Thermal-alkaline Activation Enhances the Mechanical Properties of Low-activity Recycled Concrete Powder-derived Geopolymers (Postprint)

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Abstract

The existing studies estimated that the waste concrete accounts for over 60% of the total CDW, thus improving the utilization rate of waste concrete is crucial to alleviate the burden of CDW disposal. In recent years, some scholars found that the recycled concrete powder (RCP) contained a high content of silicon (Si), aluminum (Al), and calcium (Ca) elements, which is a suitable precursor material for synthesizing geopolymer. However, a primary challenge in RCP derived geopolymer is to improve its mechanical strength suitable for engineering practice. This is attributed to the low content of amorphous substances in RCP, with most Si, Al, and Ca existing in the form of crystalline minerals. These minerals are less soluble in alkaline activators, inhibiting geopolymerization and resulting in reduced gel and lower strength. This study proposed a thermal-alkaline activation method to enhance the activity of recycled concrete powder (RCP) and then to produce high-strength geopolymers. The thermal decomposition behavior of RCP was analyzed using thermogravimetric-differential scanning calorimetry (TG-DSC) to investigate its phase decomposition characteristics across different temperature ranges, thereby determining the optimal calcination temperature range for RCP. The microstructural morphology and phase composition changes of RCP before and after calcination were further compared through scanning electron microscopy (SEM) and X-ray diffraction (XRD)analysis, revealing the influence of the calcination process on its microstructure. Based on these findings, a series of geopolymer specimens derived from RCP under various calcination conditions were prepared. The effects of calcination conditions on the unconfined compressive strength (UCS) growth of RCP-derived geopolymers were evaluated through UCS testing. Additionally, energy consumption under different calcination conditions was calculated to achieve a balance between mechanical performance enhancement and energy

efficiency, ultimately leading to the identification of the optimal calcination parameters. Within the temperature range of 650°C to 800°C, significant mass loss was observed, indicating intense mineral decomposition. The calcined RCP samples with NaOH exhibited a diffuse peak between 32° and 35°, demonstrating a higher content of amorphous substances compared to those without NaOH. RCP contained substantial amounts of Si, Al, and Ca elements, predominantly in low-reactivity crystalline forms. Calcination with preloaded sodium hydroxide (NaOH) significantly altered the microstructure and phase composition of RCP. These observations suggest that a portion of Si, Al, and Ca elements in RCP transformed from their initial low-reactivity crystalline states into highly reactive amorphous forms, thereby enhancing the reactivity of RCP. The UCS of calcined RCP-derived geopolymers gradually increased with increasing calcination time. However, when the calcination temperature rose from 650°C to 800°C, the UCS initially increased and then decreased. The optimal condition for RCP-derived geopolymers was determined to be 750°C calcination temperature for 45 minutes, achieving a 7-day UCS of 17.6 MPa—almost five times greater than that of uncalcined RCP-based geopolymers. Considering the balance between UCS growth and energy consumption, the optimal calcination scheme was determined to be 750°C for 15 minutes. The uncalcined RCP-derived geopolymers exhibited a porous microstructure with loose gel formation and numerous unreacted RCP particles after 28 days of curing. In contrast, the calcined RCP-derived geopolymers displayed a dense structure with minimal observable pores and fewer unreacted RCP particles, indicating improved reactivity due to calcination.

Full Text

Preamble

Thermal-Alkaline Activation Enhances the Mechanical Properties of Low-Activity Recycled Concrete Powder-Derived Geopolymers

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Abstract: Waste concrete constitutes over 60% of construction and demolition waste (CDW), making its enhanced utilization critical for alleviating disposal burdens. Recent research has identified recycled concrete powder (RCP) as a promising geopolymer precursor due to its high silicon (Si), aluminum (Al), and calcium (Ca) content. However, a fundamental challenge limiting the engineering application of RCP-derived geopolymers is their inadequate mechanical strength, which stems from the low amorphous content of RCP. In RCP, most Si, Al, and Ca exist as crystalline minerals with limited solubility in alkaline activators, thereby inhibiting geopolymerization and resulting in reduced gel formation and lower strength.

This study proposes a thermal-alkaline activation method to enhance RCP reactivity and produce high-strength geopolymers. The thermal decomposition behavior of RCP was first analyzed using thermogravimetric-differential scanning calorimetry (TG-DSC) to characterize phase decomposition across different temperature ranges and identify optimal calcination temperatures. Microstructural and phase composition changes before and after calcination were examined through scanning electron microscopy (SEM) and X-ray diffraction (XRD) to elucidate calcination effects. Based on these findings, a series of RCP-derived geopolymer specimens were prepared under various calcination conditions. Unconfined compressive strength (UCS) testing evaluated the influence of calcination conditions on mechanical performance, while energy consumption calculations balanced strength enhancement with efficiency to determine optimal parameters.

TG-DSC analysis revealed significant mass loss between 650°C and 800°C, indicating intense mineral decomposition. XRD patterns of NaOH-treated calcined RCP showed a diffuse peak between 32° and 35°, confirming higher amorphous content compared to untreated samples. While RCP contains substantial Si, Al, and Ca, these elements primarily exist in low-reactivity crystalline forms. Calcination with preloaded sodium hydroxide (NaOH) substantially altered RCP microstructure and phase composition, facilitating the transformation of Si, Al, and Ca from crystalline to highly reactive amorphous states and thereby enhancing overall reactivity.

UCS testing demonstrated that strength increased with calcination time but exhibited a peak response to temperature between 650°C and 800°C. The optimal mechanical performance was achieved at 750°C for 45 minutes, yielding a 7-day UCS of 17.6 MPa—nearly five times that of uncalcined RCP geopolymers. However, considering both strength development and energy consumption, the most efficient scheme was determined to be 750°C for 15 minutes.

Microstructural analysis revealed that uncalcined RCP geopolymers developed a porous structure with loose gel and numerous unreacted particles after 28 days of curing. In contrast, calcined RCP geopolymers exhibited dense matrices with minimal porosity and fewer unreacted particles, confirming enhanced reactivity through thermal-alkaline activation.

Keywords: geopolymer; recycled concrete powder; thermal-alkaline activation; calcination

Note: Figure translations are in progress. See original paper for figures.