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Research of Geopolymer Recycled Concrete

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Abstract: Geopolymer recycled concrete is a kind of green building materials, which is of great significance to reduce the waste of resources and protect the environment. This paper discusses the basic mechanical properties and durability of geopolymer recycled concrete materials, and reviews the compressive strength, modulus of elasticity and Poisson's ratio of the basic mechanical properties, the carbonation resistance, acid erosion resistance, frost resistance and the performance of fibre geopolymer recycled concrete components in the durability properties. The study shows that by changing the ratio of the amount of oxide material, the excitation conditions, the curing mechanism, the substitution rate of recycled aggregate, the volume of fibre admixture and the water glass modulus, the geopolymer concrete is able to outperform the ordinary silicate concrete in terms of the basic mechanical properties and the durability performance. However, in practical engineering applications, further research is needed to improve its material properties.

Keywords: Geopolymer; recycled aggregates; durability; basic mechanical properties; fibre components.

1. Introduction

In the process of modernization and social development, Portland cement has become one of the indispensable building materials, but the CO_2 formed and released in the process of firing ordinary Portland cement has become one of the sources of environmental pollution. In the process of firing 1kg ordinary Portland cement, 0.66 ~ 0.82kg CO_2 will be released [1].In the emission of anthropogenic carbon dioxide, the CO_2 produced by global cement production accounts for about 5%~7% [2]. The production of ordinary Portland cement requires high temperature conditions of 1400°C, which consumes a lot of energy. Ordinary Portland cement does not conform to the development direction of building materials; the exploration and research of green building materials with low energy consumption and high environmental protection has become the focus of global building materials research and development. Geopolymer is a new type of environmentally friendly inorganic cementitious material, which was first proposed by French scientist Davidovits[3]. Geopolymer is a kind of inorganic polymer, which has low CO_2 emission and can consume a certain amount of industrial solid waste. It is considered to be the most promising substitute for Portland cement in the 21 st century. And with the progress of China 's modernization, the old buildings have been demolished, resulting in a large amount of construction waste. It is not only a waste of building materials, but also a burden on the environment. How to reuse construction waste is also the key direction of the development of the construction industry. The development of waste concrete is an ' urban mine ' [4] to process it into recycled raw materials and prepare new concrete, generally referred to as recycled concrete, which can solve the problem of waste concrete consumption and alleviate the shortage of natural sand and gravel resources. The combination of the two can not only solve the problems of energy consumption and environmental pollution of Portland cement, but also reuse construction waste. As a new type of green building material, geopolymer recycled concrete has great development potential and prospect.

2. Main Features and Mechanical Properties

2.1. Main feature

There is no hydration reaction of calcium silicate in geopolymer, and its final product is zeolite-like phase [5]. Zeolite is a kind of material with skeleton structure, and zeolite material can be used in nuclear industry to adsorb and retain harmful chemical gases. Ordinary silicate concrete does not have this feature, which is also a major advantage of geopolymer concrete different from ordinary concrete. The aggregate of recycled concrete is generated by the decomposition of waste concrete, including natural gravel and randomly distributed attached old mortar. The morphology of recycled aggregate particles is characterized by many edges and corners, rough surface, and adhesion to hardened cement mortar. In the process of crushing, the cumulative microcracks are accumulated due to damage, resulting in high porosity, large water absorption, small bulk density and high crushing index. To a certain extent, it limits its wide application in structural engineering.

2.2. Mechanical property

2.2.1. Compressive strength

Compressive strength is one of the main mechanical properties of concrete. Ding Zhaoyang [6] studied the influence of the molar ratio of oxides, excitation conditions and curing mechanism on the compressive strength. The results show that with the increase of n(CaO+MgO) / n (SiO_2 + Al_2O_3) ratio, the compressive strength of geopolymer recycled aggregate concrete at each age increases first and then decreases. When the ratio of n (CaO + MgO) to n (SiO_2 + Al_2O_3) increases from 0.8 to 1.0, the geopolymer transits from low calcium system to high calcium system, and its compressive strength increases gradually. When the molar ratio exceeds 1.0, the internal structure of the geopolymer is a layered structure of the high-calcium system. CaO and MgO in the system are saturated, and the strength is controlled by the ratio of n (SiO_2) to n (Al_2O_3). When the NaOH content is too low or too high, the concrete strength is zero or very low,

which is related to the polycondensation reaction. When the NaOH content is between 0.05 and 0.09, the compressive strength increases with the increase of NaOH content. With the increase of water glass content, the compressive strength increases gradually, but when the content reaches 0.5, the strength growth is not obvious, and the content of water glass has a great influence on the early strength. The higher the liquid-binder ratio of geopolymer recycled concrete is, the lower the compressive strength is. When the liquid-binder ratio is 0.65 and 0.7, the later strength increases rapidly. With the increase of curing temperature, the compressive strength of geopolymer recycled aggregate concrete increases first and then decreases. When the curing temperature is 60°C, the compressive strength is the largest. The inflection point of the decrease of compressive strength at different ages is inconsistent; the curing time has a great influence on the early strength. Prolonging the curing time will increase the 3d strength of geopolymer recycled aggregate concrete, but as the curing time increases, the strength gradually decreases, especially the 28d strength. The maximum strength occurs when the curing time is 4h, and then the strength gradually decreases when the curing time is prolonged. Through experimental analysis, the optimal ratio scheme of geopolymer recycled aggregate concrete is obtained: NaOH content is 0.09, water glass content is 0.4, liquid-binder ratio is 0.55, curing temperature is 60 °C, and curing time is 4h. Su et al.[7] found that the modulus of water glass is inversely proportional to the compressive strength of geopolymer recycled aggregate concrete. When the modulus of water glass is 0.9, the compressive strength is the largest. Zhang et al. [8] found that geopolymer recycled concrete not only has obvious early strength characteristics, but also has better compressive properties than Portland cement recycled concrete, and found that water-binder ratio, age and slag content will have a significant impact on it. The effect of recycled aggregate replacement rate on compressive strength was studied by Ding Zhaoyang et al. [9]. The results show that all size test blocks have a unified rule: when the replacement rate of recycled aggregate is less than 50%, the compressive strength of geopolymer recycled aggregate concrete is proportional to the replacement rate of aggregate. When the replacement rate of recycled aggregate is 50%, it is inversely proportional. This is because there are a large number of pores in the old cement mortar phase of recycled aggregate, which can absorb water. When the replacement rate of recycled aggregate is low, natural stone is the main body of aggregate. Because recycled aggregate absorbs water, it is equivalent to reducing the actual water-binder ratio and has high strength. When the recycled aggregate exceeds a certain amount, although the actual water-binder ratio is further reduced, the strength of the recycled aggregate itself is lower than the strength of the natural stone. At this time, the recycled aggregate is the main body of the aggregate, and the strength of the concrete is dominated by the recycled aggregate. The strength of recycled aggregate concrete decreases. This phenomenon is called strength variation phenomenon. However, due to the different water absorption, density and old mortar content of the selected recycled aggregate, the value of the strength variation phenomenon obtained by different researchers is different.

2.2.2. Elastic modulus and Poisson 's ratio

The elastic modulus of concrete is the main index of its material deformation performance, and it is one of the basic bases for the analysis and calculation of various concrete structures. It can not only reflect its mechanical properties, but also affect the bearing capacity and deformation of the structure, which is an important index in the study of mechanical properties. The modulus of water glass will affect the elastic modulus. The decrease of water glass modulus[10] will reduce the porosity of geopolymer recycled concrete and make the structure more compact, so that it can absorb more energy without additional strain, that is, the rigidity is improved and the elastic modulus is increased. Poisson 's ratio of concrete is an important index of transverse deformation of concrete in the case of initial damage of recycled aggregate. Studies have shown that[11]: when the water-cement ratio increases, the Poisson 's ratio of recycled concrete will increase gradually. The reason for this phenomenon is that the recycled aggregate is brittle and has high water absorption. Poisson 's ratio increases with the increase of water-binder ratio and slag content, while age has little effect on Poisson 's ratio.

2.3. Durability

2.3.1. Carbonation resistance

In terms of the carbonation performance of geopolymer recycled concrete, Bernal et al.[12] believed that the carbonation mechanism of geopolymer is different from that of Portland cement. For geopolymer with high calcium content, CO_2 reacts with geopolymer gel C-A-S-H to form $CaCO_3$. For the low calcium geopolymer system, the gel product is mainly N-A-S-H, so the decalcification reaction does not occur. The carbonization process is mainly from the high alkaline pore solution to the high concentration of Na_2CO_3 solution, but the microstructure of the geopolymer does not change significantly. Hu Zeying[13] studied the carbonation performance of geopolymer formed by kaolin and slag, and found that its performance was significantly better than that of Portland cement of the same grade. At different curing ages, the carbonation depth of Portland cement is about 3.2 times that of geopolymer. The analysis is due to the fact that there is more $Ca(OH)_2$ in the capillary pore solution inside the Portland concrete. When CO_2 enters, it reacts with $Ca(OH)_2$ to form $CaCO_3$, while the geopolymer system cannot be carbonized due to the lack of $Ca(OH)_2$, so the degree of carbonation is small.

2.3.2. Sulphate resistance performance

The alkaline substances in the calcium-containing cement base in the concrete react with the acidic substances to form substances such as $CaSO_4$, $CaCO_3$ and ettringite, which causes the volume expansion to produce cracks, and further promotes the invasion of acidic substances. The process of concrete damage is the acid erosion of concrete. Tang et al. [14] found that the high concentration of sodium sulfate dry-wet cycle environment will not cause erosion damage to the fly ash-based geopolymer recycled concrete, but will accelerate its strength development, and its strength decreases with the increase of recycled aggregate replacement rate.The sulfuric acid corrosion resistance of fly ash based geopolymer recycled concrete is better than that of ordinary recycled concrete, which is due to its own dense structural characteristics and low calcium chemical properties. At the same time, the high temperature conditions provided by the experiment also contribute to the further polymerization reaction. Zhou Yanhua et al. [15] studied the sulfuric acid resistance of high-calcium fly ash based geopolymer recycled concrete. The results showed that the sulfuric acid corrosion resistance decreased after the addition of recycled aggregate.

This is because the recycled aggregate contains calcium compounds, which reacts with the acid solution to cause the mortar attached to the concrete surface to loosen and peel off, thus weakening the corrosion resistance. The increase of NaOH concentration can significantly slow down its mass loss and enhance its erosion resistance.

2.3.3. Frost resistance

Fu et al. [16] studied the reaction of slag powder geopolymer concrete in freeze-thaw cycles, and obtained the conclusion that the elastic modulus loss is less than 12% and the mass loss is less than 6% (300 freeze-thaw cycles) compared with ordinary concrete. Zhou Yanhua et al. [15] measured the penetration depth of chloride ions by AgCl precipitation content, and obtained the conclusion that geopolymer concrete is more resistant to chloride ions than ordinary concrete. Xu [17] studied the frost resistance of geopolymer recycled concrete in high territories. Geopolymer recycled concrete was prepared by changing Na_2O equivalent, alkali activator modulus and water-solid ratio. The basic characteristics of geopolymer such as setting time and microstructure were studied. The test results show that under the condition of rapid freezing method, the ultimate freezing and thawing times of metakaolin-based geopolymer recycled concrete are not more than 75 times. The Na_2O equivalent and the modulus of alkali activator have great influence on the frost resistance and mechanical properties of geopolymer recycled concrete. Under the condition of Na_2O equivalent of 16% and alkali activator modulus of 1.5, the frost resistance of metakaolin-based geopolymer recycled concrete is the best. The slag can shorten the setting time of geopolymer and significantly improve the mechanical properties of geopolymer recycled concrete by more than 20%.

The above studies have found that geopolymer recycled concrete is quite different from traditional Portland cement concrete in terms of carbonation resistance, sulfate resistance, freeze-thaw resistance, etc., and it is generally believed that the durability of geopolymer recycled concrete is better than that of ordinary Portland concrete. At the same time, many studies have been carried out on improving the durability of geopolymer recycled concrete. However, most of the research on durability only focuses on the influence of single environmental factor on the durability of geopolymer recycled concrete, and it is necessary to further explore its durability under various environmental factors.

3. Fiber Component

Material is an important part of the performance of components and structures. Although the performance of a single material is important, the overall performance of components and structures depends on the interaction between materials in the structure. Researchers have found that adding fiber compression to geopolymer concrete improves its mechanical properties such as strength and ductility.

Zhao Qiuhong et al.[18]configured test blocks with different coarse aggregate replacement rates and steel fiber volume fractions, and conducted uniaxial compression full-curve experiments. The experimental results show that with the incorporation of steel fiber, the failure mode of steel fiber reinforced geopolymer recycled concrete changes from brittleness to ductility. The cube compressive strength, peak stress corresponding strain, compressive toughness and ductility increase with the increase of steel fiber content. The compressive strength, elastic modulus and compressive toughness of the cube decrease with the increase of the replacement rate of recycled coarse aggregate, but the strain corresponding to the peak stress increases. Mao Zhijie et al. [19] aimed at the defects of low strength and ductility of recycled aggregate, low utilization rate of tailings resources, and brittleness of geopolymer concrete. They used fiber reinforced composite materials to constrain concrete to improve its strength and ductility and other mechanical properties and improve the utilization rate of resources. The results show that the strength and ductility of core concrete are significantly improved. The more layers of fiber reinforced composite materials, the stronger the reinforcement effect, and the reinforcement effect of confined low-strength concrete is more obvious.

4. Conclusion

In this paper, the research status of compressive strength, elastic modulus, Poisson 's ratio in the basic properties of geopolymer recycled concrete and carbonation resistance, acid corrosion resistance, frost resistance and fiber geopolymer recycled concrete component performance in durability are reviewed.

(1) The amount of oxide material ratio, excitation conditions, curing mechanism, recycled concrete aggregate replacement rate and fiber volume content will have an impact on the compressive strength.

(2) The modulus of water glass will affect the elastic modulus. The decrease of the modulus of water glass will make the structure more compact, the rigidity is improved, and the elastic modulus is increased. Poisson 's ratio increases with the increase of water-binder ratio and slag content.

(3) The durability of geopolymer recycled concrete is quite different from that of traditional Portland cement concrete in terms of carbonation resistance, sulfate resistance and frost resistance, and it is generally believed that the durability of geopolymer recycled concrete is better than that of ordinary Portland concrete.

(4) After adding fiber, the ductility of geopolymer recycled concrete is enhanced. The failure mode of fiber reinforced geopolymer recycled concrete changes from brittleness to ductility. The compressive strength, peak stress corresponding strain, compressive toughness and ductility of the cube increase with the increase of steel fiber content. The more layers of fiber-reinforced composite materials, the stronger the strength and ductility enhancement of core concrete, and the enhancement effect of fiber-reinforced composite materials on low-strength concrete is more obvious.

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