ISSN: 1813-4890

Current status of research on durability of geopolymer concrete

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Abstract

Geopolymer is a new type of chemically-inspired cementitious material which has been very actively researched internationally in the past 10 years or so, and it may become a green cementitious material to replace cement in large quantities. To address the durability of alkali excited fly ash (AAFA) geopolymer, the current domestic and international research status of AAFA geopolymer concrete was systematically compiled and analysed in terms of carbonation resistance, freeze-thaw resistance, chloride penetration resistance, acid and sulphate erosion resistance, and weathering resistance, respectively. The results show that the durability of geopolymer concrete is affected by many factors such as the type of precursor raw material, alkali stimulant type, alkali stimulant mixing amount, external admixtures, curing mode and curing temperature, etc. Compared with ordinary cement concrete, geopolymer concrete shows better durability in terms of resistance to carbonation, chloride penetration, acid erosion, sulphate erosion, freezing and thawing, etc. because of its dense internal structure and stable chemical properties. It shows better durability.

Keywords

Geopolymer; resistance to carbonation; resistance to chloride penetration; freeze-thaw resistance; acid resistance; water absorption; weathering.

1. Introduction

Concrete, as one of the most commonly used building materials in all kinds of modern engineering and construction, is driven by the rapid development of social and economic external drive, which makes the demand and production of cement continue to climb. However, it can not be ignored that cement in the rapid development of the construction industry at the same time, but also increase the load pressure on the ecological environment, specifically manifested in the cement industry with high energy consumption, high pollution, high carbon emissions, such as the "three high" characteristics of the cement industry in the production and preparation of a large number of non-renewable resources will be consumed in the process, the emission of a series of gases, dust and other pollutants, as well as the release of nearly equal mass of CO At the same time, it will release approximately the same mass of CO_2 . Statistics show that the cement industry has become the largest source of CO_2 emission in the world, and the CO_2 released by the cement industry alone accounts for about 5%~8% of the global CO_2 emission. The above results show that the large-scale production and application of cement is incompatible with the "green and sustainable development concept" of the construction industry advocated by China, and hinders the timely promotion of the "dual-carbon" national strategic goal. In view of this, the research and development of new green cementitious materials has become a research hotspot in the field of construction cementitious materials.

In recent years, scholars at home and abroad have carried out more extensive and in-depth experimental research around the properties of geopolymer concrete and have obtained stage-by-stage research results, but the current research mainly focuses on the basic physical and mechanical properties of geopolymer concrete, and relatively few investigations on its durability. Based on this, this paper summarises the research reports on the durability of geopolymer concrete by scholars at home and abroad in recent years, focuses on the current research status of the resistance of geopolymer concrete to carbonation, chloride penetration, acid erosion, sulphate erosion and freeze-thawing, and points out the shortcomings of the existing research stage, and looks forward to the development trend of the development trend, with a view to provide reference for the research on the engineering application of geopolymer concrete and Reference.

2. The current status of domestic and overseas research on geopolymer materials

2.1. Current status of domestic research

China's research on mineral geopolymer concrete started compared to foreign countries to lag behind a lot, the main research areas in the preparation of mineral polymer materials, factors affecting the strength of mineral polymer materials and related performance testing, as well as the preparation of concrete with polymers, exploring the study of the influence of concrete performance factors and part of the durability. And geopolymer and geopolymer concrete to meet the requirements of engineering performance, but also to carry out in-depth research.

The research groups of Dr Yunsheng Zhang, Professor Wei Sun[1] and Professor Zongjin Li of the Hong Kong University of Science and Technology (HKUST) are the most representative and started as early as 2000 on the matching design of geopolymers, process system, physical properties, durability (resistance to chloride penetration, freeze-thaw, chemical corrosion, high temperature, etc.) and conducted research on their application in civil engineering. In three years, a large number of microscopic and macroscopic experiments were carried out, and many significant research results were achieved. The research was supported by the National Science and Technology Foundation of China in 2003.

Yang Nanru et al, in the course of their research, classified alkali-inspired cementitious materials according to the raw material varieties: aluminosilicate vitreous, alkali - burnt clay, alkali - ore tailings, alkali - calcium carbonate; Shi Caijun et al, according to the composition of the cementitious components, classified them into five types: alkali slag cement, alkali Portland composite cement, alkali volcanic ash cement, alkali lime-volcanic ash/slag cement, and alkali calcium aluminate composite cement.

Zhang et al. studied the effects of exciters and dopants on the mechanical properties of phosphate slag. The excitation effect of water glass on phosphate slag was better than that of NaOH.The early strength of phosphate slag was significantly improved by mixing certain amount of silicate cement into the slag. The optimum mixing ratio is 10% Portland cement blended in phosphate slag, 15% graphite tailing slag excited with NaOH and Na_2SiO_3 (alkali concentration 5%), the flexural strength of 12h reaches 3.3MPa, the compressive strength reaches 18.6MPa. 28d compressive strength is as high as 75.4MPa.

Chen et al. investigated the mechanical properties of alkali-excited fly ash-slag net paste maintained at room temperature. The compressive strength at 20°C was as high as 87 MPa, and its mechanical properties were better than the strength of the net slurry maintained at 60°C.17) Wang et al. investigated the mechanical properties of alkali-activated materials under the -25°C to 25°C maintenance conditions. The electrical conductivity of alkali-activated slag-base polymer slurry gradually decreased with the decrease of curing temperature, and its mechanical properties also decreased substantially. The 28d compressive strengths at 25°C, 10°C, 0°C, -10°C,-25°C were 110.8MPa, 61.9MPa, 52.1MPa, 18.9MPa, and 2.2MPa, respectively.

For the first time, Sun Jiaying discussed the physical and mechanical properties of composite grouting materials of geopolymer and fly ash, and investigated the preparation process. The composite grouting material was prepared with fly ash, slag, steel slag, accelerator and alkaline activator as raw materials, and the geopolymer and fly ash material was prepared. It has high fluidity and early strength. Ground polymer fly ash composite grouting material is characterised by low viscosity and good fluidity. It is suitable for single-liquid grouting, with good stability, a stone strength greater than 3MPa, and volume stability and durability better than that of superfine cement grouting materials. The ground polymer fly ash composite grouting material formulated by the research is fully suitable for grouting for foundation reinforcement and soil consolidation.

Fu Xinghua, Tao Wenhong and Sun Fengjin investigated the effects of water glass modulus, calcination temperature and alkali content on the properties of polymer cementitious materials. The main mineral compositions of kaolinite after heat treatment from 600℃ to 1300℃were analysed using X-ray diffractometer. The results showed that after calcination at 800℃for 2 h, Wangcun kaolin had the best activity, and the compressive strength of the cementitious material was 74 MPa at 28 d. The compressive strength was higher when the water glass modulus was 1.3 and the alkali content (mass fraction) was 6%-8%, and the setting time was similar to that of ordinary silicate cements, and it had a better resistance to acid, sulphate, and sea salt, as well as a better resistance to erosion and to high temperatures.

Wang Guodong and Fan Zhiguo studied the effects of silicon and aluminium raw materials on the preparation and properties of polymers. And the metakaolin-based polymer cementitious materials were prepared by using metakaolin as the main raw material, mixing some fly ash and slag, and using water glass as the exciter. The mixing ratio of metakaolin and fly ash mainly affects the early strength, and the content of metakaolin, modulus of water glass and other factors have a great influence on the coagulation properties and late strength of geopolymer. Ground aggregates with 28d compressive strength of 77.8 MPa were prepared at room temperature when the fly ash admixture was 65% and the modulus of water glass was 1.4. Mullite and quartz in the fly ash do not participate in the geopolymerisation reaction and their crystal compositions are different. The 6-coordinated Al-O bond of metakaolin was converted into 4 coordination centres. The Al in the polymer is mainly in a four-coordinated form.The Si is bonded mainly as SiQ_4(4Al) with a small amount of SiQ_4(2Al) and the product is of PS type.

Yunfen Hou, Dongmin Wang and Pretty Li conducted an experimental study on the effect of different exciters on the compressive strength of fly ash base polymers. It was shown that under the action of suitable excitants, ground polymers with certain compressive strength could be synthesised using fly ash.The excitation effect of KOH and NaOH soda ash solutions on fly ash was poor, and the compressive strength of fly ash base polymers was very low. However, when KOH or NaOH is compounded with K_2SiO_3 , the compressive strength of the fly ash based polymer can be improved. Among them, K_2SiO_3 had the best excitation effect, and the strength of the fly ash based polymer was improved with the increase of its concentration. When the concentration of K_2SiO_3 was 2 mol/L, the 28d compressive strength of the fly ash-based polymer was the highest, which was 28.75 MPa. However, the compressive strength of the polymer decreased when the concentration of K_2SiO_3 continued to increase.

Wang Jiangyu et al. immersed the metakaolin-based polymers in hydrochloric acid solution for 28 days and measured the retention of flexural and compressive strengths to be 102.3% and 101.4%, respectively. This indicates that the metakaolin-based polymer has excellent resistance to acid attack.

2.2. Current status of foreign research

Mineral polymers (geopolymers) is in recent years research and development - a new type of green cementitious materials, this material was originally proposed by the French chemist Davidovits in 1978, the original intention is to refer to the formation of aluminosilicate mineral polymers by the geochemical effect (chemistry) or mineral synthesis effect (Geosynthesis).

ISSN: 1813-4890

Mineral geopolymers are based on industrial solid waste or aluminosilicate minerals as the main raw material, in which alkali silicate solution is used as an exciter, and the solid-liquid two-phase is fully mixed and hardened at low temperatures to form a three-dimensional semi-crystalline phase polymer gel material containing a wide variety of amorphous aluminosilicate minerals.

Abroad, in addition to Davidovits, materials scientists and research institutes in other countries have carried out many fruitful studies on geopolymers. J.Temuujin,A.van Riessen from Australia studied the effect of preliminary calcination of volcanic ash on the properties of geopolymers. The preparation of polymeric binders from low purity clay minerals was investigated by calcining individual low purity clays at 750°C for 4 h. The calcined clays were chemically activated with an alkaline solution of NaOH and Na_2SiO_3; the change in compressive strength with curing time was determined at room temperature and 85°C and compared with pure kaolin samples. In all binders, amorphous aluminosilicate polymers were formed at both processing temperatures, and the results indicate that the mechanical properties depend on the type and amount of activated aluminosilicate under the same conditions of starting clay material, impurities and processing temperature.

Glukhovsky et al. classified gelling materials into two major systems based on raw material composition:

Me_2O-Me_2O_3-SiO_2-H_2O (alkali series) and Me_2O-MeO-Me_2O_3-SiO_2-H_2O (alkaline-earth series); and Provis et al. classified the collodion materials into three systems, low, medium, and high calcium, based on their chemical composition.

Soutsos et al. investigated the effect of alkali exciter concentration and modulus on the strength of fly ash slurry at a water cement ratio of 0.37 and sand cement ratio of 2.75. The strength increased with increasing alkalinity. However, the strength decreased when the alkali concentration exceeded 12.5%. The strength of the mortar was better when the modulus of the exciter was between 0.75-1.0. The optimum parameters of the exciter were 12.5% alkalinity and 0.90 modulus, when the mortar was cured at 70°C for 28d and the compressive strength was up to 70MPa.

This process for the preparation of geopolymers by using oxidised bottom ash from flowing riverbeds was studied by R. Slavik, V. Bednarik et al. The effect of hydrothermal treatment on the structure of aluminosilicate polymers prepared by the polycondensation reaction of aluminosilicate with hydroxyaluminate in alkaline aqueous solution was investigated, and the structural changes were studied and characterised by means of X-ray diffraction analysis, Fourier-transform infrared spectroscopy, scanning electron microscopy and thermogravimetric analysis. The results showed that the amorphous aluminosilicate polymer was transformed into a crystalline product during hydrothermal treatment at 145°C. The crystalline phase was identified as a mineral of the zeolite group, and this transformation required an alkaline environment during the hydrothermal treatment.

Carcia-Lodeiro et al. suggested that C-S-H gels and C-A-S-H gels are preferentially produced in high-calcium and silica systems; however, in silica- and aluminium-rich systems, the products are dominated by N-C-A-S-H and C-A-S-H gels. The formation of the gel structure is influenced by the C/S and S/A ratio of the feedstock. A high aluminium content in the system results in more Q_4 (nAl).

Golek et al. found that Al_2O_3 /SiO_2 has a large effect on the reaction process of alkali excited slag. Low Al_2O_3 /SiO_2 ratios resulted in C-S-H hydration products and high Al_2O_3 /SiO_2 ratios resulted in C-A-S-H gels. Walkley suggested that the content of MgO had a greater effect on the alkali excited slag. The content of Mg^{2+} determined the formation of the reaction product as a (C-(N)-(A)-S-H) gel and the second reaction product as a hydrotalcite. Monasterio et al. used water glass with different modulus to excite slag and found that during the first two weeks of hydration the products formed very complex crystal forms. excited slag and found that the products formed very complex and different crystalline and amorphous phases during the first two weeks of hydration. The amount of crystalline forms formed in the low modulus water glass excited products was much lower, leading to higher early strengths. When the water glass modulus was higher (2.59), the depolymerisation reaction of the silicate continued after two weeks.

A team of researchers, including Rushdi lbrahim Yousef and Mazen Alshaaer, studied the geopolymer products prepared from natural Jordanian zeolites and their chemical and physical properties and adsorption. In this study, a new methodology for geopolymers based on the production of kaolinite in a steam curing cycle was used with the aim of accelerating the geopolymer reaction and eliminating the residual alkaline earth mineral polymer mass, thus improving its mechanical strength; and the mineral morphology of the prepared samples was determined using X-ray diffraction, scanning electron microscopy and energy dispersive X-ray spectroscopy. The physical and mechanical properties of the final products were determined by drying and soaking the styles and determining their compressive strength, bulk density, water absorption and shrinkage; and the effect of steam curing on the presence of residual alkali and the formation of water-soluble salts during mineral polymerisation was investigated.

Ma et al. investigated the effect of Na_2O content, Ms on the migration of chloride ions in alkali-excited slag concrete (AAS) using the method of diffusion coefficients of chloride ions in concrete under the standard non-steady state conditions of NT Build 443. It was shown that the surface chloride concentration (Cs) of AAS concrete is higher than that of OPC due to the binding of CI- and severe loss of OH- . However, the chloride diffusion coefficient (Dnssd) of AAS concrete is lower than that of OPC due to its denser pore structure and the ability of alkali ions to bind to the chloride ions.The increase of Na_2O% from 4 to 8 decreases the Dnssd, and there is the lowest Dnssd at Ms = 1.5.

PutreasF et al. investigated the chemical erosion resistance of three types of geopolymers, NaOH-excited granulated blast furnace slag, a mixture of fly ash and granulated blast furnace slag, and sodium-water-glass-excited granulated blast furnace slag, immersed in artificial seawater and 4.4% sodium sulfate erosive solution, respectively. The results show that only when immersed in artificial seawater for 90 days and 180 days, the compressive strength of NaWG-inspired granulated blast furnace slag geopolymer showed a big change, which decreased by 15.0% and 27.1%, respectively. While the strength of the remaining two geopolymers (sodium water glass-excited granulated blast furnace slag and NaOH-excited fly ash and granulated blast furnace slag mixture) after erosion basically did not change much compared with the control specimens soaked with tap water, the NaOH-excited granulated blast furnace slag geopolymer immersed in the sodium sulphate erosive solution showed a decrease in flexural and compressive strengths, with decreases ranging from 15% to 20%. The XRD test showed that when the ground polymer was excited with NaOH, some colloids were generated inside the ground polymer, in which mainly ordered C-S-H gels were generated. The best resistance to chemical erosion of this geopolymer was found by Hg-pressure test, which showed that the mixture of fly ash and granulated blast furnace slag excited with NaOH had the highest pore content but the smallest average pore diameter. This is due to the strong bonding of the generated amorphous inorganic gel product and, on the other hand, to the filling effect of the microaggregates of the fly ash particles that did not participate in the reaction[2].

3. The current status of research on the durability of geopolymer concrete

3.1. Carbonation resistance

Carbonation of cement-based concrete refers to the alkaline hydration substances such as calcium hydroxide ($Ca(OH)_2$) and calcium hydrated silicate (C-S-H), which exist inside the concrete, generate calcium carbonate by combining with the free CO_2 in the air and water to produce calcium carbonate, which makes the alkalinity of the internal concrete pore liquid weakened, resulting in the damage of the passivation film on the surface of the steel reinforcement, which results in the destruction of the internal structure of the concrete and the deterioration process of macroscopic and mechanical properties. This results in the destruction of the internal structure of the concrete and the deterioration of its macroscopic and mechanical properties. Unlike cement-based concrete, the carbonation mechanism of geopolymer concrete is closely related to the calcium content in the hydration products. The calcium-based hydration products in high-calcium system geopolymer concrete do not contain $Ca(OH)_2$, but are dominated by hydrated calcium silicoaluminate (C-A-S-H) gel, which is directly carbonated with CO_2 and water to produce calcium carbonate. However, the crystalline phase of hydrotalcite in the geopolymer concrete can bind carbonate ions and slow down the intrusion of CO_2 , which can improve the carbonation resistance of geopolymer concrete. Low-calcium system of geopolymer concrete lacks calcium-based hydration products, mainly sodium silicate-aluminate hydrate (N-A-S-H) gel, which has a solid microstructure and stable chemical properties, and under the action of carbonation, it does not generate calcium carbonate and other traditional carbonation products, but the pore solution inside the structure is gradually transformed from a high alkalinity to a high concentration of sodium carbonate, but the internal microstructure of the phenomenon does not undergo a significant deterioration.

Some existing scholars have found that the carbonation resistance of ground polymer concrete is higher than that of cement-based concrete. Huang Qi et al. based on the indoor simulation of accelerated carbonation test, through the carbonation depth, compressive strength and microstructural changes and other means of characterisation, compared and analysed the carbonation resistance of fly ash based polymer concrete and ordinary concrete, and the results of the study show that the carbonation resistance of fly ash based polymer concrete is more excellent; BADAR et al. systematically explored the effect of the calcium content in the raw materials of precursors on the carbonation resistance of fly ash based polymer concrete, and pointed out that the carbonation resistance of low-calcium fly ash based polymer concrete is better than that of high-calcium fly ash based polymer concrete. BADAR et al. systematically investigated the effect of calcium content in precursor raw materials on the carbonation resistance of fly ash-based polymer concrete, and pointed out that the carbonation resistance of low-calcium fly ash-based polymer concrete is better than that of high-calcium fly ash-based polymer concrete, the reason is that low-calcium fly ash-based polymer lacks calcium-based hydration products, and carbonation reaction does not take place; HU Zeying comparatively researched the carbonation resistance of ordinary concrete and biogausside-slag-based polymer concrete, and the results of the study showed that the depth of carbonation of ordinary concrete was significantly higher than that of biogausside-slag-based polymer concrete under the same carbonation conditions. The results show that the carbonation depth of ordinary concrete is significantly higher than that of metakaolin-slag-based polymer concrete under the same carbonation conditions, which is mainly due to the carbonation reaction of the hydration products in ordinary concrete combined with the CO2 in the air, while the hydration products in the metakaolin-slag-based polymer concrete are more stable in chemical properties.

However, some scholars have found that the carbonation resistance of ordinary concrete is better than that of geopolymer concrete.PROVIS et al. found that the carbonation rate of slag-based geopolymer concrete is about 5 times higher than that of ordinary concrete under the same carbonation conditions, and the corrosion of reinforcement inside the structure is much faster; YUAN Yuan et al. investigated the mechanical properties of ordinary and geopolymer concretes after carbonation, in which the resistance of geopolymer concrete is weaker than ordinary concrete. Yuan Yuan et al. investigated the mechanical properties of ordinary concrete and geopolymer concrete after carbonation, in which the carbonation resistance of geopolymer concrete was weak compared with that of ordinary concrete because the representative gel product C-A-S-H in the hydration product would be decomposed by the erosion of CO_2 , which led to the disturbance of the pore distribution characteristics within the structure, thus accelerating the carbonation and erosion efficiency.

In summary, the current researchers and scholars have not reached a consensus on the understanding of the carbonation mechanism of geopolymer concrete, which is mainly due to the wide variety of geopolymer precursor raw materials, alkali exciters, and the large differences in the nature of the geopolymer precursor raw materials and alkali exciters. In the future, more microscopic characterisation methods should be used to carry out research, and the carbonation mechanism of geopolymer concrete should be clarified to construct a more accurate carbonation mechanism model.

3.2. Resistance to chloride permeation

Reinforcement corrosion is the main factor that triggers the damage of reinforced concrete structure, and chloride ion penetration is one of the main reasons for the occurrence of corrosion of reinforcing steel in concrete structure, so the study of chloride ion penetration resistance of geopolymer concrete is an important index for evaluating its durability. At present, the methods commonly used to determine the chloride ion permeability characteristics are mainly fast chloride ion migration coefficient method and electric flux method .LEE et al. used the fast chloride ion migration coefficient method to compare the determination of chloride ion permeability of ordinary concrete and geopolymer concrete, and the test results show that the chloride ion migration coefficient of geopolymer concrete is only 3% of that of ordinary concrete, in which the resistance of the geopolymer concrete to chloride ion permeability is positively correlated with the calcium content. Positive correlation between the chloride permeability of geopolymer concrete and calcium content. BERNAL et al. analysed the chloride permeability of slag base polymer concrete with different dosages of metakaolin by the electric flux method, and the test results showed that the dosage of metakaolin had a negative effect on the chloride permeability of slag base polymer concrete.

Pore structure is an important factor affecting the chloride permeability of porous materials such as concrete.THOMAS et al. pointed out that the chloride permeability of slag-based polymer concrete is better than that of fly ash-based polymer concrete.The reason for this is that the early hydration rate of slag-based polymer concrete is fast, and there are many geopolymer gel products generated, and the internal microstructure is dense, while the early hydration rate of fly ash-based concrete is slow, and there are fewer geopolymer gel products and poor pore structure characteristics. The early hydration rate of fly ash based polymer concrete is slow, the geopolymer gel products are less, the pore structure is poorly characterised and the porosity is larger.GUNASEKA-RA et al. found that the geopolymerisation reaction that occurs in fly ash based polymer concrete continues to enhance along with the growth of the age of curing, and the number of geopolymer gel products continues to grow, which results in the improvement of the degree of internal structural densification, the porosity is reduced significantly, and the resistance to chloride penetration is enhanced.

Chloride ions in the form of penetration into the concrete after the existence of two types of free state and solid state, in which the number of solid state chloride ions, the greater the number of concrete chloride ions indicate that the better the resistance to chloride permeability. Junior et al. through the migration of chloride test, a comparison of the anti-chlorine permeability of kaolin clay-based polymer concrete and ordinary concrete, the results show that the anti-chlorine permeability of the ground polymer concrete is more excellent, which mainly comes from the three-dimensional network-like spatial structure system formed by the ground polymer gel products to strengthen the ability to stabilise chloride ions.

CHINDAPRASIRT et al. investigated the effect of NaOH concentration on the chloride binding capacity of fly ash-based polymer concrete in marine environment, and found that the chloride binding capacity of fly ash-based polymer concrete increased significantly with the increase of NaOH concentration, which was explained by the fact that the high alkaline environment promoted the chloride binding capacity of fly ash-based polymer concrete, and the high alkaline environment promoted the chloride binding capacity of fly ash-based polymer concrete, which was explained by the fact that the high alkaline environment promoted the chloride binding capacity of fly ash-based polymer concrete. The alkaline environment promotes the geological polymerisation reaction rate of fly ash based polymer concrete and increases the number of gel products, so that more chloride ions are attached to the surface of the gel products in the form of physical adsorption.

In summary, geopolymer concrete has better chloride permeability than ordinary silicate cement concrete, mainly due to its denser internal pore structure. However, the means used for the determination of the chloride permeability of geopolymer concrete is relatively single, and more characterisation means should be combined in the future so that the chloride permeability of geopolymer concrete can be evaluated more accurately.

3.3. Freeze-thaw resistance

Freeze-thaw damage refers to the freezing process, the water in the internal pore wall of concrete under the action of freezing from liquid water to solid ice crystals, the volume of expansion occurs, resulting in freezing and expansion stress, destroying the internal microstructure, and in the process of thawing, the melted water is transferred to the periphery of the pores, the volume of concrete can not be restored to its original state, subject to a certain degree of shrinkage. Under the action of repeated freeze-thaw cycles, the internal structural characteristics of concrete are disturbed, and the load-bearing performance decreases.

FU et al. found that after 300 freeze-thaw cycles of slag-based polymer concrete, the loss of modulus of elasticity was about 10%, the rate of mass change was small, and the surface freeze-thaw damage layer was thin, which reflected good resistance to freezing and thawing.ZHAO et al. pointed out that based on the rapid freezing and thawing test, the admixture of slag was beneficial to improve the freeze-thawing resistance of fly ash-based polymer concrete, which was mainly due to the fact that the admixture of slag increased the generation of calcium-based hydration products in the interior of fly ash-based polymer concrete, improving the pore structure characteristics and enhancing the densification of the microstructure.ZHANG et al. investigated the effects of the proportion of rubber powder replacing river sand and geopolymer replacing cement on the freeze-thaw resistance and mechanical properties of geopolymer concrete, respectively. Replacing normal silicate cement by incorporating geopolymer significantly reduces the freeze-thaw resistance of concrete.

In summary, geopolymer concrete has good freeze-thaw resistance, and can be changed by adding mineral admixture of geopolymer concrete freeze-thaw resistance, but the current research on the type of mineral admixture is relatively single, the future should be around more kinds of mineral admixture to carry out the corresponding experimental research and theoretical analysis, and to seek for different types of geopolymer concrete applicable to the type of mineral admixture and the amount of admixture.

3.4. Acid resistance

Acid erosion damage refers to the decalcification of calcium-based hydration products in concrete under the erosive effect of acid, which makes the hydration products disintegrate and disperse, and weakens the bonding and adsorption effect on aggregates, resulting in a decrease in the load-bearing capacity of concrete.BAKHAREV et al. comparatively studied the durability of slag-based polymer concrete and ordinary concrete under acid erosion, and the results showed that under the same erosion age, the magnitude of mechanical property deterioration damage of slag-based polymer concrete was smaller. MEHTA et al. found that the incorporation of cement accelerates the quality loss of fly ash based polymer concrete under acid erosion, mainly because the increasing calcium content improves the generation of gypsum, which destroys the internal microstructure of fly ash based polymer concrete and accelerates the invasion efficiency of the acidic solution. PATHER et al. investigated the effect of siliceous granite and calcareous dolomite aggregates on the acid erosion resistance of fly ash based polymer concrete and showed that both siliceous granite and calcareous dolomite aggregates are beneficial for the improvement of acid erosion resistance of fly ash based polymer concrete. Compared with ordinary concrete, geopolymer concrete has better resistance to acid erosion, mainly because geopolymer concrete in the role of its gel products, the internal structure of the dense, chemically stable, not easy to acidic substances to chemical reaction. In addition, the mixing of specific mineral additives can effectively enhance the acid erosion resistance of geopolymer concrete[4]。

3.5. Water absorption

Due to the lower fineness of fly ash compared to cement concrete and smaller porosity, alkali-excited fly ash geopolymer concrete has lower water absorption compared to cement concrete. Farhana et al. observed that the porosity and permeability of alkali-excited fly ash geopolymer decreased with increasing age, which may be due to increased hydration of alkali-excited fly ash geopolymer matrix and decreased porosity. In general, increasing the concentration of NaOH in the exciter and prolonging the high temperature curing resulted in a decrease in the water absorption of alkali-excited fly ash ground polymer concrete. In a study of ground polymers prepared from low-calcium fly ash, slag powder, ceramic powder, and glass powder, it was found that the water absorption of the ground polymers increases as the NaOH concentration in the exciter increases and the Na_2SiO_3 content decreases. However, in pure AAFA geopolymer, a higher ratio of Na_2SiO_3 to NaOH content in the exciter solution will make the water absorption of alkali-excited fly ash geopolymer very high.Nazari et al. doped rice husk ash in alkali-excited fly ash geopolymer and the best impermeability of geopolymer was obtained when the ratio of SiO_2 to Al_2O_3 of the gelling material was 2.99. In addition, the incorporation of an appropriate amount of nanoparticles will also cause a decrease in the water absorption of the alkali-excited fly ash geopolymer. For example, amorphous nano-SiO_2 particles produce a denser matrix with lower water absorption due to accelerated geopolymerisation reactions. Crystalline nanoparticles of Al_2O_3 contribute to the silica-aluminate reaction and act as nanofillers, thereby reducing the water absorption of the alkali-inspired fly ash geopolymer.

3.6. Weathering resistance

Weathering of concrete is mainly the reaction of CO_2 in the air with the alkaline $Ca(OH)_2$ in the concrete to produce a white salt layer. Due to the large amount of soluble alkali in the geopolymer, there is inevitably a risk of weathering. After accelerated weathering, the alkali-excited fly ash geopolymer concrete (GP(L)) with a mass ratio of 3.9% of fly ash to Na_2O in the exciter was more porous, while the microstructure of the cross-section of alkali-excited fly ash geopolymer concrete (GP(H)) with a mass ratio of 4.6% of Na_2O in the exciter was similar to that of the natural environment. It has been shown that highly porous ground polymers weather rapidly. Although weathering does not change its mineralogical characteristics, a decrease in PH negatively affects the development of compressive strength as well as modulus of elasticity. Six typical geopolymers synthesised from three different fly ashes (Gladstone, Callide and Millmerran) and two different exciters (NaOH and Na_2O-1.5SiO_2) have been systematically studied. Under dry, water contact and immersion conditions, the dry specimens showed the highest 28d compressive strength, while the immersion specimens showed the lowest strength. In the water-contact condition, the NaOH-excited samples rapidly (within 3h) developed strong weathering due to the porous system and exhibited lower strengths than in the water-immersion condition. For OPC concrete, weathering is usually harmless except for discolouration. Obviously, this observation is not valid in AAFA concrete. The addition of less than 50% slag to AAFA had little effect on weathering, but at slag contents above 50%, the FA-BFS ground aggregates exhibited faster weathering rates than pure AAFA, even though the slag powder refined the pore structure of AAFA. This may be due to the fact that slag-based ground aggregates are more susceptible to weathering. At the same alkali content, NaOH-excited AAFA exhibited a slower weathering rate than Na_2SiO_3 excited ones. Yao et al. found that when fly ash-metakaolin geopolymer was locally in contact with water, alkali-rich pore solutions reacted with atmospheric CO_2 to form crystalline deposits, capstones and calcite. The crystal deposits gradually develop in the matrix, eventually exceeding the pore volume and causing damage.Zhang et al. concluded that the weathering products of the geopolymer are mainly sodium carbonate heptahydrate (Na_2CO_3-$7H_2O$). Under the same alkali content, the weathering rate of ground polymer synthesised at high temperature (80℃×28d) was smaller than that of ground polymer synthesised at low temperature (20℃×28d), and the addition of 20% slag could effectively reduce the initial weathering rate of fly ash ground polymer. In humid environments, silica-aluminate polymeric materials are susceptible to weathering phenomena, which is due to the presence of sodium (Na) in the silica-aluminate polymeric structure as $Na(H_2O)_n^+$ bonds, instead of Na bonds, which are chemically weaker. However, above 600℃, the Na bonding in the geopolymer produces a fundamental change, with a significant decrease in Na leaching and a gradual disappearance of the weathering phenomenon. Further studies also showed that increasing the curing temperature and time, adding aluminium-rich additives, lowering the target sodium to aluminium molar ratio and decreasing the water content of the geopolymer, and adding nano-SiO_2 , all of which could control the weathering of the geopolymer well. In addition, weathering of fly ash-based geopolymers can also be inhibited by silane surface modification. This is due to the fact that after the modification, the surface of the ground polymer is changed from hydrophilic to hydrophobic, the capillary absorption and diffusion of water are obviously inhibited, and the leaching of soluble alkali ions is reduced[5].

4. Conclusion

Geopolymer concrete is prepared from industrial solid waste as precursor raw material, and is regarded as an emerging green building material that can replace ordinary cement concrete because of its excellent mechanical properties, good durability, ecological and environmental protection, and high utilisation rate of industrial solid waste resources. The durability of geopolymer concrete is affected by many factors such as the type of precursor raw material, type of alkali exciters, alkali exciters dosage, admixture, curing method and curing temperature, etc. Compared with ordinary cement concrete, geopolymer concrete has a denser internal structure and a stable chemical nature, which makes it show more considerable durability in the aspects of resistance to carbonation, chlorine ion penetration, acid erosion, freezing and thawing, water absorption, and weathering. The durability of polymer concrete is more considerable.

In general, geopolymer concrete has good durability and has a wide range of application prospects in engineering practice. With regard to geopolymer concrete, it can be studied and improved more fully and deeply in the following aspects in the future.

(1) The types of precursor raw materials, alkali exciters, the diversity of preparation processes and the physicochemical properties of aggregates in geopolymer concrete are very different, which leads to the large dispersion of test results and unpredictability. In the future, more

systematic and in-depth experimental studies and theoretical analyses should be carried out around the above factors to establish an effective theoretical framework system.

(2) The existing methods for determining the durability of geopolymer concrete still follow the durability assessment methods for ordinary concrete, while the unique activation reaction mechanism, types and existence forms of hydration gel products of geopolymer itself are different from those of ordinary concrete, leading to a large controversy over whether the durability assessment methods for ordinary concrete are applicable to geopolymer concrete. Therefore, it is necessary to carry out systematic and rich experimental research to confirm the reasonableness and accuracy of various assessment methods, and establish an evaluation system applicable to the durability of geopolymer concrete.

(3) Existing research work on the durability of geopolymer concrete mainly focuses on the macro-mechanical properties testing, while for its micro-mechanisms of the research is rarely reported, after which micro-mechanisms should be analysed around the various types of micro-mechanisms characterisation means.

(4) The current durability study of geopolymer concrete is mostly carried out under the influence of a single factor, but the actual engineering of the various influencing factors are co-existing, in order to meet the actual engineering applications, the need to carry out durability research under the common role of multiple factors.

Acknowledgements

Natural Science Foundation.

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