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Activation of municipal solid waste incineration ashes for green concrete

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Abstract. Due to the variable characteristics of municipal solid waste incineration (MSWI) ashes and the lack of coherent standards and regulations, a majority of MSWI ashes is landfilled currently. It is an urgent issue that the significant amount of residue MSWI ashes need to be better handled and reused as a renewable source. MSWI ashes have great potential to be utilized as a cementitious replacement material in concrete mixing, which is beneficial for both promoting MSWI ash reuse and reducing cement consumption. However, there are major challenges associated with MSWI ash reuse, including the presence of lack of efficient approach to restore the reactivity of MSWI ashes as a binding agent, because such ashes are usually low in reactivity or even inert. This study aims to develop an effective and reliable activation method to enable the pozzolanic and hydraulic properties of MSWI ashes. A novel activation methodology by means of physiochemical treatments, including particle size reduction and high pH activator was proposed to increase the reactivity of such bottom ashes. A rapid test method, namely solution test, was developed to test the potential reactivity after the activation. Thermogravimetric analysis (TGA) and ion chromatography (IC) were employed to evaluate the degree of reactivity. The results showed that the physicochemical treatment can indeed increase the reactivity of MSWI ashes. Compared to the existing test protocols using normal activator the new solution test can more effectively examine the latent pozzolanic activities of MSWI ashes. The successful application of the proposed activation methodology together with the developed solution test could turn those “inert or low reactivity” to-be-landfilled ashes into an active binding agent as a cement replacement material, which would contribute greatly to recycle and reuse of waste materials and reduce CO₂ emission.

1. Introduction

This study echoes the UN SDG 9.4 by studying the potential of bottom ashes as a functional binding agent within the concrete production [1]. If such characteristics are demonstrated, landfilling and CO₂ emission can be reduced, and a greener concrete can be developed [2]. However, in Sweden, there are about 400 000 tonnes bottom ashes produced per year [3]. According to the data provided by Stena Recycling International AB and Renova AB, Swedish MSWI ashes contain significant amounts of chemically reactive compositions such as SiO₂ (30-40%), CaO (20-30%) and Al₂O₃ (10-15%), which are potentially hydraulic and can possibly be used in concrete as supplementary cementitious materials if properly activated under suitable alkaline conditions. However, due to the varying characteristics of the MSWI ashes and the lack of harmonized standards and regulations, at the present, a large portion of MSWI ashes is simply used as landfilling cover. In the viewpoint of sustainability, it is desired to find better applications of these MSWI ashes rather than simply landfilling. This paper presents a newly proposed activation methodology and a rapid test method, which could turn those “inert or low reactivity” to-be-landfilled ashes into an active binding agent as a cement replacement material. The applications of the proposed approach are aimed to be employed at Gothenburg in Sweden as a pilot



demonstration. With the successful results, this approach can be adopted nationally, coordinating local incineration plants as MSWI ash providers.

2. Methodology

The proposed activation methodology is a physiochemical treatment for the MSWI ashes, including particle size reduction and alkaline solution activation. The particle size reduction was achieved by mechanical grinding so that the reactivity of the ashes will be increased. To activate the pozzolanic reactions, a proper activator must be selected, depending on the chemical compositions of the ashes. To examine whether the pozzolanic reactions are activated, an assessment test should be carried out.

The rapid test method proposed in the study is called the “solution test”. The results were compared to a recent recommended method R^3 test. The solution test means to activate the bottom ashes with high alkaline solutions ($NaOH$ or KOH). The reactivity of bottom ashes after the activation can be characterized in terms of ion concentrations and chemically bound water, measured by ion chromatography (IC) and thermogravimetric analysis (TGA). In the R^3 test, the MSWI ashes were activated in a typical concrete pore solution environment, which has lower pH level than that of $NaOH$ or KOH solutions. The parameters measured in the R^3 test were the content of chemically bound water and the Portlandite consumption.

2.1. Raw materials

Two different kinds of bottom ashes were studied in this work, bottom ashes provided by Stena Metal (STENA BA) and bottom ashes provided by Research Institutes of Sweden (RISE BA). To study the reactivity of bottom ashes, a commercial slag (SLAG), Merit 5000 from Merox Sweden, was used here as a benchmark to a better interpretation of results, because slag is known for its high reactivity. The chemical compositions and average particle sizes of the slag and the two bottom ashes are shown in Table 1. Before the grinding, the average particle size of the two bottom ashes were around several mm.

Table 1. Chemical compositions and average particle size of the raw materials

| | SiO ₂ | Al ₂ O ₃ | Fe ₂ O ₃ | CaO | MgO | Na ₂ O | K ₂ O | Others | Particle size (μm) |
|----------|------------------|--------------------------------|--------------------------------|-----|-----|-------------------|------------------|--------|--------------------|
| SLAG | 34% | 13% | 0.4% | 31% | 17% | 0.9% | - | 4.75% | 4.8 – 6 |
| RISE BA | 36% | 8% | 3% | 32% | 5% | 2% | 5% | 10% | 58 |
| STENA BA | 40% | 11% | 12% | 20% | 3% | 4% | 1% | 10% | 172 |

2.2. Experiment procedures

The solution test was developed in this study, using 1 M $NaOH$ or KOH as activator. The mass ratio of solution to solid sample was fixed at 20:1. The dissolution rate of ashes was studied at five different testing durations: 6 hours, 1 day, 2 days, 4 days and 7 days. The experiment procedure is exemplified in Figure 1.

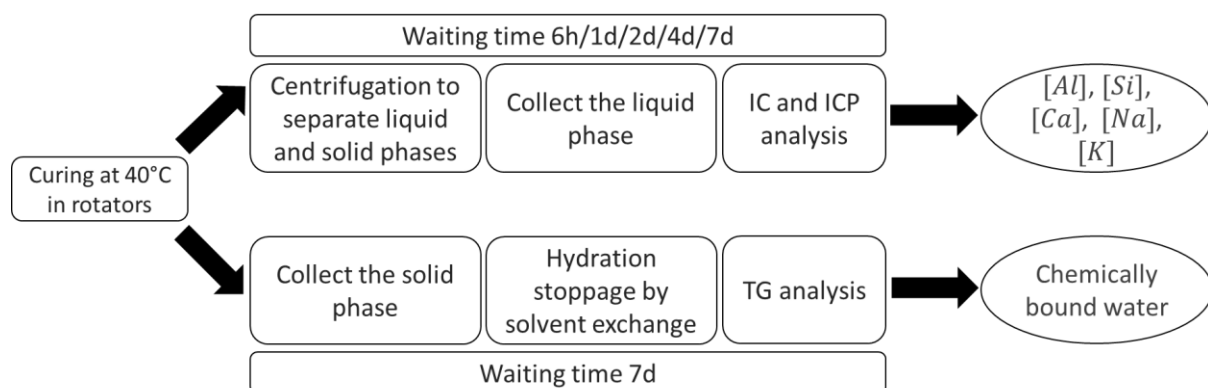


Figure 1. Experiment procedure for the solution test.

2.3. Experiment procedure of the R^3 test

The procedure recommended by RILEM TC 267-TRM [4] was followed in this study. Different cement paste environments can be reproduced in this test. An environment related to an LC³-50 cement paste mix design was the one selected for developing the R^3 test in this study. The experiment procedure is represented in Figure 2.

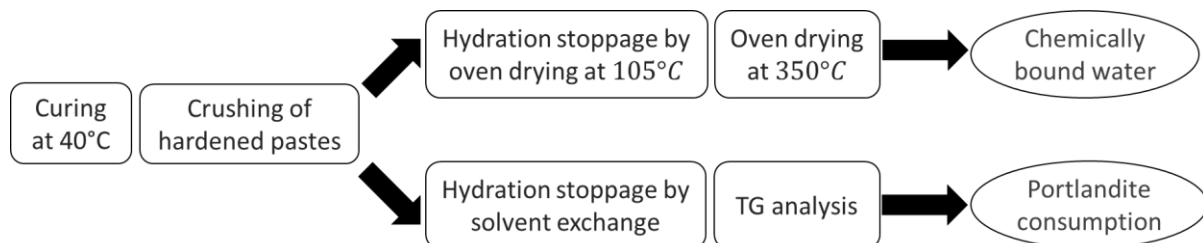


Figure 2. Experiment procedure for the R^3 test.

3. Results

3.1. Chemically bound water

The content of chemically bound water in the solution test and the R^3 test are shown in Figure 3 and Figure 4. Similar results were obtained from both testing methods, that is, SLAG showed the highest reactivity and followed by RISE BA, and STENA BA showed the lowest reactivity. Higher content of chemically bound water was gained when the ashes was activated by sodium hydroxide ($NaOH$), rather than potassium hydroxide (KOH), as demonstrated in Figure 3. There were three replicates samples tested in the R^3 test. In the 3rd series, a slightly higher temperature was applied for 10 minutes during drying process, compared to the first two series, due to technical issues. This could explain the lower values in the results of Series 3.

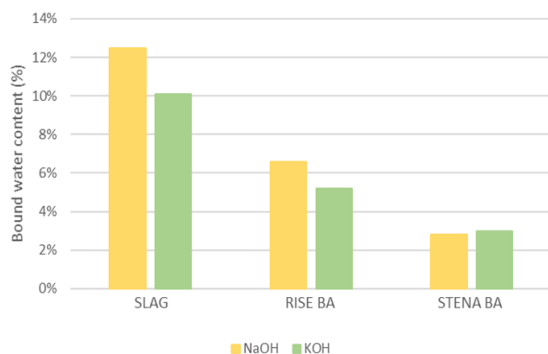


Figure 3 Chemically bound water in the solution test.

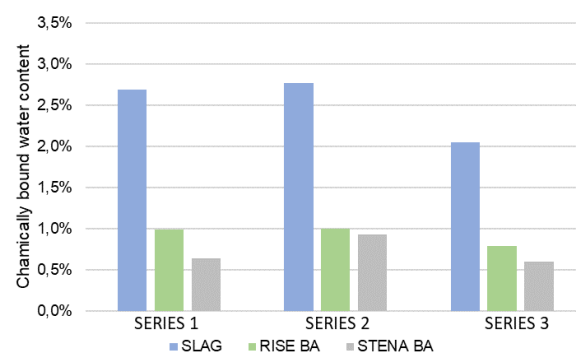


Figure 4 Chemically bound water in the R^3 test.

If we take the SLAG as reference sample, the ratio of chemically bound water in the target ash to that in the SLAG can be considered as an indicator of reactivity after activation. Table 2 lists the ratios of chemically bound water tested in this study. For RISE BA, the solution test showed a better activation than the R^3 test. While for STENA BA, the ratios were low in both tests, because STENA BA was still inert and has not been activated yet, greatly due to its coarser particles.

Table 2. Ratios of chemically bound water.

| Bound water | Solution test | | R^3 test |
|-----------------|---------------|------|------------|
| | NaOH | KOH | |
| RISE BA / SLAG | 0.53 | 0.52 | 0.37 |
| STENA BA / SLAG | 0.22 | 0.30 | 0.29 |

3.2. Ion concentrations

Figure 5 and Figure 6 illustrates the development of ion concentrations over time. In general, the trend was a decrease in the first day and then increase slightly after. However, there was no clear difference between SLAG and the two tested bottom ashes. Whether the changes of sodium and potassium ion concentrations can be an indicator for reactivity need to be further investigated.

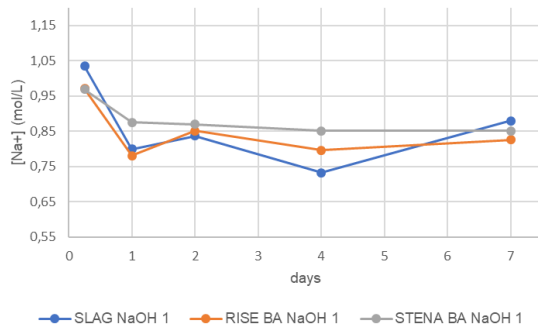


Figure 5 Concentration of sodium ions vs time

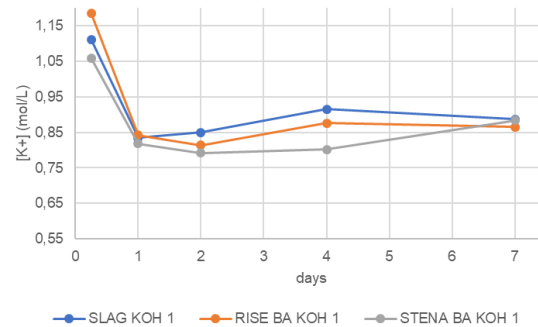


Figure 6 Concentration of potassium ions vs time

4. Concluding remarks

The following conclusions can be drawn from the study:

- Based on the experimental results, the reactivity of MSWI ashes are increased by reducing the particle size.
- The experiment results from the R^3 test revealed that a concrete pore solution environment is not able to activate RISE BA and STENA BA. Only SLAG, which is known to be highly reactive, was activated by $Ca(OH)_2$.
- $NaOH$ and KOH activators can activate RISE BA, while $Ca(OH)_2$ cannot. However, STENA BA were still inert. The reason could be due to its coarser particles.
- The proposed solution test provides a promising starting point for a new supplementary testing method for MSWI ashes and other potential cement replacement materials.

Moreover, it is worth to point out that the $Ca(OH)_2$ activator may not be environmentally friendly, because the production process involves burning of $CaCO_3$ and will increase CO_2 emission. Hence, it might be a hinder for large-scale applications. On the other hand, the $NaOH$ activator can be produced from sea water by electrochemical treatment. HCl as a by-product can also be used in other industrial purpose. Therefore, it will not add more CO_2 footprint.

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