cracking is prone to occur during construction, which affects the durability of concrete structures. Therefore, Xiao (2023) studied the effects of single addition of fly coal, single addition of mineral powder, and composite addition of fly ash and mineral powder on the hardening and durability properties of self-compacting concrete. They conducted flowability tests, mechanical performance tests, shrinkage performance tests, and carbonation tests, The final conclusions may offer a theoretical foundation for the engineering use of self-compacting concrete. Wang et al. (2022) found that the addition of fly ash and mineral powder increased the first cracking time of self-compacting concrete, but at the same time, it also increased the water evaporation of self-compacting concrete, leading to an expansion of the cracking area of self-compacting concrete. In addition, when the dosage of blended mineral powder exceeds that of fly ash, the effect of increasing the cracking area by 1 day with blended mineral powder is more significant. The above research differs from other scholars' attention to the workability and mechanical properties of self-compacting concrete, with a focus on hardening and durability. However, there are relatively few types of research on mineral admixtures. In subsequent studies, other mineral admixtures can be selected as objects for further research.

SILICA FUME

Adding silica fume to concrete preparation can not only improve the cohesiveness of the mixture, but also significantly enhance the mechanical properties, durability, frost resistance, impermeability, and chemical corrosion resistance of concrete. At the same time, it can inhibit alkali aggregate reactions (Almusallam et al., 2004; Zhang, 2015).

Regarding the study of silica fume in self-compacting concrete, Li et al. (2019) examined the mechanical properties of silica fume in self-compacting concrete and determined that using silica fume enhances both compressive and tensile strength. Wang et al. (2020) designed three different mix proportions for three different strength grades of concrete, C40, C60, and C80, with a total of nine mix proportions. By conducting compressive strength tests on concrete mixed with silica fume with different silica contents, the influence of silica fume with different silica contents on the compressive strength of concrete was analysed. Hua (2022) replaced fly ash, cement slurry, and cement with different dosages and qualities of silica fume, and studied its influence on the workability, mechanical properties, hydration process, pore structure, and microstructure characteristics of ordinary concrete and self-compacting concrete. The aforementioned studies only analysed the effect of silica fume on the performance of concrete, without considering other mineral admixtures, which is relatively single and limited.

In concrete production, solid waste silica fume is commonly utilised as a replacement for cement and fly ash. Zhang and Zhu (2022) discovered that substituting up to 10% of cement with silica fume markedly enhances the compressive strength of the paste at 3 days, minimally diminishes the increase in compressive strength at 7 days, and maintains a superior compressive strength at 28 days compared to the control group. Nagrockien et al. (2019) investigated that at a water-to-cement ratio of 0.47 and a silica content of 93.35% in silica fume, substituting 2.5%, 5%, 7.5%, and 10% of cement with silica fume led to increases of 3.5%, 9.1%, 10.1%, and 13.4% in the 28-day compressive strength of concrete cubes relative to a silica fume content of 0%. Das et al. (2020) investigated the impact of substituting fly ash with lime and silica fume on the composition, strength, and microstructural characteristics of geopolymer concrete. The research findings demonstrate that an increase in silica fume level correlates with heightened slump and extended setting time of geopolymer concrete. Simultaneously, when the silica fume percentage is 2%, the compressive strength achieved by substituting fly ash is maximised, and the microstructure is notably denser.

In the investigation of combining silica fume with various materials, Yin et al. (2021) performed workability, compressive strength, and flexural strength tests on self-compacting concrete using single fly ash, compound fly ash, and silica fume, confirming the beneficial effects of mineral admixtures on the performance of self-compacting concrete. Xie et al. (2021) investigated C30 and C50 concrete, examining the impact of individual additions of silica fume, fly ash, mineral powder, and silica fume on the workability and mechanical qualities of the concrete. The conclusion indicated that in medium to high-grade concrete, the workability and mechanical qualities improved when silica fume, at a ratio of 1:3 and 1:4, substituted cement dosage. Xu et al. (2024) formulated self-compacting high-strength concrete utilising 530 kg of cementitious materials, with a mass ratio of 15:25:60 for fly ash, slag, and cement. Substitute cement with 3.0%, 4.5%, 6.0%, 7.5%, and 9.0% silica fume, respectively, and examine the influence of silica fume content on the workability and mechanical qualities of self-compacting high-strength concrete. Studies indicate that using a suitable quantity of silica fume enhances the workability of self-compacting concrete, decreases expansion duration, and elevates the degree of expansion; Properly incorporating silica fume into self-compacting concrete can enhance its compressive strength.

It can be found that researchers predominantly examine the impact of silica fume on the workability and mechanical properties of self-compacting concrete, whereas there is comparatively limited investigation into its carbonation resistance, microcracking, corrosion resistance, and self-shrinkage.

LIMESTONE POWDER

Limestone powder replaces some cement and other mineral admixtures in concrete preparation, fully utilising the "micro aggregate filling effect" and "morphology effect" of limestone powder. Proper addition can improve the workability of concrete to a certain extent.

Regarding the study of workability and mechanical properties, Cao (2020) replaced cement, fly ash, and slag powder with ultrafine limestone powder, and experimentally studied the effects of different dosages of ultrafine limestone powder on the workability and mechanical properties of self-compacting concrete. The study concluded that an appropriate substitution of ultrafine limestone powder improves filling ability, gap permeability, and the basic mechanical properties of self-compacting concrete. Elemam et al. (2020) used the central composite design method to design and optimise the mix proportion of self-compacting concrete with fly ash, silica fume, limestone powder, and water reducing agent. The artificial neural network model was used to verify the experimental results and establish a performance prediction model for self-compacting concrete. Research has found that increasing the dosage of fly ash improves the workability of self-compacting concrete and reduces the amount of water reducing agent used, but it does not enhance compressive strength; The increase of silica fume content improves the anti-segregation performance and compressive strength of self-compacting concrete, but it will increase the amount of water reducing agent used; limestone powder improves the anti-segregation performance, but is not conducive to the progression of compressive strength.

For the study of durability and shrinkage performance, He (2022) conducted experiments utilising various water-cement ratios and stone powder mass fractions. The findings demonstrate that self-shrinkage escalates as the water-cement ratio diminishes and the stone powder mass fraction intensifies; when the water-cement ratio ranges from 0.30 to 0.37, its impact on drying shrinkage is negligible. A moderate quantity of stone powder has no impact on drying shrinkage, however a mass fraction of 20% of stone powder results in a significant increase in drying shrinkage. A predictive model for self-shrinkage and drying shrinkage of self-compacting concrete, accounting for the effects of water-cement ratio and stone powder mass fraction, was developed based on experimental data. Alaghebandian et al. (2020) studied the durability of self-compacting concrete and mortar prepared by ternary or quaternary blending of cementitious materials such as silica fume, natural zeolite powder, and limestone powder in simulated marine environments. The results show that the water absorption rate of self-compacting concrete slurry is the lowest when the quaternary compound is added; Silica fume and natural zeolite powder have a significant impact on durability.

CONCLUSION

The incorporation of industrial waste as an internal admixture in self-compacting concrete can help mitigate environmental pollution and reduce production costs, while also enhancing material performance in line with sustainable development strategies. Effective usage can yield significant economic and social advantages. The number of studies on durability is the second most studied aspect by scholars and currently the vast majority of research focuses on impermeability, relatively neglecting other evaluation indicators of durability, such as frost resistance, erosion resistance, carbonation of concrete, alkali aggregate reaction, etc. Moreover, there is a paucity of studies regarding the microstructure and shrinkage characteristics of self-compacting concrete, and research that holistically addresses workability, mechanical properties, durability, shrinkage performance, and microstructure of self-compacting concrete is virtually nonexistent.

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