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Rice husk and sewage sludge co-combustion ash: Leaching behavior analysis and cementitious property

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HIGHLIGHTS

- Co-combustion ash of rice husk and sewage sludge is used as cementitious materials.
- Co-combustion ash has excellent pozzolanic activity.
- Combining mechanical property, SEM and XRD to show the solidification mechanism.
- The transformation of heavy metal speciation to assess stabilization mechanism.

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ABSTRACT

The co-combustion of sewage sludge with rice husk is expected to become a trend because of its economic and environmental benefits. In this work, the ashes and its cementitious forms were investigated. The leachability characteristic of heavy metals and mechanical properties in cementitious forms was evaluated. The stabilization/solidification (S/S) mechanism of cementitious forms was also studied. Results showed that the leachability of heavy metals in co-combustion ashes decreased by an average of 30% after the hydration process. Non-crystal hydrates gradually formed and the compact structure hydrates became apparent in RSCA30 after 28 d (relative to SSMA30 and OPC1). The chemical speciation of heavy metals is transformed into immobilization state after hydration. In general, ashes from the co-combustion of rice husk and sewage sludge are beneficial to the development of cementitious materials.

1. Introduction

Biomass is an alternative to traditional fossil fuels, which are used as renewable energy sources in industrial scale [1]. Currently, direct combustion is the simplest and most common successful thermo-chemical process for converting biomass into energy. The average low heating value of rice husk is about 13–16 MJ/kg among all kinds of biomasses. Rice husks are typically used as bio-fuels for power plants [2]. Sewage sludges are generated from the wastewater treatment process. Hazardous components, such as organic and toxic inorganic substances, and pathogenic microorganisms, are found in sewage sludges [3]. These substances are enhanced in the sludge and transferred to the water and soil environments. In addition, the high quantity of stored sludge and the inaccurate measurement of sludge for resource utilization are the two main problems that affect the operation of waste water treatment facilities, landfills for sludge, and daily life significantly. Mono-combustion and co-combustion with other fuels, such as coal or biomass, can be used to treat of huge quantities of sludge by converting sludge into useful energy [4]. The combination of different fossil fuels, bio-fuels, and other flammable matters, such as sewage sludge or municipal solid waste that contains organic matters, can be well-combusted. Co-combustion is an efficient and direct method for reusing, reducing, and ensuring the safety of dealing sewage sludge. In addition, sludge can be used to supply the energy demand through co-combustion. The co-combustion of biomass and sewage sludge can decrease the emission of harmful components during the mono-combustion of sewage sludge into the air, water, and soil environments [5]. Sewage sludge cannot be burned easily and directly due to its high moisture and low volatile matter contents, which results in a relative lower heat

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value. Therefore, the co-combustion of biomass fuels with sludge can simplify the burning process [6].

The environmental impact caused by the thermal process of co-combustion of sewage sludge and other fuels should be investigated. Especially, the residues from co-combustion contains large number of heavy metal. In evaluating the environmental effect of such co-combustion residues or co-combustion ashes, the toxicity characteristic leaching procedure (TCLP) and the stabilization/solidification (S/S) technology [7] are the assessment and remediation methods used, respectively. Meanwhile, the leaching behavior of the leachable and toxic metals should be discussed to obtain valuable knowledge about the chemical speciation of leached metals, which can be analyzed by sequential extraction (SE) methods in co-combustion ashes and S/S forms. The characteristics of heavy metals, such as distribution, mobility, and bioavailability, are dependent on the total concentrations and the chemical forms that exist in solid phase [8]. The TCLP method issued by the US Environmental Protection Agency [9] was designed and developed to simulate the possible and relative worst case scenario for the TCLP. S/S technologies are widely applied for hazardous waste treatment. For example, aqueous waste, sludge, slag, and ash that contain toxic and hazardous metals and contaminated soils can be treated by S/S technologies before the final disposal process or reutilization. Many stabilized and solidified binders, such as Portland silicate cement, power plant fly ash, lime, slags from iron and the steelmaking process, asphalt or bitumen, and geopolymer, are used in the S/S treatment process of hazardous matters [10]. SE methods are widely utilized for investigating the fraction of chemical speciation and possible combinations of heavy metals and soil or sediment components [11]. The distribution, possible binding mechanisms, and leaching behavior of heavy metals can be evaluated by such a method [12]. Several experimental schemes have been provided for discontinuously or sequentially fractionating and classifying heavy metals based on the extractable components of different chemical reagents. Among these schemes, the SE procedure presented by Tessier et al. [13] was applied in previous studies.

Several studies have investigated the leaching characterization, S/S process, and metals speciation of ashes formed from the combustion of bio-fuels, such as coal, biomass, sludge, and municipal solid waste [14,15]. A few have focused on the ashes from biomass and sewage sludge co-combustion. Published works on the co-combustion of sewage sludge with rice husk are limited. Specifically, the interaction of co-combustion on leaching characterization and metals chemical speciation of rice husk and sewage sludge co-combustion ash are unknown. Co-combusted ashes should be investigated because the properties of ash materials from co-combustion cannot be determined from the known characteristics of ashes formed from each participant fuel [16]. Generally, the environment is potentially exposed to danger because of the hazardous elements contained in co-combustion ash residues [17]. In fact, several mineral nutrients of ashes may have a vitalizing effect on the recycling of ashes to agricultural or forest soils, while the other nutrients may affect the living environment by leaching or releasing toxic elements when used as construction and building materials [18]. Therefore, the experiment conclusion about the composition and influences of mixtures on the leaching characterization and chemical speciation of metals in ashes from co-combustion and cement-based S/S forms can provide ways to avoid the undesirable properties of co-combustion ashes during the utilization process of different fuel combinations [19].

The present work aims to investigate, collect, and process information about the leaching behavior and metals speciation of ashes from the co-combustion of rice husk and sewage sludge and then propose the potential resource utilization of ashes. To analyze the leaching behavior, chemical speciation, and binding mechanisms of heavy metals, SE tests based on the combined analytical results were performed, while the concentrations of leached heavy metals were evaluated by the TCLP test. Cements were partially replaced co-combusted ashes. They stabilized/solidified heavy metals and utilized the pozzolanic activity of ashes. The hydration mechanism and leaching behavior were also analyzed.

2. Materials and methods

2.1. Materials and ash samples preparation

In this study, rice husks were collected from a local rice mill. Sewage sludges were obtained from the Sha Lake wastewater treatment unit in Wuhan, China. The half-dried sludges were mixed with rice husks and stored in plastic bottles for 1 h at 20 °C with 75% relative humidity before the combustion treatment. To avoid sintering the ash at high temperature and burning it fully at low temperature, a muffle furnace installed with ventilation was used to co-combust the rice husk and sludge combinations at 750 ± 10 °C [20] for the preparation of co-combustion ash samples. The mixtures of rice husk/sludge materials were used in sludge percentages of 30 wt%. The ashes derived from co-combustion were defined as rice-husk sludge co-combustion ashes (RSCA). Sewage sludge mono-combustion ashes (SSMA) were produced at 600 ± 10 °C. After air drying, homogenization, and riffling, SSMA and RSCA samples were ground to a particle size of 80 μm for subsequent testing. The images of raw materials, SSMA, and RSCA are shown in Fig. 1.

2.2. Elemental analysis

A chemical analysis of the major elements in ashes (Table 1) was conducted using an X-ray fluorescence spectrometer. The leachates outside the detection range of trace elements concentration were tested using an inductive coupled plasma mass spectrometer. The major chemical compositions of ashes are listed in Table 1. The total trace heavy metal concentrations of SSMA and RSCA are listed in Table 3.

2.3. Leaching test procedure

Several leaching test methods have been used to evaluate the leachability of coal or biomass ashes. The TCLP-1311 standard method with a liquid-to-solid ratio of 20 and an 18-h agitation in sealed vessels has been widely used [21]. To study the leaching behavior further, two- and three-step continual TCLP tests were also used to analyze the leachability of the samples without and with S/S treatment, respectively. The test procedure followed the TCLP-1311 standard method [22].

2.4. Metals speciation analysis

The metals speciation analyzed using the SE scheme and the procedure proposed by Tessier et al. was used for the chemical speciation of metals [13]. Five fractions of metals speciation, including exchangeable (F1), bound to carbonates (F2), bound to iron and manganese oxides, reducible (F3), bound to organic and sulfide (F4), and residual (F5), were categorized according to the methods above. After each successive extraction, separation was completed and the supernatant was removed, filtered, and analyzed for the concentrations of selected heavy metals. The residue was washed, shook with 8 ml of de-ionized water for 30 min, and centrifuged for the next extraction step, and the washing specimen was mixed with the supernatant of each step [23]. To minimize experimental errors and control the reliability of every speciation procedure, the