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Research progress and application of iron tailings as UHPC aggregate

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Abstract: With the advancement of environmental protection and sustainable development of resources, the comprehensive utilization of iron tailings has gradually become a research hotspot. As a kind of solid waste, the application of iron tailings in ultra-high-performance concrete (UHPC) shows great potential. This paper systematically reviews the application status of iron tailings in UHPC, including the modification methods of material properties, the research conclusions and research progress of durability and mechanical properties, and the application cases in practical engineering. By summarizing the research results at home and abroad, the existing technical challenges are put forward, and the future research direction is prospected, which provides a scientific basis for the efficient utilization of iron tailings.

Keywords: Iron tailings; Ultra-high-performance concrete (UHPC); Durability; Resource utilization.

1. Introduction

With the continuous acceleration of China 's industrialization process, the large-scale development of mineral resources has produced a large number of tailings, especially iron tailings, which not only occupy a large amount of land resources, but also cause serious environmental pollution. According to statistics, the stock of iron tailings in China has exceeded 10 billion tons, with an annual increase of more than 400 million tons, which poses a serious challenge to environmental protection and resource utilization [1]. Ultra-high performance concrete (UHPC) is a kind of building material with excellent mechanical properties and durability, which is widely used in bridges, high-rise buildings and marine engineering. However, UHPC has higher requirements on the performance of aggregates, and the resources of traditional aggregates are decreasing day by day, which makes iron tailings have great research value as an alternative aggregate.

In this paper, the application status of iron tailings in UHPC is systematically analyzed, and the research progress in mechanical properties, durability and processing technology is summarized. The advantages and limitations of practical application are analyzed, and the future research direction is prospected [2].

2. Research background of iron tailings as UHPC aggregate

2.1. The necessity of the generation and resource utilization of iron tailings

Iron tailings are the main solid waste produced in the process of mineral resources development. Their storage not only occupies a large amount of land resources, but also pollutes the surrounding ecological environment. Although there are many ways to comprehensively utilize iron tailings, the overall utilization rate is low. The main problem is that the historical stock is too large, the land is occupied, and the storage risk is high. Moreover, the current technology and process are not enough to support large-scale resource utilization, resulting in many tailings can only be stockpiled, and it is difficult to truly achieve harmlessness and resource utilization [3].

In recent years, with the continuous growth of steel production, the production of iron tailings has been growing rapidly. However, thanks to the gradual progress of resource utilization technology, its comprehensive utilization rate has increased significantly, from 7 % in 2008 to 27.69 % in 2018. The resource utilization of iron tailings is mainly reflected in the following aspects: re-separation of iron, recovery of valuable elements, production of building materials, use as soil conditioner and other fields. These applications not only improve the economic added value of tailings, but also reduce their adverse effects on the environment, providing multiple benefits for regional economic development and ecological protection [4].

As a composite waste raw material containing a variety of mineral components, iron tailings have significant resource utilization potential. Its rational development and utilization can effectively alleviate the shortage of iron resources, promote the development of circular economy model, and provide technical support for the realization of green and low-carbon transformation in the mining field. This way of resource utilization is not only an important means of environmental governance, but also an important part of the sustainable development strategy of mining industry in the future [4].

2.2. Physicochemical properties of iron tailings aggregate

The main components of iron tailings are silica (SiO2) and alumina (Al2O3), and also contain a small amount of iron oxide (Fe2O3) and calcium oxide (CaO), which have the potential to be used as concrete aggregates. Compared with ordinary aggregate, the iron tailings aggregate particles are rough and irregular, and the porosity and water absorption rate are higher, but the density is larger, which helps to improve the mechanical properties of concrete.

The content of iron tailings aggregate powder is high (> 12 %), which has a filling effect, which can reduce the porosity of UHPC matrix and improve the compactness and durability. In addition, active components such as SiO 2 and Fe 2O 3 can form calcium silicate hydrate (C-S-H) in the hydration reaction, filling pores and enhancing the bonding

properties of the interfacial transition zone, thereby improving the overall strength and durability of concrete [5].

By optimizing the particle size distribution, adjusting the content of fine powder and curing conditions, the application potential of iron tailings aggregate in UHPC will be further released, providing new opportunities for the improvement of building material performance and the utilization of tailings resources [6-7].

2.3. Characteristics of iron tailings in China

China 's iron tailings have a wide variety, huge output and complex chemical composition due to the different types of iron ore, origin and beneficiation methods. Fig.1 [8] shows the surface micro-shape of iron tailings in different regions. The main components of iron tailings in some areas of China are shown in Table 1 [9].

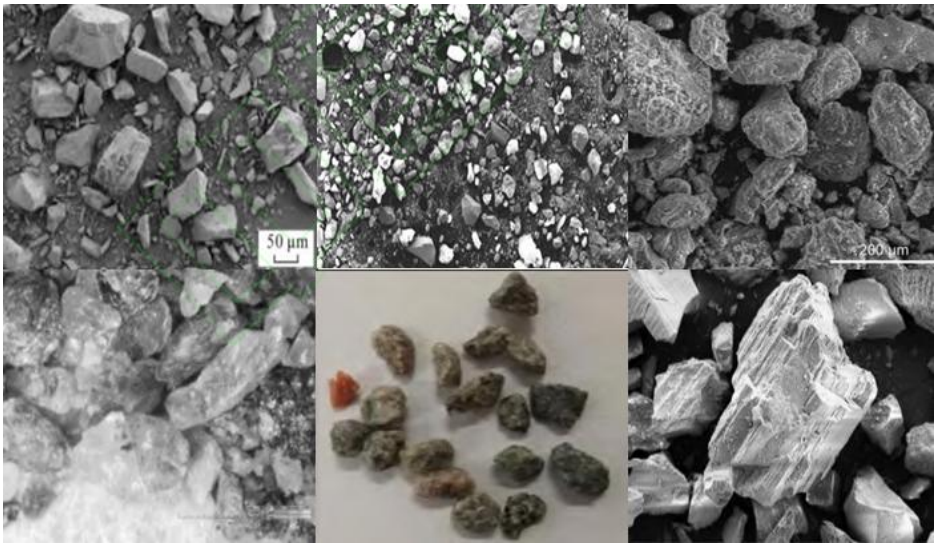

Fig.1 Microscopic shape of iron tailings surface in different regions

Table 1. Main components of iron tailings in some parts of China

Iron tailings producing area	SiO2/%	Fe_2O_3/%	CaO/%	Mg0/%	Al_2O_3/%	TiO_2/%	Na_2O/%	K_2O/%	Other/%
Qidashan Iron Mine of Angang	75.46	15.25	1.70	-	1.65	0.06	0.32	0.34	5.22
Daxigou Iron Mine of Shaanxi Steel	71.06	5.21	5.65	1.73	8.04	0.97	-	1.85	5.49
Jidong sijiaying iron ore mine	71.70	7.99	3.24	3.69	4.34	-	0.38	2.07	6.59
Yunnan mica-bearing iron ore	43.88	24.96	4.08	3.05	12.20	2.00	3.03	1.44	5.36
Miyunweike iron mine, Beijing	61.07	13.38	2.90	2.78	9.15	-	2.29	2.14	6.29
Baierfa red mud iron ore	10.97	35.90	13.81	0.92	23.28	9.78	5.08	-	0.26
Xishimen iron mine, Hebei	30.17	7.42	27.52	8.55	5.13	-	1.50	0.90	18.81
Shaanxi Danfeng Iron Mine	38.00	18.66	23.53	10.74	6.52	0.90	0.78	0.34	0.21
Baotou Baiyunebo Iron Mine	9.70	25.32	20.82	3.00	0.63	0.66	0.75	0.38	38.74
Fluorite iron ore containing rare earth	10.02	28.20	24.72	5.18	0.72	0.55	1.44	0.84	28.32

3. Research progress of iron tailings as UHPC aggregate

3.1. Effect on mechanical properties

3.1.1. Compressive strength

Appropriate amount of iron tailings aggregate can significantly improve the compressive strength of UHPC. This is mainly due to the effect of micro-powder filling effect in iron tailings aggregate, which reduces the porosity of concrete and improves the compactness. At the same time, the active components in the iron tailings (such as SiO2 and Fe2O3) react with calcium hydroxide to form calcium silicate hydrate (C-S-H gel), which enhances the bonding performance of the interface transition zone (ITZ) [5]. However, when the content is too high, the rough aggregate surface is easy to cause stress concentration, resulting in the formation of microcracks. At the same time, the increase of

water absorption will reduce the fluidity and uniformity of the mixture, and ultimately weaken the compressive performance [10].

3.1.2. Tensile strength

The appropriate addition of iron tailings aggregate also significantly improves the tensile strength of UHPC. The formation of C-S-H gel and the decrease of porosity help to reduce micro-cracks and improve the tensile properties of the material. However, too high content will lead to loose internal structure of concrete and increase porosity, reduce the stability of the interface area, and thus have a negative impact on the tensile strength [11]. Therefore, the amount of iron tailings aggregate needs to be reasonably controlled to optimize its tensile properties.

3.2. The impact of durability

Iron tailings aggregate has a significant effect on the durability of ordinary concrete, especially in frost resistance, impermeability and carbonation resistance, which should have the same effect on UHPC concrete [12]. Durability is an important index to evaluate the service life of concrete, and the incorporation of iron tailings may also introduce new challenges while improving some durability. The following analysis is carried out from three aspects: frost resistance, impermeability and carbonation resistance.

3.2.1. Frost resistance

The content of iron tailings aggregate has a significant effect on the freeze-thaw performance of UHPC. Under the action of freeze-thaw cycles, the water inside the concrete freezes and expands, and the retention rate of dynamic elastic modulus may be high, indicating that it has good frost resistance. This is mainly due to the filling effect of micro-powder in iron tailings aggregate, which leads to the generation and expansion of internal micro-cracks, and ultimately weakens the overall performance of concrete. Studies have shown that when an appropriate amount of iron tailings aggregate is added, the enhancement effect of the concrete and the interfacial transition zone reduces the internal porosity and reduces the migration and freezing of water in the pores. However, when the iron tailings aggregate content is too high (more than 75 %), the porosity in the concrete increases, and the micro-cracks are more likely to initiate and expand in the freeze-thaw cycle, resulting in a rapid decrease in the dynamic elastic modulus retention rate. This indicates that the excessive incorporation of iron tailings aggregate may weaken the frost resistance of UHPC. In practical application, the reasonable design and optimization of dosage is the key to improve the frost resistance of UHPC.

3.2.2. Impermeability

The filling effect of micro-powder in iron tailings aggregate has a positive effect on the impermeability of UHPC. The fine powder can effectively fill the pores in the cement matrix and reduce the porosity inside the concrete, thereby improving its impermeability. Figure 2 shows the influence of iron tailings aggregate content on the impermeability grade of iron tailings sand concrete. With the increase of the content, the impermeability grade first increases and then decreases. This is due to the high content of iron tailings aggregate may introduce more large-size pores, weakening the compactness of concrete[13].

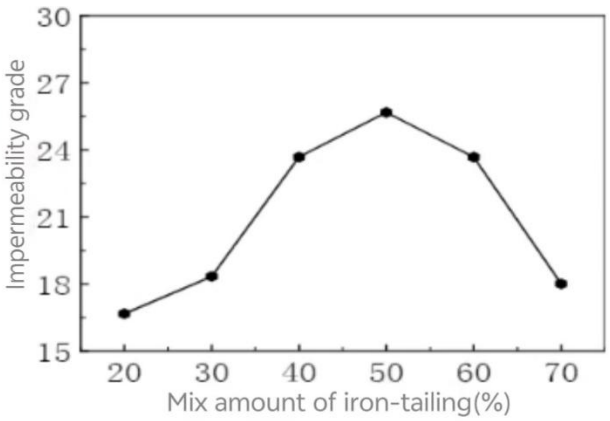

Fig.2. Effect of iron tailing sand content on impermeability grade of iron tailings sandconcrete

3.2.3. Carbonation resistance

In addition to frost resistance and impermeability, carbonation resistance is also an important durability index of UHPC. The introduction of iron tailings aggregate has a dual effect on the carbonation resistance of concrete. On the one hand, the fine powder in the iron tailings aggregate can fill the pores and improve the compactness of the concrete, thereby reducing the penetration channel of the carbonized gas (such as CO 2) ; on the other hand, the high content of iron tailings aggregate may cause an increase in porosity, so that CO2 is more likely to invade the interior of the concrete, thus accelerating the carbonation reaction [14]. The results show that when the content of iron tailings aggregate is less than 30 %, the carbonation depth of UHPC is small, showing good carbonation resistance, which is closely related to the increase of porosity. And the average depth of carbonization increases with the extension of carbonization time.

4. Conclusion and foresight

As the aggregate of ultra-high performance concrete (UHPC), iron tailings show good application potential. Appropriate amount of iron tailings aggregate can not only optimize the mechanical properties and durability of UHPC, but also provide a new path for the utilization of tailings resources, and realize the unity of environmental benefits and economic value. Existing studies have shown that the compactness and interfacial transition zone performance of UHPC can be effectively improved by rationally designing the mix ratio of iron tailings aggregate and appropriate modification treatment. However, the application of iron tailings aggregate in practical engineering still faces technical challenges such as high water absorption, insufficient interfacial bonding performance and insufficient research on long-term service performance.

In the future, the large-scale application of iron tailings in UHPC requires breakthroughs in many aspects, including the development of efficient modification technologies to improve aggregate performance, the systematic study of long-term service behavior in extreme environments, and the establishment of perfect technical specifications for engineering applications. At the same time, big data and intelligent models should be introduced to promote the performance optimization and life prediction of iron tailings UHPC, so as to provide scientific support for material design and resource utilization. Under the background of green and sustainable development, through technological innovation and standardized practice, UHPC from iron tailings is

expected to move from laboratory research to large-scale engineering application, and to help the development of high-performance building materials and the win-win goal of resource utilization [15-16].

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