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The Effect of Calcination Temperature on the Chemical and Physical Properties of Corn Straw Ash

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Abstract
This study aims to explore the effect of different calcination temperatures (600°C, 700°C, 800°C, and 900°C) on the chemical and physical properties of corn straw ash. Through X-ray fluorescence (XRF) and X-ray diffraction (XRD) techniques, the chemical composition and mineral phase changes of the ash after calcination were analyzed. The results indicate that calcination temperature significantly affects the chemical composition and physical properties of the ash. Among the temperatures studied, corn straw ash calcined at 700°C and 800°C exhibited relatively ideal chemical stability and superior physical structure, particularly with higher contents of silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3), while the volatilization of unfavorable components such as chlorine and potassium was stronger. The study suggests that controlling calcination temperature can optimize the properties of corn straw ash, thereby enhancing its potential application in cement-based building materials. This research provides a theoretical basis for promoting the resource utilization of agricultural waste and the development of sustainable building materials.

Keywords: Corn straw ash, calcination temperature, chemical composition, physical properties.

I. Introduction

With the increasing global focus on environmental protection and sustainable development, the effective utilization of agricultural waste has become an important research direction. In agricultural production, large amounts of corn straw are treated as waste, often being burned or buried, which not only wastes resources but also causes environmental pollution. Transforming this waste into value-added products has become a focal point for researchers (Harshwardhan & Upadhyay, 2017).

Corn straw ash, obtained by calcining corn straw, is rich in active silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3). These components theoretically make corn straw ash a potential substitute material for cement. However, the chemical composition and physical properties of corn straw ash are significantly affected by the temperature during the calcination process. Different calcination temperatures not only affect the content and stability of various elements in the ash but also alter its physical structure, thereby influencing its application in building materials (Memon et al., 2020; Šupić et al., 2023; Xiao et al., 2023).

In the field of building materials, extensive research has been conducted on the application of agricultural wastes such as rice husk ash, sugarcane bagasse ash, and bamboo leaf ash in cement and concrete (Cordeiro et al., 2017; Memon & Khan, 2018, 2018; Rodier et al., 2019). These studies have shown that reasonable control of calcination conditions can significantly enhance the activity and reactivity of these wastes, thereby improving the mechanical properties and durability of building materials. However, systematic and in-depth analysis of the chemical and physical properties of corn straw ash at different calcination temperatures is relatively scarce (Bahri et al., 2018; Rithuparna et al., 2021).

Therefore, this study aims to systematically analyze the chemical composition and physical properties of corn straw ash at different calcination temperatures and to explore how these changes affect its potential as a cement substitute. By using X-ray fluorescence (XRF) and X-ray diffraction (XRD) techniques, this study will detail the chemical composition and mineral phase changes of corn straw ash at 600°C, 700°C, 800°C, and 900°C. The results will provide a theoretical basis for optimizing the production process of corn straw ash and its application in building materials, contributing to the resource utilization of agricultural waste and the reduction of environmental pollution (De Lima & Cordeiro, 2021; Pandey & Kumar, 2019; Šupić et al., 2023)

II. Materials and Methods

2.1 Materials

2.1.1 Corn Straw

Corn straw, the primary raw material in this study, was sourced from agricultural waste in Heilongjiang Province, China. To ensure the reproducibility of the experiments, all corn straw was cleaned before use to remove surface impurities and ensure stability during the calcination process.

2.2 Preparation and Characterization of Corn Straw Ash

2.2.1 Selection and Operation of Calcination Temperatures

The dried corn straw was first naturally burned to ash, which was then placed in a muffle furnace for calcination. Four different calcination temperatures were selected for this study: 600°C, 700°C, 800°C, and 900°C to explore the effect of calcination temperature on the chemical and physical properties of corn straw ash. The calcination time at each temperature was set to 2 hours to ensure the complete combustion and transformation of the straw into ash. After calcination, the ash was naturally cooled at room temperature, collected, and stored in sealed containers for further analysis.

2.2.2 XRF and XRD Analysis

The calcined corn straw ash samples were analyzed using X-ray fluorescence (XRF) and X-ray diffraction (XRD) techniques to determine their chemical composition and mineral phases.

XRF Analysis: XRF analysis was used to quantitatively measure the mass fraction of major elements in the ash. This technique provides accurate element content, helping to understand the effect of calcination temperature on the distribution of elements in corn straw ash.

XRD Analysis: XRD technology was used to identify the mineral phases and crystal structures in the ash. Through XRD analysis, the effect of calcination temperature on the crystalline and amorphous phases in corn straw ash can be determined, which is important for understanding the potential applications of the ash.

These analyses enable a comprehensive evaluation of the effect of calcination temperature on the chemical and physical properties of corn straw ash, providing a scientific basis for its application in building materials.

III. Analysis of Ash Physical and Chemical Properties

3.1 Physical Properties of Ash

Appearance Characteristics

The corn straw ash exhibited different colors at various calcination temperatures. At 600°C, the corn straw ash appeared dark gray. At 700°C, it turned brown. At 800°C, the color shifted to light reddish-brown, and at 900°C, it became grayish-white. The color of the straw ash lightened with increasing calcination temperature, as shown in Figure 1.

Figure 1 Calcined straw ash at different temperatures

3.2 Chemical properties of ash

The chemical element composition and oxide composition of ash were obtained by XRF experiments. Table 1 shows that the sodium (Na) mass fraction in ash is lowest (0.23%) at 600°C, reaches its highest (0.61%) at 700°C and 800°C, and then decreases (0.42%) at 900°C. The magnesium (Mg) mass fraction increased gradually with increasing temperature from 3.47% at 600°C to 5.1% at 900°C. The aluminum (Al) mass fraction gradually increases with temperature from 0.52% at 600°C to 0.78% at 900°C. The silicon (Si) mass fraction is lower (18.5%) at 600°C, reaches a maximum (20.5%) at 700°C, and then decreases at higher temperatures. The phosphorus (P) mass fraction increased gradually with increasing temperature from 1.69% at 600°C to 2.31% at 900°C. The sulfur (S) mass fraction fluctuated greatly at different temperatures but showed an overall upward trend, increasing from 1.52% at 600°C to 2.11% at 900°C. The chlorine (Cl) mass fraction decreased significantly from 4.41% at 600°C to 0.11% at 900°C. The potassium (K) mass fraction is highest at 600°C (22.5%) and then gradually decreases at higher temperatures. The calcium (Ca) mass fraction gradually increased with increasing temperature from 7.85% at 600°C to 9.01% at 900°C. The iron (Fe) mass fraction gradually increases with increasing temperature from 0.71% at 600°C to 1.17% at 800°C and then decreases slightly at 900°C.

Stability and Temperature of the Elements: As the temperature increases, the content of certain elements such as magnesium, calcium, and iron continues to increase, which may be related to the stability of these elements at high temperatures.

Elemental Volatility: The mass fraction of chlorine decreases significantly, indicating that chlorine is volatile at high temperatures.

Interactions Between Elements: Trends in silicon, potassium, and sodium suggest that high temperatures may lead to repartitioning and interaction of certain elements.

Table 1 Element composition of the corn stover ash at different temperatures

Temperature/°C	Elemental mass fraction in corn straw ash/%									
	Na	Mg	Al	Si	P	S	Cl	K	Ca	Fe
600	0.23	3.47	0.52	18.5	1.69	1.52	4.41	22.5	7.85	0.71
700	0.58	4.1	0.61	20.5	1.88	1.35	0.91	17.9	8.1	0.87
800	0.61	4.6	0.71	19.7	2.15	1.51	0.15	17.1	8.04	1.17
900	0.42	5.1	0.78	18.7	2.31	2.11	0.11	17.5	9.01	1.05

Through the analysis of the data in Table 2, the silica (SiO_2) content was 40.49% at 600°C, increased to 42.01% at 700°C, and decreased slightly at 800°C and 900°C but remained above 40%. The content of alumina (Al_2O_3) gradually increased with temperature from 0.91% at 600°C to 1.49% at 900°C. The phosphorus pentoxide (P_2O_5) content gradually increased from 3.85% at 600°C to 4.85% at 900°C. The ferric oxide (Fe_2O_3) content does not change much with increasing temperature but fluctuates slightly. The calcium oxide (CaO) content increased gradually with the increase in temperature from 10.51% at 600°C to 12.49% at 900°C. The magnesium oxide (MgO) content increased gradually with the increase in temperature from 6.03% at 600°C to 8.36% at 900°C. The sulfur trioxide (SO_3) content increased gradually with increasing temperature from 3.55% at 600°C to 5.21% at 900°C. The potassium oxide (K_2O) content was highest at 600°C (26.09%) and then gradually decreased at higher temperatures. The sodium oxide (Na_2O) content was lower (0.44%) at 600°C, increased to 0.89% at 700°C, and then decreased at 800°C and 900°C.

Table 2 The distribution of metal oxide content in corn stover ash

Temperature/°C	Mass fraction of metal oxides in corn straw ash/%									
	SiO_2	Al_2O_3	P_2O_5	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	Cl
600	40.49	0.91	3.85	1.21	10.51	6.03	3.55	26.09	0.44	4.41
700	42.01	1.11	4.44	1.31	11.31	6.51	3.53	21.71	0.89	0.91
800	41.31	1.31	4.54	1.63	11.45	7.51	4.16	20.4	0.72	0.15
900	40.69	1.49	4.85	1.59	12.49	8.36	5.21	21.4	0.55	0.1122

Combining Table 1 and Table 2, it can be found that the element and metal oxide content of corn straw ash showed significant changes at different temperatures. Most of the elements are mainly in the form of corresponding metal oxides, such as silicon mainly in the form of SiO_2 and aluminum mainly in the form of Al_2O_3, and their content increases with increasing temperature. At the same time, the contents of calcium and magnesium also increased significantly with the increase in temperature, indicating that high temperature promoted the formation of CaO and MgO. However, the levels of potassium and potassium oxide decreased at high temperatures, while chlorine volatilized significantly. The comprehensive analysis shows that high temperature not only affects the mass fraction of the element but also promotes its conversion into a stable oxide form. These trends provide an important reference for optimizing the biomass combustion process, especially the management of volatile elements such as chlorine and the formation of metal oxides at high temperatures.

IV. Conclusion

This study systematically explored the effect of different calcination temperatures (600°C, 700°C, 800°C, and 900°C) on the chemical and physical properties of corn straw ash. Through the analysis using X-ray fluorescence (XRF) and X-ray diffraction (XRD) techniques, we found that calcination temperature significantly affects the chemical composition and mineral phases of corn straw ash.

The results showed that as the calcination temperature increased, the content of key elements and metal oxides in corn straw ash changed significantly. Notably, corn straw ash produced at calcination temperatures of 700°C and 800°C exhibited the most stable chemical properties and ideal physical characteristics, making the ash produced at these temperatures most promising for application in building materials. Specifically, calcination at 700°C and 800°C helps to form high contents of SiO_2 and Al_2O_3 while reducing the volatilization of unfavorable components such as chlorine and potassium, thereby enhancing the stability and durability of the ash.

These findings provide valuable scientific evidence for optimizing the application of corn straw ash in cement-based materials. By reasonably controlling the calcination temperature, high-performance corn straw ash can be produced, thereby improving the mechanical properties and environmental performance of building materials. Future research should continue to explore the effects of other calcination conditions (e.g., calcination time, atmosphere control) on the properties of corn straw ash and investigate its application in the production of actual building materials. Additionally, similar studies on corn straw from different sources will help further promote the application of this environmentally friendly material.

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