ISSN: 1813-4890

Current status of all-solid waste concrete research

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Abstract

With the rapid development of the construction industry and the increasing requirements of environmental protection, all-solid-waste concrete has become a research hotspot in the field of construction materials by virtue of its advantages of efficiently utilizing industrial waste, reducing resource consumption and environmental pollution. This paper systematically reviews the composition of steel slag powder, slag powder, desulfurization gypsum and other cementitious materials in all-solid-waste concrete, analyzes its chemical mechanism, and discusses the influence of solid waste on concrete performance in terms of compatibility, strength and durability. The study shows that a reasonable proportion of solid waste can significantly improve the working performance and mechanical properties of concrete, and some of the solid waste admixture can also enhance the durability of concrete. However, there are still challenges in the large-scale engineering application and long-term performance evaluation of all-solid waste concrete. The purpose of this paper is to provide theoretical references for the further research and popularization of all-solid-waste concrete, and to help realize the green and sustainable development of the construction materials field.

Keywords

Solid waste, concrete, concrete properties.

1. Introduction

Steel slag is a steelmaking raw materials in the smelting process and a variety of fluxes and slagging materials formed in the reaction of the by-products, generally speaking, every refining 1 ton of steel will be accompanied by 120-210kg of steel slag produced. Over the years, with the green concept of sustainable development year by year deep into all walks of life, but also due to the complex composition of steel slag, production, processing difficulties and other characteristics, so that the comprehensive utilization of steel slag there are a variety of challenges. The application of steel slag in the concrete industry is a feasible way to comprehensively utilize steel slag.

This paper combines the application of solid waste in concrete in recent years, and summarizes the research results of some relevant research workers. The utilization of steel slag, waste tailings and other solid waste crushed in concrete is summarized and summarized.

2. All Solid Waste Concrete Cementitious Material Composition

All solid waste concrete mainly consists of steel slag powder, slag powder and desulfurization gypsum as cementitious materials, waste rock as coarse aggregate and tailing sand as fine aggregate thus configuring the concrete.

ISSN: 1813-4890

2.1. Steel slag powder

The main chemical composition of steel slag powder is calcium oxide (CaO), silicon dioxide (SiO_2), iron trioxide (Fe_2O_3) and ferrous oxide (FeO), aluminum trioxide (Al_2O_3), magnesium oxide (MgO) and so on. The main contents are shown in Table 1

Table 1 Main chemical composition of steel slag powder

Chemical composition and content					
CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	MnO
30% - 50%	10% - 25%	5% - 15%	10% - 30%	5% - 15%	1% - 8%

2.2. Slag powder.

Slag powder, full name granulated blast furnace slag powder, is a powdered product obtained by fine grinding of water quenched slag discharged from ironmaking blast furnace. In the blast furnace ironmaking process, iron ore, fuel (coke), limestone and dolomite and other raw materials to react, the generation of silicate and silica-aluminate as the main component of the melt, floating on the surface of the iron, quenched by the water into a granular form of granulated blast furnace slag, and then processed to become blast furnace slag powder. Its main chemical composition is silicon dioxide (SiO_2), calcium oxide (CaO) and aluminum oxide (Al_2O_3), the total content of these three oxides usually up to about 90%. In addition, it also contains small amounts of magnesium oxide (MgO), iron trioxide (Fe_2O_3), sodium oxide (Na_2O), and other components are shown in Table 2

Table 2 Main chemical composition of slag powder

Chemical composition and content					
SiO_2	CaO	Al_2O_3	Fe_2O_3	MgO	Na_2O
30% - 45%	30% - 40%	10% - 20%	0.5% - 3%	2% - 10%	0.1% - 1%

2.3. Desulfurization gypsum.

Desulfurization gypsum is an industrial by-product produced in the process of flue gas desulfurization in coal-fired power plants, and its chemical composition is similar to that of natural gypsum, but there will be some differences in the percentage of the composition due to the desulfurization process and coal quality. Its main chemical composition and common percentage range are shown in Table 3.

Table 3 Main chemical composition of desulfurization gypsum

Chemical composition and content					
$CaSO_4 \cdot 2H_2O$	SO_3	CaO	SiO_2	Al_2O_3	Fe_2O_3
90%～95%	30%～40%	1%～5%	1%～3%	0.5%～2%	0.2%～1%

3. Chemical mechanism of cementitious materials

Steel slag contains converter slag and refining slag, of which the refining slag hydration speed, hydration can provide a large number of OH- for the system, can make up for the lack of converter slag early hydration of slow, to promote the slag in the silicon (aluminum) oxygen tetrahedral depolymerization, and its aluminum content is high, the hydration will release a large number of aluminum elements. In the system, slag provides Ca^{2+} and Al^{3+}, converter slag provides divalent metal cations and OH-, refining slag provides Al^{3+} and Ca^{2+}, gypsum provides Ca^{2+} and SO_4^{2-}, and the four raw materials synergistically promote the crystallization of ultra-

ISSN: 1813-4890

low solubility chalcocite complex salts, which facilitates the depolymerization of silica (alumina)-oxygen tetrahedra, and promotes the formation of hydrated calcium silicate gels and waste-stone-like phases [1]. At the same time, the exothermic hydration of refinery slag increases the system temperature, which can improve the hydration reaction rate. After hydration, abundant gel-like products are generated, and calcium alunite crystals are wrapped by the gel to form a dense composite structure.

In the early hydration process, the slag-converter slag-gypsum cementitious material system can have a synergistic effect, forming the hydration products dominated by calcite and C-S-H gel, slag, converter slag and gypsum provide silica-oxygen tetrahedra and aluminum-oxygen tetrahedra, alkaline environment and sulfate ions, respectively, and the slag-converter slag-gypsum cementitious material system can be driven by the generation of calcite to promote the hydration reaction to continue [1].

4. Solid Waste Concrete Research Status

With the increasingly serious environmental problems and the gradual scarcity of resources, the study of solid waste concrete has received more and more attention. All-solid-waste concrete refers to the concrete prepared by using various industrial solid wastes as raw materials, which has significant environmental benefits and resource utilization value. The cementitious materials of all-solid-waste concrete mainly consist of steel slag powder, slag powder and desulfurization gypsum, and the aggregate mainly consists of tailing sand and waste rock.

4.1. Effect of solid waste on compatibility.

After experiments by Law Hsien-Hsun et al [2], it was found that in case of equal replacement, the flowability of the concrete gradually decreases because of the increasing steel slag sand admixture. In this case, the slump of steel slag sand dosed at 100% of concrete was reduced by 80 mm compared to granite mechanism sand concrete without steel slag sand. This is mainly because the steel slag sand has a rough and porous surface with high water absorption, which requires more water to wet, and also absorbs part of the water reducing agent, resulting in a significant reduction in the fluidity of steel slag sand-admixed concrete under the same conditions of water use and water reducing agent dosage.

Xie Weipeng [3] after a series of experimental investigation for the performance test of steel slag powder high concrete in different admixture found that when the steel slag powder replaces the cement in high strength concrete, along with the substitution rate gradually increased, its setting time will be continuously extended. When the substitution amount of steel slag powder reaches 30%, the increase in the initial setting time and the final setting time is far more than that of other lower substitution amounts. In-depth analysis shows that the steel slag powder is mainly presented in the form of spherical particles. These spherical particles can effectively reduce the friction coefficient between the aggregates, play an excellent lubrication effect, and then improve the rheological properties of the cement paste, so that the flow characteristics of the concrete parameters can be enhanced, and the workability of the workability of the index has been significantly improved.

YuanB [4] and others found that the use of steel slag powder to replace part of the cement in pavement concrete, different water-cement ratios, different steel slag parameters and different particle size of the coarse aggregate group test, and found that under a constant water-cement ratio, increase the proportion of steel slag can improve the fluidity of concrete.

4.2. Effect of solid waste on strength.

As steel slag contains water-hardening cementitious materials, when the hydration reaction between steel slag and cement occurs, the bond between steel slag and cement stone will be enhanced, which has an improved effect on strength.

Xu Bing et al [5] made an innovative attempt in a shore protection project in Shanghai, adding solid waste such as steel slag powder instead of mineral powder, converter drum steel slag instead of sand, and electric furnace steel slag instead of gravel into concrete. After testing, 28 days of age, the mechanical properties and durability of the concrete is not inferior to ordinary concrete, and compressive and flexural strength has been significantly improved, to achieve the performance optimization and solid waste utilization of the dual objectives.

Yang Chen et al [6] showed that with the increase in the amount of steel slag, the compressive strength of concrete increased, while the split tensile strength decreased. The hydration activity and surface properties of steel slag played an important role in improving the mechanical properties of concrete, but reduced the strength due to its poor volume stability. The results of the study showed that replacing natural coarse aggregate with steel slag can significantly improve the compressive and cracking strength of concrete at no more than 50%.

The results of experimental study by Lin Dong et al [7] showed that steel slag concrete and ordinary concrete exhibited significant strength differences under the same water cement ratio, where the compressive strength of steel slag concrete was significantly higher than that of ordinary concrete. This is mainly due to the fact that steel slag as a coarse aggregate has high strength, and due to its certain hydration activity, it can form a closer connection with the cementitious material, further improving the overall strength performance of concrete. In addition, when the hydrogel ratio is low and the age is short, the role of aggregate is relatively enhanced, making the compressive strength advantage of waste slag concrete more significant.

The test results of Zhang Renwei et al [8] showed that the growth rate of compressive strength of concrete increased continuously from 0 to 30% steel slag admixture. When the dosage reaches 20%, the growth rate of cubic compressive strength reaches the lowest value; when the dosage is 30%, its growth rate is the fastest. The reason for this is the gradual increase with the gradual decrease in the amount of concrete and the addition of steel slag. After grinding, steel slag has certain hydration activity, although it does not participate in hydration at the initial stage, but it will play a certain role in the later stage, thus improving the compressive strength in the later stage.

NingS [9] et al. experimentally proved that with the increase of steel slag content, the compressive strength of concrete increases and then decreases, and a certain proportion of steel slag can optimize the compressive strength of concrete.

4.3. Impact of solid waste on durability.

Jin Jing et al [10] found experimentally that after many freeze-thaw cycles, as the fineness of steel slag decreases from 23.1 μm to 4.2 μm, the frost resistance of concrete is gradually enhanced, and the carbonation depth is reduced.

Huang Lijie et al [11] experimental study found that the steel slag dosage in the range of 20%-30%, its resistance to chloride salt erosion is significantly stronger than the general standard concrete, indicating that steel slag has a positive effect on the resistance of concrete to chloride salt erosion. From the perspective of permeability grading, the chloride permeability of steel slag concrete belongs to a relatively low level. The test also showed that under the condition of 20%-30% of steel slag and the same water-cement ratio, the carbonation resistance of steel slag-added concrete was slightly worse than that of ordinary standard concrete, but the difference was not significant; however, with the increase of steel slag admixture, its carbonation resistance was improved, which was manifested in the reduction of carbonation depth, but the increase was small.

Zhu Leilei [12] through the 100mm × 100mm × 50mm different dosage of steel slag concrete cubic specimens, the resistance to chlorine ion penetration performance research, its results show that with the increase of steel slag substitution rate of its flux gradually decreased, steel slag dosage is greater than 50%, the concrete resistance to chlorine ions better performance.

5. Conclusion and outlook.

Through the study of different literatures, it is found that steel slag powder, slag powder and desulfurization gypsum can build a good performance cementitious system through reasonable proportioning, and the characteristics of each component complement each other, and give full play to its activity and function through process treatment and synergistic effect. The complex chemical reaction between solid waste synergistically affects the hydration process and determines the performance of concrete. The right amount of solid waste can optimize the concrete compatibility, strength and durability, and the specific ratio can meet the strength requirements of the project. These theoretical and practical results show that the whole solid waste concrete has opened up an effective path for the utilization of solid waste resources and the green development of concrete. However, the large-scale engineering application of all-solid waste concrete still faces challenges, and in the future, it is necessary to deepen the basic research, clarify the reaction and synergistic mechanism of solid waste, and optimize the mix ratio; research and development of high-efficiency pre-treatment technology to stabilize the quality of solid waste; improve the production process to reduce costs and ensure the quality of uniformity; improve the standards and specifications to support the promotion of the application; and at the same time, strengthen the publicity and education, and promote the industry chain's collaborative innovation to realize the green, low-carbon and sustainable development of the construction industry. The construction industry can realize green, low-carbon and sustainable development.

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