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Development and Application of Fly Ash-based Geopolymer

Luyao Wang[1, 2, 3, 4], Biao Peng[1, 2, 3, 4]

[1]Institute of Land Engineering and Technology, Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi`an, 710075, China

[2]Shaanxi Provincial Land Engineering Construction Group Co., Ltd., Xi`an, 710075, China

[3]Key Laboratory of Degraded and Unused Land Consolidation Engineering, the Ministry of Natural Resources of China, Xi`an, 710075, China

[4]Shaanxi Provincial Land Consolidation Engineering Technology Research Center, Xi`an 710075, China

Abstract

Fly ash is one of the common solid wastes in coal-fired power plants. In recent years, it has been widely studied for its resource reuse. As a raw material for preparing geopolymers, fly ash can not only take advantage of low carbon dioxide emissions, high mechanical strength and strong durability of geopolymers, but also embed and fix harmful heavy metals in fly ash, thereby realizing efficient use of natural resources. This paper starts from the definition and classification of fly ash, and then mainly describes the preparation process and advantages of fly ash geopolymers, summarizes the research and application of fly ash geopolymers at home and abroad in recent years, and proceeds from the future development trend Outlook.

Keywords

Fly Ash; Geopolymers; Heavy Metal; Concrete.

1. Introduction

Fly ash is one of the solid residues composed of fine particles driven out of the boiler flue gas of coal-fired power plants. Before the flue gas reaches the chimney, fly ash is usually filtered from the flue gas by electrostatic precipitator or other particle filtering equipment. The composition of fly ash is closely related to the source of burning coal, usually including SiO_2, Al_2O_3, CaO and Fe_2O_3, which exist in the form of amorphous and crystalline oxides or various minerals [1].

2. Classification of Fly Ash

According to the American Society for Testing and Materials Standard C 618 (ASTM C618-12a, 2012), fly ash can be classified into C and F levels according to its calcium oxide content. Class C fly ash has high calcium content, mainly from the combustion of lignite, in which the total content of SiO_2, Al_2O_3 and Fe_2O_3 is between 50% and 70%, and the content of CaO is greater than 20%. Grade F fly ash has a low calcium content, which is produced by burning anthracite or bituminous coal. The total content of SiO_2, Al_2O_3 and Fe_2O_3 is greater than 70%, and the content of CaO is less than 10%. In addition to Si, Al, Fe and Ca, fly ash usually contains many other trace metal elements, such as Ti, V, Cr, Mn, Co, As, Sr, Mo, Pb and Hg, etc. The concentration may be 4 to 10 times higher than that in coal, and it may also include low concentrations of dioxins and polycyclic aromatic hydrocarbons. Therefore, fly ash is considered a dangerous substance, and improper disposal of fly ash will not only increase the occupation of land, but may also endanger the ecological environment.

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3. Preparation and Advantages of Fly Ash-based Geopolymers

As oil and natural gas energy is not easily available, non-renewable and high mining costs, coal-fired power plants will continue to operate for a long time in the current stage of development, especially in countries with rich coal resources, such as China, the United States, India and Australia. In this case, the production of fly ash is still inevitable, so it is necessary to develop economical and green utilization technology of fly ash. In the current existing technology, fly ash can be used for soil improvement, it can also be used to make low-cost adsorbents for pollutants, or as a source of silica and alumina for the production of zeolite, and it can also be used to prepare geopolymers. Geopolymer is a new type of binder or cement whose appearance, reactivity and performance are roughly the same as those of ordinary hydrated cement. The geopolymer has a three-dimensional aluminosilicate network structure. In terms of its formation mechanism, it can be obtained from any aluminosilicate material by alkali activation [2], and its empirical formula is $Mn[-(SiO_2)_z-AlO_2]_n \cdot wH_2O$, where z is the molar ratio of Si/Al, M is an alkali metal cation, such as Na+ or K+, n is the degree of polymerization, and w is the water content. z is one of the important factors affecting the mechanical strength of geopolymers, and different alkali metal cations have different sizes and charge densities, which will affect the nucleation, growth and charge density of aluminosilicate chains, the rate of formation and the degree of polymerization.

Studies have shown that for every ton of OPC produced; approximately 0.8 ton of carbon dioxide will be produced. The geopolymer not only emits almost no carbon dioxide during the preparation process, but also has mechanical strength and durability equivalent to OPC cement, so it can be promoted and applied as green cement.

4. Application of Fly Ash-based Geopolymer

4.1. Fly Ash-based Geopolymers Adsorb and Fix Heavy Metals

Many recent studies have shown that soluble heavy metals in fly ash, slag or other industrial and residential wastes, such as Ba, Cd, Co, Cr, Cu, Nb, Ni, Pb, Sn and U, can be fixed in the fly ash base In the three-dimensional structure of high-quality polymers, the main mechanisms include physical encapsulation and chemical stabilization. J. Temuujin et al. [3] used fly ash with high radium radioactivity (314~343 Bq/kg) and high CaO content (14~30 wt%) produced by the burning of radioactive Mongolian coal from the Fourth Thermal Power Station in Ulaanbaatar as Raw material, add a mixed solution of sodium hydroxide and sodium silicate solution, solidify at 70°C for 22 hours, and finally obtain a geopolymer with good compressive strength and freeze-thaw resistance, while the radioactivity is reduced to 130~152 Bq/kg , In line with the safety limit standards for the construction of houses. Zhang et al. [4] used sodium silicate solution to alkaline activated fly ash to make geopolymer binder. The results show that the chemical combination in fly ash geopolymers can immobilize Pb very effectively, and the effect of geopolymers in immobilizing heavy metal ions and its influence on its own structure are closely related to the properties of heavy metals, and soluble heavy metals can be evenly dispersed throughout the entire In the geopolymer matrix, the slightly soluble heavy metals remain separated from most of the binder. Regardless of the degree of pollution, the strength of the fly ash-based geopolymer activated by sodium silicate far exceeds the strength required for solidification/stabilization of solid waste.

4.2. Fly Ash-based Geopolymer Used as Concrete

As people's awareness of environmental protection and the demand for efficient use of natural resources continue to increase, the construction industry is also seeking more green and environmentally friendly materials. The fly ash base polymer is a good binder, which can be used as a mixture of cement and aggregate to produce geopolymer concrete. It has been used as an auxiliary cement material in the concrete industry for more than 50 years.

In the hydration process of traditional cement, fly ash with high content of Al_2O_3 and SiO_2 can be activated by $Ca(OH)_2$, thereby producing more C-S-H gels, C-A-H gels and C-A-S-H gels. This process effectively fills the capillaries in the concrete, thereby increasing the strength of the concrete. Fly ash can reduce the hydration heat and thermal cracking of the concrete in the early stage, and improve the mechanical and durability performance. Compared with OPC concrete, fly ash-based polymer concrete has a denser microstructure, lower chlorine diffusion and lower porosity. In addition, fly ash-based geopolymer concrete can achieve low CO_2 emissions, which is useful for slowing down Global warming has far-reaching significance.

4.3. Fly Ash Base Polymer Cement as Carbon Storage

Some scholars have proposed that injecting and storing carbon dioxide underground can be one of the long-term strategies to deal with greenhouse gases. After injecting carbon dioxide into underground wells based on OPC cement, long-term storage results show that OPC cement has a tendency to continuously degrade and carbon dioxide also slowly leaks. The low permeability of fly ash-based polymers can effectively prevent CO_2 leakage. Research by Nasvi et al. [5] found that the CO_2 permeability of fly ash-based polymers increases with the increase of curing temperature, and the increase is as high as 200~1000%. At any test temperature, its maximum permeability (0.04lD) is about 5000 times lower than the permeability value (200lD) recommended by the American Petroleum Industry (API) for a typical well sealant. Although the permeability of geopolymers increases with temperature, its value is far below the limit recommended by traditional OPC cement and API. Therefore, geopolymers have the potential as the main sealant material in underground well construction materials.

5. Conclusion

In practical applications, it is necessary to comprehensively consider the mechanical properties of fly ash-based geopolymers such as compressive strength, bending strength, and split tensile strength, as well as chloride resistance, acid resistance, heat resistance, freeze-thaw resistance, weathering resistance, etc. The durability can be improved by adjusting the Si/Al ratio, alkali solution, curing conditions, and adding slag, red mud, calcium and other materials. Although there have been decades of research on fly ash-based polymers, there are still many problems to be solved and optimized, including further exploration of the reaction mechanism of fly ash-based polymers, and the adsorption or solidification of heavy metals by fly ash-based polymers. The further improvement of ionic performance, the promotion of the application of fly ash base polymers, etc., I believe that this green environmental protection material will be better utilized in the future development.

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