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Preparation of a tuff polymer and the mechanism of alkaline solution influences on compressive strengths

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ABSTRACT
To promote the effective utilization of the tuff powder waste, this paper proposes a preparation method for a tuff polymer. The raw material is the by-product in the machine-made tuff-based aggregate production process. NaOH and Na_2SiO_3 were added to the raw material successively and cured in an airtight condition at 60 ℃. Compared to the production of Portland cement, higher temperature excitation was not necessary, and lower carbon dioxide emissions during the chemical reaction were achieved. Based on the compressive strength, pH value, scanning electron microscopy, X-ray energy dispersive spectrometer, X-ray diffraction spectrogram, and Fourier transform infrared spectroscopy tests on samples with a variety modulus ($n(SiO_2)/n(Na_2O)$) of the activator, the mechanism of the modulus of activator influences on the compressive strengths of this tuff polymer was investigated. This work 0.042 –0.055 at a range of 0.034 –0.150, and the corresponding maximum strength of the tuff powder was 71.33 MPa. (2) The comprehensive microscopic characterization proved the mechanism of strength development. Microscopic characterization results revealed that the alkali activator mainly acted with the surface of tuff powder particles. With the decrease of the modulus of the activator, the dissolution extent of particles increased, and more aluminosilicate was produced, resulting in strength development. When the modulus was below the optimum value, defects such as pore diameter increased, and the contacting area of the polymer on the surface of the tuff particles decreased, resulting in strength deterioration. When the modulus of the activator was 0.150 and 0.080, the strength development occurred between three and seven days. When the modulus of the activator was 0.050, 0.042, and 0.034, the strength development mainly occurred between 7 and 14 days. The pH value variety of the leaching solution generally corresponded to strength development. The increased strengths are attributed to the consumption of OH^- in the polymerization and polycondensation stages. Meanwhile, a pH value that is too high may result in depolymerization of the production in the polymerization and polycondensation stages. In addition, the electrostatic repulsion increased, and therefore the strengths of the tuff polymer decreased.

KEYWORDS:
tuff powder activator modulus mechanical property microstructure characterization mechanism of strength development

1. Introduction

The dry process of producing artificial sand and gravel requires grading, crushing, screening and other processes, and stone powder accounting for about 20% of the total mass of artificial sand and gravel will be produced during the process [1]. Tuff, which is widely distributed in the Yellow River Basin, has become an important raw material for artificial sand and gravel in the region [2], [3]. Therefore, a large amount of tuff stone powder is produced every year due to the production of artificial sand and gravel in the region, most of which is collected by vacuum dust collection devices [1]. The collected tuff stone powder is sharp and flake-shaped, with a particle size smaller than the minimum particle size of artificial sand (0.15 mm), and is mixed with clay particles. If used to prepare concrete, it will affect the workability of concrete due to the adsorption of water reducers and irregular particle shape [4], [5]. The storage of stone powder will cause environmental pollution such as air, soil, and water sources, and there is currently a lack of effective recycling methods.

Many scholars at home and abroad have found in their research that many solid wastes with high silicon and aluminum content, such as fly ash and blast furnace slag, can be used to prepare geopolymers by alkali activation. This method provides a reference for the secondary utilization of tuff stone powder. At present, research has been conducted on the activation methods, maintenance conditions and material properties of different geopolymer materials. The research objects include: industrial by-products such as metallurgy and power generation (such as fly ash, silica fume and blast furnace slag), mining waste (rock fragments, powder), natural volcanic ash and calcined clay (metakaolin). Shi and Day studied and compared three methods of activating the activity of natural volcanic ash: mechanical, thermal treatment and chemical activation, and found that the chemical activation method is the best in terms of effect, cost and feasibility [6]. Zhang Yunsheng et al. prepared geopolymers using kaolin as raw material and found that the performance was optimal when $n(SiO2)/ n(Al2O3)=4.5$, $n(Na2O)/ n(Al2O3)=0.8$, and $n(H2O)/ n(Na2O)=5.0$, and established its molecular structure model [7]. Oh et al. studied the strength and crystalline phase development of blast furnace slag and fly ash-based polymers. It was found that hydrotalcite was formed in both alkali-activated slag cement and fly ash-based cement [8]. Bondar et al. studied the type and form of activator.

The effects of formula and dosage on the strength of alkali-activated natural volcanic ash were studied, and it was found that KOH had a better activation effect than NaOH solution. The geopolymer had the highest strength at 60 °C and an activator modulus of 2.1 [9]. Shi Huisheng et al. reviewed the role of alkali components, silicon-aluminum components, calcium components and water in fly ash-based polymerization [10]. Cheng et al. studied the effect of SiO2/Na2O molar ratio on alkali-activated metakaolin and found that the optimal SiO2/Na2O molar ratio was 1.93 [11]. Aziz et al. studied the microstructure and pore evolution of alkali-activated slag at 800-1200 °C and found that the evolution of pores and crystal phases in high temperature environments caused the development of internal strain [12]. Gijbels et al. studied the effect of NaOH dosage on the hydration process, mineral composition, porosity and strength of sulfate alkali-activated blast furnace slag and phosphogypsum [13]. Nikolov et al. et al. optimized the performance of natural clinoptilolite geopolymer using aluminate, increasing its strength by nearly 3 times, making the product more stable and reducing the shrinkage of the material [14]. Li Shuang et al. found that the rheological properties of 3D printed fly ash-based polymer increased with the increase of magnesium aluminum silicate admixture, and showed an increasing trend with the standing time [15]. Yang Kai et al. studied the drying shrinkage mechanism of slag/metakaolin composite cementitious materials and found that excessive alkali equivalent and excessive high temperature curing time would reduce the drying shrinkage [16]. However, tuff is a volcanic clastic rock, which is cemented by volcanic ash and sand after volcanic eruption. The powder produced during its crushing process is different from the geopolymer materials that have been widely studied in terms of mineral composition and formation process. Whether it can form polymer cementitious materials through alkali activation method is less studied.

2. Conclusions

In this paper, the chemical excitation of tuff machine-made sand powder waste was studied by using a variety of characterization methods such as pH value determination, scanning electron microscopy, X-ray energy spectrum analysis, X-ray diffraction analysis and Fourier transform infrared spectroscopy to study the influence mechanism of the modulus of the exciter on the compressive strength development of tuff-based polymer. The specific conclusions are as follows:

(1) When the curing period is greater than 14 days, the optimal excitation modulus of tuff-based polymer is 0.042-0.055, and the corresponding maximum strength is 71.33 MPa. When the exciter modulus is 0.150 and 0.080, the strength development mainly occurs between 3 and 7 days, and when the exciter modulus is 0.055, 0.042 and 0.034, the strength development mainly occurs between 7 and 14 days.

(2) Natural tuff stone powder has irregular flaky morphology, large specific surface area and high Si and Al content. From the microscopic morphology analysis, Alkali activators mainly act on the surface of tuff stone powder particles, dissolving and bonding the surfaces of different particles together. The compressive strength is mainly affected by defects such as the contact area and macropores of the cement. From the analysis of the product composition, with the increase of NaOH concentration in the activator, the amount of main minerals dissolved in the tuff stone powder increases, aluminosilicates are generated on the surface, the proportion of Al element in the product increases, and the vibration peak formed by the asymmetric stretching vibration of Si-O-T shifts to the direction of low wavenumber. At the optimal excitation concentration, the ratio of Si/Al atoms is the smallest, and the wavenumber of the O-H stretching vibration peak is the lowest.

(3) The pH value of the sample leachate changes with age and has a good correspondence with the strength. The lowest pH value corresponds to the maximum strength of the corresponding age. Excessive OH- may cause the products of the polymerization and polycondensation stages to depolymerize again, and the increase of electrostatic repulsion at one end of the lamellar particles may cause the particles to mainly contact in point-to-surface, thereby reducing the strength of the material.

3. References

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