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Study on Durability of Recycled Aggregate Concrete in High-Temperature and Complex Environments

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Abstract: Recycled aggregate concrete refers to a new type of concrete material made by processing waste concrete materials through grading, crushing, and cleaning, and then mixing them with cement, water, and other materials in a certain gradation or proportion. This type of concrete is highly suitable for modern construction waste disposal and reuse and has been widely used in various construction projects. It can also be used as an environmentally friendly permeable brick material to promote the development of modern green buildings. However, practical applications have found that compared to ordinary concrete, the durability of this type of concrete is more susceptible to high-temperature and complex environments. Based on this, this paper conducts theoretical research on its durability in high-temperature and complex environments, including the current research status, existing problems, and application prospects of recycled aggregate concrete's durability in such environments. It is hoped that this analysis can provide some reference for studying the influence of high-temperature and complex environments on recycled aggregate concrete and its subsequent application strategies.

Keywords: Recycled aggregate concrete; Construction engineering; High-temperature and complex environment; Durability

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1. Introduction

With the continuous aging of reinforced concrete buildings and the increasing amount of construction waste generated by demolition and renovation due to urban construction, the annual output of construction waste in China accounts for 30% to 40% of the total urban waste. According to the latest plan announced by the Ministry of Housing and Urban-Rural Development, China will build 30 billion square meters of new housing by 2020, resulting in at least 5 billion tons of construction waste. Targeted utilization of construction waste and the preparation of recycled aggregate concrete not only conserves overall resources but also prevent environmental pollution caused by piles of waste concrete. It is a sustainable and green concrete that aligns with the scientific development goals concept proposed by the country [1].

During the casting, molding, and curing processes of recycled concrete, a large number of initial defects such as micro-cracks and micro-pores are generated, which affect the strength of the recycled concrete. These are referred to as initial damage [2]. Later, under the influence of external factors (corrosion, load, temperature, etc.), these initial defects continue to expand and connect, forming macro cracks that ultimately lead to the failure of components and even structures.

2. Analysis of current research status both domestically and internationally

Currently, experts and scholars both domestically and internationally have achieved fruitful results in the durability research of recycled aggregate concrete from both experimental and theoretical aspects. These studies mainly focus on establishing damage evolution equations for recycled aggregate concrete under different conditions and analyzing the mechanical performance parameters that characterize concrete damage. Among them, established damage equations include thermal-hydro-mechanical coupling damage evolution equations, chemo-mechanical coupling damage evolution equations, and compression-shear coupling damage evolution equations. However, due to differences in curing and working environments, it is difficult to use a single model to reflect the coupled damage situation of recycled aggregate concrete in high-temperature and complex environments. Therefore, this paper proposes research on the durability of recycled aggregate concrete in high-temperature and complex environments.

2.1. Analysis of the international research status

In foreign countries, research on the durability of ordinary concrete in high-temperature and complex environments began in the 1950s to 1960s. With the continuous development of the construction engineering industry, recycled aggregate concrete has also begun to be gradually put into use and has become popular in multi-story and high-rise buildings. Based on this, the durability of recycled aggregate concrete, especially in high-temperature and complex environments, has become a focus of research for many foreign scholars.

Weide *et al.* studied the changes in cement paste in recycled aggregate concrete under different temperatures using differential scanning calorimetry [2]. The study found that the cement paste undergoes significant changes when exposed to different temperatures. When the temperature rises to about 120°C, the free water within the paste evaporates completely and when the temperature increases from 120°C to 172°C, the hydrated calcium carboaluminate dehydrates. At 180°C to 300°C, hydrated calcium silicate dehydrates and at 450°C to 550°C, calcium hydroxide dehydrates and decomposes.

Lucia *et al.* conducted high-temperature environmental tests on cylindrical samples of recycled aggregate concrete and compared them with ordinary concrete [3]. They evaluated cracks, mass loss, porosity, and thermomechanical properties. The study revealed that, compared to ordinary concrete, the cubic compressive strength of recycled aggregate concrete decreases more significantly under high-temperature conditions, with a reduction range typically reaching 15% to 42%.

Belen *et al.* proposed that the water absorption rate of recycled aggregates in recycled aggregate concrete directly affects its compressive strength in high-temperature and complex environments [4]. Specifically, if pre-water absorption treatment is performed before completing the subsequent preparation of recycled aggregate concrete, even with a 100% replacement rate of recycled aggregates, the reduction in compressive strength under high-temperature and complex environments will not exceed that of ordinary concrete by much.

2.2. Analysis of the domestic research status

Although the application and related research of recycled aggregate concrete in China started slightly later than in foreign countries, with the continuous development of the domestic construction engineering industry in recent years, as well as the continuous innovation of construction engineering materials and technologies, recycled aggregate concrete with advantages such as energy saving, environmental protection, and economy has begun to be widely used. Meanwhile, research on its durability in high-temperature and complex environments has increasingly attracted the attention of relevant domestic scholars.

Xiao Jianzhuang *et al.* conducted experimental research on recycled aggregate concrete in high-temperature and complex environments [5]. They found that when the ambient temperature is between 100℃ to 300℃, the elastic modulus of this type of concrete loses 10% to 20% compared to normal temperature conditions. When the ambient temperature exceeds 700℃, the loss of elastic modulus of this type of concrete reaches 45% to 50%.

Yao Guohuang *et al.*, based on the study of high-temperature thermal and mechanical properties of recycled concrete, used ABAOUS software to establish analysis models for the temperature field, fire resistance limit, and residual mechanical properties after standard heating and cooling fire exposure of reinforced recycled concrete components (slabs, beams, columns) under ISO 834 standard fire conditions [6]. The reliability of the models was also verified. By dividing the one-dimensional and two-dimensional heat transfer areas of the components, a simplified calculation formula for the temperature of reinforced recycled concrete components under fire was proposed. The focus was on analyzing the influence of the replacement rate of recycled coarse aggregates on the temperature field, fire resistance limit, and residual bearing capacity of reinforced recycled concrete components under fire conditions.

Li Weina researched the loss of ignition, compressive strength, bearing capacity, and bonding performance of recycled concrete with different proportions of old materials [7]. The results showed that as the proportion of old materials increased from 0% to 100%, the compressive strength of recycled concrete decreased by 22.3%. Higher burning temperatures led to a greater mass loss rate of recycled concrete and more significant color changes. Higher proportions of old materials and higher fire temperatures resulted in lower strength of recycled concrete. The load-displacement curve of recycled concrete columns exhibited a three-phase trend: an approximately linear increase, then a slow increase, and finally a decrease. The relative slip curve of steel-reinforced recycled concrete columns showed a trend of rapid increase, followed by a rapid decrease and then a rapid increase, with two significant peaks. When the temperature increased from 300°C to 600°C, the peak displacement of steel-reinforced recycled concrete columns increased by 16.7%, and the final slip increased by 9.5%. Under 600°C conditions, compared to conventional concrete columns, the peak displacement of steel-reinforced recycled concrete columns with a 100% proportion of old materials increased by 115.4%, and the final slip increased by 35.3%.

3. Analysis of existing problems and application prospects

3.1. Analysis of existing problems

Based on the research results of domestic and foreign scholars regarding the durability of recycled aggregate concrete in high-temperature and complex environments, it is evident that recycled aggregate concrete has poorer durability compared to ordinary concrete under such conditions. High-temperature environments can lead to the evaporation of water in structural materials, resulting in increased porosity and affecting the internal crystal structure of the materials. As the temperature rises, the evaporation of water within the structural materials leads to greater porosity, reducing the compactness and strength of the materials. Additionally, high-temperature environments can alter the chemical properties within the structural materials, such as promoting carbonation reactions, which can lead to a decrease in material strength [8]. However, compared to ordinary concrete, the performance degradation of recycled aggregate concrete structural materials is more significant under the same high-temperature and complex environmental conditions.

Through existing research and practical applications, the following differences in durability have been observed between recycled aggregate concrete and ordinary concrete:

(1) As the ambient temperature gradually rises, recycled aggregate concrete begins to experience increasing mass loss, its color gradually turns to grayish-white, and surface cracks become more prominent. During this process, the higher the proportion of waste material in the recycled aggregate concrete, the more pronounced these changes are. Experimental data comparisons show that, compared to concrete without waste material, the loss on ignition of recycled aggregate concrete is always higher after adding waste material, and the increase is proportional to the amount of waste material added.

(2) The impact of high-temperature and complex environments on the compressive strength of recycled aggregate concrete is not significantly different from that of conventional concrete. This is because, after exposure to high temperatures, all types of concrete exhibit a significant decrease in compressive strength, making the variations in compressive strength among different types of concrete less significant. However, comparisons of compressive strength among different types of concrete within the same temperature range reveal that, as the proportion of waste material in the concrete increases, the compressive strength of coarse aggregate concrete decreases significantly in high-temperature and complex environments.

(3) Recycled aggregate concrete with added waste material always exhibits greater displacement and faster failure rates than conventional concrete without waste material, indicating a more severe reduction in bearing capacity. Especially in complex environments where the ambient temperature exceeds 600°C, the reduction in bearing capacity of recycled aggregate concrete steel structures becomes more significant as the proportion of waste material increases.

(4) As the proportion of waste material in recycled aggregate concrete increases, the slip of the recycled aggregate concrete steel structure also increases under the same high-temperature and complex environment conditions [9]. Especially in high-temperature and complex environments, this type of concrete steel structure will have a greater amount of slip.

Therefore, it can be seen that in high-temperature and complex environments, the higher the proportion of waste material in recycled aggregate concrete, the lower its fire resistance, bearing capacity, and anti-slip performance will be, resulting in poorer overall structural durability.

3.2. Application prospect analysis

Recycled aggregate concrete is a green concrete strongly promoted by the country. Its performance has similarities and differences compared to ordinary concrete, posing new technical challenges for its application in high-temperature environmental engineering. Based on this, in the construction of building engineering projects, engineering units should reasonably apply recycled aggregate concrete based on actual engineering conditions and application requirements. Typically, engineering units can use this type of concrete material in conditions such as road construction or underwater construction to avoid adverse effects on its durability from high-temperature and complex environments.

To apply recycled aggregate concrete in ordinary building construction projects, engineering units need to consider the actual fire resistance level of the building structure, concrete bearing capacity, concrete-steel structure bearing capacity, and anti-slip design requirements to properly formulate this type of concrete. The proportion of concrete waste should be reasonably determined to ensure the performance of the overall building structure [10]. During the specific formulation process, engineering units should not arbitrarily increase the amount of waste material in recycled aggregate concrete to save costs, as this may adversely affect its durability.

Through the reasonable implementation of the above application schemes and measures, the performance of recycled aggregate concrete can be well guaranteed, minimizing the adverse effects of high-temperature and complex environments on its basic properties and further enhancing the durability of recycled aggregate concrete structures. This will be very beneficial for the rational application of recycled aggregate concrete materials, thereby effectively promoting the sound development of the modern construction industry.

4. Conclusion

Currently, research on the time-varying laws of recycled aggregate concrete performance, damage evolution mechanisms, and constitutive models under the coupled effects of multiple factors in high-temperature and complex environments remains a gap. Therefore, researching the damage evolution mechanism of recycled aggregate concrete in high-temperature and complex environments not only has important scientific significance but also holds significant promise for engineering applications.

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