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Geopolymer concrete structure and development

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Abstract

Geopolymer concrete is a new type of green building materials, industrial solid waste and industrial waste as the main raw material, in the industrial waste production process through the geopolymer chemical synthesis reaction generated by the excellent mechanical properties of the new cementitious materials. Geopolymer concrete in structural reinforcement with corrosion resistance, durability, freeze-thaw resistance and other characteristics, can be used in bridges, subway tunnels, underground engineering and other structures. The material properties will directly affect the working performance and the scope of application. The use of geopolymer concrete is of great significance to cut down the resource exploitation, maintain the ecological environment and reduce the geological disasters, and it is necessary to study the structural components and properties of geopolymer concrete to promote the application of geopolymer concrete. This paper summarizes the structure of geopolymer concrete and its development history, in order to provide reference for further research and application of geopolymer concrete.

Keywords

Geopolymer concrete; Mechanical properties; Structural properties.

1. Introduction

With the gradual development of the social economy, the demand for construction materials has increased dramatically, and the demand for silicate construction materials has also increased further. The resulting environmental problems are becoming more and more serious, therefore, there is an urgent need to use a new type of concrete material to solve the increasingly prominent environmental problems [1] [2]. Ground polymer was first proposed by the French Davidovits [3], is a silicate cement clinker, silica fume, slag, water, etc. as the main raw material, generated by chemical synthesis reaction of new materials. It is characterized by high strength, high toughness and low cost, and has been widely used at home and abroad in recent years. Geopolymer has excellent mechanical properties and durability, high engineering stability, the use of a wide range of prospects [4] [5]. In recent years, many scholars have carried out in-depth research on geopolymer, Ding Qin et al [6] geopolymer concrete prepared by active excitation method. Wen Tian [7] geopolymer concrete is prepared by mixing different types and contents of active mineral admixtures and cementitious materials. Liu Yi-Wei et al [8] prepared geopolymer concrete by admixture of fly ash and silica fume. Chen et al. studied the preparation process of geopolymer concrete [9]. Due to the excellent performance of geopolymer concrete, it has been widely used in bridges, subway tunnels, underground engineering and other fields. The current research status of geopolymer concrete at home and abroad was analyzed the structural properties and future development trend of geopolymer concrete.

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2. Preparation and properties of geopolymer cementitious materials

Considering the raw materials and process of preparation, geopolymer can be defined as a new material with properties similar to those of ceramics, which is obtained by chemical reaction with burnt clay (metakaolin) and alkali exciters as raw materials after appropriate processing. The raw materials for the preparation of geopolymer materials are mainly natural minerals containing "aluminum silicates" (such as kaolin, metakaolin, diatomaceous earth, etc.) or industrial waste (such as clay, volcanic ash, slag, fly ash, silica fume, tailings, red mud, steel slag, etc.); followed by alkali exciters (such as water glass, caustic, caustic sodium, potassium silicate, etc.).

Li Feng et al.[10] used Shangluo molybdenum tailings to prepare geopolymer cementitious materials, and obtained the optimal conditions for the preparation of molybdenum tailings geopolymer cementitious materials, which is to mix N a O H solid and water glass according to the modulus of 1.6 as the alkali excitant; pro-activate the molybdenum tailings by wet method with alkali calcination and mix it with sodium aluminate according to a certain proportion, add appropriate amount of alkali excitant; silica-aluminum molar ratio of 2.8, liquid-solid ratio of 0.3, open air at room temperature, and maintain in sealed bags. Sealed bag maintenance. Microanalysis showed that under alkaline conditions, the active Si and Al in the silica-alumina raw materials dissolved and participated in the dehydration and condensation reaction, and with the increase of age, the hydration degree was deepened, and the geopolymer became denser internally and had better mechanical properties.

Sun Yan [11] prepared metakaolin geopolymer by alkali excitation, replaced metakaolin with marble waste powder to prepare marble waste powder geopolymer cementitious materials, and explored the effect of powder replacement and fine aggregate replacement on the properties of marble waste powder geopolymer concrete under the optimal cementitious material mix ratio. The study showed that the powder substitution rate of the prepared marble waste powder geopolymer geopolymer cementitious material was larger when the alkali content was 18%, the marble waste powder admixture was 50%, and the modulus of exciter was 1.4. Through microanalysis, it was found that a large number of C-S-H amorphous gel substances were generated in the geopolymer, which filled in the gap between the marble waste powder and the metakaolin particles, and formed a lot of dense gel structure, which not only met the strength requirements but also maximized the utilization rate of resources. The slumps of geopolymer concrete with different substitution rates were all within 200mm, but its compressive, flexural and splitting strengths all decreased with the increase of substitution rate, then increased and finally decreased again.

The study of Li Ziming [12] showed that the optimum ratio of slag fly ash for geopolymer cementitious material is 8:2, and the strength of geopolymer concrete reaches its maximum when the water cement ratio, alkali admixture, and water-glass modulus are 0.4, 6%, and 1.0, respectively, and the best freezing resistance is achieved when the water cement ratio is 0.45, alkali admixture is 6%, and the water-glass modulus is 1.0, all of which is the most significant effect of the alkali admixture. The best resistance to chloride penetration of geopolymer concrete was achieved at 0.4, 5% and 1.0 for water cement ratio, alkali admixture and water glass modulus, with the most significant effect of water cement ratio; the modulus of elasticity reached a maximum value of 6.3 at 0.45 water cement ratio, 6% alkali admixture and 1 water glass modulus, and the degree of influence of each factor on the elasticity of its modulus was water glass modulus > alkali admixture > water cement ratio.

3. Basic mechanical properties of geopolymer cementitious materials

Geopolymer concrete is a special kind of concrete in which silica-aluminate is excited by alkali exciters as a gelling material. The components are mainly bonded together by the adhesion of CASH, NASH and other gel molecules, and the expansion of microscopic cracks at the time of destruction mainly starts from here, so it can be considered that the source of its strength is the strength of each gel molecule. In turn, the generation of gel molecules is affected by alkali exciters, gelling materials and water-cement ratio, so the mechanical properties of geopolymer concrete are related to all three factors.

Wang Ying et al [13] studied the effect of the composition of fly ash-based geopolymer cementitious materials on their properties, the mechanical properties of two types of geopolymer grit test blocks were studied after pure fly ash (Class C) was mixed with metakaolin and slag powder with mass fraction less than 17%, and compared with the ordinary silicate cement grit test blocks with the same proportion and the same production and maintenance conditions. The results showed that: the strength of class C geopolymer cementitious material was lower than that of P.O 42.5 cement; when the mass fraction of external admixtures was greater than 17%, the strength of fly ash base polymer cementitious material exceeded that of cement of the same age (14 d); and the compressive strength of fly ash base polymer admixed with slag powder was higher than that of fly ash base polymer admixed with an equal amount of biotite kaolin.

Li Xufeng et al[14] investigated the effects of alkali stimulant dosage, water-cement ratio, and the ratio of slag to fly ash on the mechanical properties of slag-fly ash based polymer through the unconfined compressive strength test. The results show that the mechanical properties of slag-fly ash based polymer are best when the dosage of alkali exciter is 30%, the water-to-cement ratio is 0.40, and the ratio of slag:fly ash is 80:20. In different water cement ratio, when the alkali exciter dosage in 20% ~ 40%, slag - fly ash based polymer UCS with the alkali exciter dosage increase showed a trend of increase and then decrease, indicating that the lower or higher alkali exciter dosage of the slag - fly ash based polymer UCS play a negative role in the development of the UCS. When the dosage of alkali exciter is less than 30%, the UCS of slag-fly ash based polymer shows a tendency of increasing and then decreasing with the increase of the water-to-cement ratio, which indicates that the low or high water-to-cement ratio will have a certain inhibition on the development of the strength of slag-fly ash based polymer.

4. Application of geopolymer concrete in structures

As people's awareness of environmental protection increases, the limitations on pollutant emissions in various countries are becoming more and more stringent, and the requirements for energy saving and emission reduction in the cement industry are becoming higher and higher, geopolymer materials, which can consume a large amount of industrial wastes and have lower CO2 emissions, will receive more and more attention. Geopolymer materials have a unique three-dimensional network structure and excellent performance, its application prospects are broad, can be applied to the following aspects.

4.1. Civil engineering materials and quick-fix materials

Geopolymer material has the characteristics of fast hardening speed and high early strength, which can be used in civil engineering to greatly shorten the time of demolding, accelerate the cycle of template operation and improve the construction speed. It is often used in rapid road repair, especially airports, highways and other public places. Due to its high early strength and high interfacial bonding with aggregate, it is also often used for rapid repair of concrete and other materials [15].

4.2. Development of industrial toxic waste and nuclear waste containment materials

The end product of geopolymer is zeolite-like phase, and zeolite is a hydrous aluminum silicate with skeleton (also known as three-dimensional mesh, cage) structure, zeolite material can adsorb toxic chemical wastes, so the geopolymer is an effective cementitious material for curing all kinds of chemical wastes, and sealing the poisonous heavy metal ions and nuclear radioactive elements. Conventional cements are not suitable for curing many chemical wastes containing alkali metals, nor are they suitable for curing metal mine tailings with high concentrations of sulfuric acid in the end product. Unlike conventional cements, geopolymers do not contain lime and are very stable in alkali metal or sulfuric acid solutions. At present, the operation of nuclear power plants and other nuclear utilization facilities will produce a large amount of high, medium and low radioactive nuclear waste, nuclear waste encapsulation methods: asphalt, glass, cement, ceramic, of which the cement method is simple, without high temperature and high pressure and special equipment, investment and operating costs are low, but its stability is poor, the exudation rate is high. Utilizing the skeleton structure of geopolymer-like zeolite phase to sequester nuclear radioactive elements has both the process simplicity of the cement method and the stability of the ceramic method [16]. Germany's BPS project has taken the lead in the use of this material for the treatment of toxic waste and radioactive elements, while China's application in this regard is still blank.

4.3. Geopolymer reinforced soils

In geotechnical engineering construction, it is inevitable to encounter soils with poor engineering properties, which usually require reinforcement treatment to meet the requirements of engineering construction. Cement and lime are the most commonly used cementitious materials for chemical reinforcement of soils. Although these traditional cementitious materials can significantly improve the strength and stiffness of weak soils, their durability is poor, especially under the erosion of sulfate or chloride salts, and the physical and mechanical properties of the cured soils will be seriously deteriorated. The disadvantages of cement and lime, such as high energy consumption and high carbon dioxide emission, also limit their application in soil reinforcement. Therefore, it is of great significance to research and develop new soil reinforcement materials with low carbon, low energy consumption and excellent performance. Currently, alkali-inspired geopolymer cementitious materials prepared from various industrial solid wastes are receiving extensive attention from domestic and international geotechnical engineering researchers [17].

4.4. Development of fire- and heat-resistant materials

In recent years, frequent fires in building exterior insulation materials around the world have prompted the rapid development of non-combustible inorganic insulation materials, green, high-strength, non-burning porous geopolymers are also receiving unprecedented attention. Geopolymers can withstand high temperatures up to 1200°C and can be used to make furnace chambers, metallurgical piping, insulation materials, etc., which are widely used in non-ferrous casting and metallurgical industries.Prof. Davidovits has successfully used geopolymers to cast aluminum products.

5. Conclusion

1. Geopolymer concrete is an emerging building material, which is rich in variety, green and has excellent mechanical properties. As a new type of building material, geopolymer concrete has been widely used in the construction industry, and its excellent mechanical properties and durability have been widely concerned by scholars at home and abroad.

2. Geopolymer concrete has various preparation methods, and it is necessary to choose the appropriate method for preparation according to different situations. At present, scholars at home and abroad mainly through the test on the performance of geopolymer concrete materials, such as strength, shrinkage, seepage resistance and other aspects of the research.
3. The durability of geopolymer concrete is good, but it will produce different degrees of damage in the process of use. By analyzing the damage mechanism of geopolymer concrete, reasonable solutions are proposed to effectively improve the structural performance of geopolymer concrete.
4. As a new type of construction material, geopolymer concrete needs to be tested and researched before it is applied to engineering structures. At present, the research on the structural properties and damage mechanism of geopolymer concrete is relatively small, and still need to continue in-depth research, in order to achieve the purpose of improving the structural properties of geopolymer concrete components and structures.
5. The current research status for fly ash and slag geopolymer concrete is relatively more, while the use of construction waste dust and other materials such as low-activity slag instead of silicate cement, geopolymer concrete research is less, and urgently need to be further improved.

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