Reuse Resource of Food Processing Sludge-Derived Fuel Incinerated Ash

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Abstract

The heat value of food processing sludge is similar to that of bituminous coal, thus is suitable as biofuel; however, the problem of incinerated ash disposal after combustion should be addressed. This study evaluated the applicability of food processing sludge-derived fuel incinerated ash (FA) to pozzolanic material and soil improvement, and proposed reuse strategies. When applied to pozzolanic material, the addition of FA reduced the hydration heat of fresh incinerated ash cement paste (FACP) significantly (85.96~91.23%), and prolonged the initial setting times (87.88~134.85%) and final setting times (87.88~134.85%) of FACP significantly. When the FA addition was 10% and 20% respectively, the pozzolanic strength activity index (SAI) was greater than 75% until the hardened FACP was cured for 28 days and 90 days respectively. When applied in soil improvement, the final seed germination of Chinese cabbage and water spinach in the original soil (ash content 0%) and improved soil (ash content 20%) was 98% and 90% respectively. There was no significant effect on the growth rate of Chinese cabbage and water spinach.

Keywords: Food processing sludge-derived fuel incinerated ash (FA); Pozzolanic material; Soil improvement; Germination

Introduction

According to the statistics of Industrial Development Bureau of ROC, about 12 million MT industrial waste could be reused directly in 2012, about 88% was used in construction engineering. The fresh concrete uses pozzolanic materials of fly ash, furnace slag and silica fume. The cement content can be reduced, and the durability and working performance can be improved. The pozzolanic material has become an important material for enhancing the concrete performance and quality. In addition, about 90,000 MT industrial waste was reused for soil improvement in 2012, meaning the industrial waste can be applied to soil improvement. According to Taiwan Ready-Mixed Concrete Industry Association, the consumption of ready-mixed concrete has been stable in Taiwan in recent years, namely 40 million m³/year in 2012. If each cubic meter concrete is mixed with 10% mineral admixtures (e.g. coal ash and slag), the concrete industry has a large demand for mineral admixtures.

The concrete can use pozzolanic material to partially replace cement or aggregate, not only to improve the concrete performance, but also to reuse the waste. A great variety of pozzolanic materials is used extensively, such as blast furnace slag [1], silicomanganese slag [2], pulp sludge incinerated ash [3], sugarcane incinerated ash [4], palm oil fuel incinerated ash, rice husk ash [5,6], waste glass, ceramics, metakaolin, swelling clay [7-9], cattle manure incinerated ash, coal ash [10], semiconductor industry sludge [11], and TFT-LCD waste glass [12]. Some studies have used industrial wastes, such as soda-lime glass [13], industrial sludge, ocean sludge, fly ash [14-16], waste glass, recycled concrete aggregate and slag, to make artificial aggregate and lightweight aggregate [17,18]. The incinerated ash of the derived fuel made from the mixture of pulp sludge and textile sludge is suitable as the filler of controlled low-strength materials (CLSM) [19]. To sum up, the incinerated ash of different industries mostly has pozzolanic effect, applicable to cement, aggregate and concrete materials.

As the heat value of food processing sludge is similar to that of bituminous coal, it is suitable as biofuel. After the food processing sludge-derived fuel with high heat value is combusted, there is problem of FA disposal. Therefore, this study uses the properties of FA, rheological properties and mechanical properties of FACP and the seed germination to evaluate the feasibility of FA to pozzolanic material and soil improvement, and proposes reuse strategies. The purpose to handle the disposal of FA and achieve “zero waste”.

Methodology

Experimental materials

This study used the dewatered sludge from a food processing plant that produces dairy products and beverage in Taoyuan City. The food processing sludge-derived fuel was produced by preprocessing and extrusion at normal temperature. The mixture of derived fuel was mixed with 10% lime (Ca(OH)2) in the extrusion process, so as to reduce the emission of contaminants (e.g. SOx, NOx). As the sludge-derived fuel was used for boilers, where the flame temperature can reach over 900°C [20], the combustion was maintained at this temperature for 2 h. When the FA was cooled, crushed and sieved (<100 sieve), the fineness was 250 m2/kg (Blaine) (Table 1). The cement met the specification of CNS 61 "Portland cement" with a fineness of 300 m2/kg (Blaine) (Table 1).

The soil samples were collected from a farmland in Taoyuan City without heavy metal pollution. The soil was crushed and sieved to prepare the original soil. The fineness modulus of the sieved original soil was 3.0. The original soil was mixed with 20% incinerated ash thoroughly to prepare the improved soil.

Methods

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There were four weight ratios of cement (PC) in this study, 100%, 90%, 80% and 70%. The weight ratio of FA addition was 0%, 10%, 20% and 30% respectively. They were mixed to make FACP (FACP numbers are PC100FA0, PC90FA10, PC80FA20 and PC70FA30). The water to cement ratio was determined at standard flow (i.e. 110 ± 5%) to make 1 cubic inch FACP. The specimen was cured in 25°C saturated limewater for 3 to 120 days. The impact of FA addition level on the pozzolanic effect of FACP was discussed.

This study used original soil (with 0% FA) and improved soil (with 20% FA), as well as Chinese cabbage and water spinach seeds. The soil was placed in well drained plastic containers (60 cm x 20 cm), tested according to the standard germination rate specified by International Seed Testing Association (ISTA). Experiments were conducted in replicates. Each plastic container was divided into 5 blocks, and each block was planted with 20 seeds, meaning each container was planted with 100 seeds (Figure 1). The data were recorded on a daily basis for 30 days to observe the seed germination and growth rate of Chinese cabbage and water spinach.

The chemical composition of FA (Table 1) was mainly Fe₂O₃, CaO and P₂O₅, accounting for 27.35%, 22.70% and 18.63% respectively, and then SiO₂, Al₂O₃, SO₃, K₂O, MgO and Na₂O, accounting for 11.07%, 9.03%, 6.91%, 1.77%, 1.73% and 0.82% respectively. The CaO content in FA was 22.7%, resulted from the addition of 10% lime (Ca(OH)₂) to the food processing sludge-derived fuel. The CaO in FA was much lower than Portland cement, meaning the activity of FA was lower than cement. According to the SEM image, the FA was irregular particles (Figure 2). The water soluble chloride ion (Cl⁻) content in FA was 0.071%, resulted from the addition of 10% incinerated ash, as well as Chinese cabbage and water spinach seeds.

Properties of hardened cement pastes: The rheological properties of fresh FACP were evaluated by hydration heat, setting time and consistency. The flow value of fresh FACP was controlled within the standard flow range (100-115%), so as to obtain the optimal mixing water consumption. At the standard flow (103–104%), the water-cement ratio corresponding to mix proportions PC100FA0, PC90FA10, PC80FA20 and PC70FA30 was 0.36, 0.38, 0.40 and 0.44 respectively (Table 2). In other words, for each addition of 10% FA, the mixing water for fresh FACP was increased by 6.5%, meaning the FA has high water absorption.

According to the SEM image of hardened cement paste, at the curing age of 7 days, the hydration product of mix proportion PC100FA0 increased gradually, in plate-like structure. The mix proportions PC90FA10, PC80FA20 and PC70FA30 had more particles and pores, especially the mix proportion PC70FA30. At the curing age of 60 days, the mix proportion PC100FA0 had obvious hydration product. The hydration products of mix proportions PC100FA0, PC90FA10 and PC80FA20 increased gradually. The mix proportion PC70FA30 had a little hydration product, mostly particles and pores. At the curing age of 120 days, the mix proportions PC100FA0, PC90FA10, PC80FA20 and PC70FA30 had apparent hydration products (Figure 6).

Results and Discussion

Application on cement materials

Rheological properties of fresh cement pastes: The rheological properties of fresh FACP were evaluated by hydration heat, setting time and consistency. The flow value of fresh FACP was controlled within
### Table 1: Composition of raw materials.

<table>
<thead>
<tr>
<th>Oxides (wt.%)</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>Fe₂O₃</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>SO₃</th>
<th>P₂O₅</th>
<th>Fineness (m²/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>20.5</td>
<td>6.50</td>
<td>62.5</td>
<td>1.90</td>
<td>3.20</td>
<td>-</td>
<td>-</td>
<td>2.20</td>
<td>-</td>
<td>300</td>
</tr>
<tr>
<td>FA</td>
<td>11.07</td>
<td>9.03</td>
<td>22.7</td>
<td>1.73</td>
<td>27.4</td>
<td>0.82</td>
<td>1.77</td>
<td>6.91</td>
<td>18.63</td>
<td></td>
</tr>
</tbody>
</table>

PC: Portland cement; FA: Food processing sludge-derived fuel incinerated ash

### Table 2: Properties of fresh cement paste.

<table>
<thead>
<tr>
<th>Properties</th>
<th>PC100FA0</th>
<th>PC90FA10</th>
<th>PC80FA20</th>
<th>PC70FA30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flowability (%)</td>
<td>103</td>
<td>104</td>
<td>104</td>
<td>104</td>
</tr>
<tr>
<td>Water to cement ratio</td>
<td>0.36</td>
<td>0.38</td>
<td>0.40</td>
<td>0.44</td>
</tr>
<tr>
<td>Initial setting (min)</td>
<td>293</td>
<td>471</td>
<td>580</td>
<td>705</td>
</tr>
<tr>
<td>Final setting (min)</td>
<td>330</td>
<td>620</td>
<td>661</td>
<td>775</td>
</tr>
</tbody>
</table>

PC: Portland cement; FA: Food processing sludge-derived fuel incinerated ash

### Application on soil improvement

**Seed germination:** According to the standard germination test specified by ISTA, the Chinese cabbage and water spinach were planted in the original soil and improved soil respectively, observed on a daily basis for 30 days. The seed germination of Chinese cabbage in the original soil on Day 1, Day 3, Day 5, Day 10 and Day 15 was 0%, 47%, 75%, 92% and 98% respectively, and that in the improved soil was 0%, 81%, 93%, 98% and 98% respectively. This suggested that the seed germination of Chinese cabbage planted in the original soil and improved soil reached its maximum on Day 14 and Day 7 respectively (98%) (Figures 7 and 8).

In terms of water spinach, the seed germination in the original soil on Day 1, Day 3, Day 5, Day 10 and Day 15 was 0%, 47%, 75%, 82% and 98% respectively, and that in the improved soil was 0%, 81%, 93%, 98% and 98% respectively. This suggested that the seed germination of water spinach planted in the original soil and improved soil reached its maximum on Day 14 and Day 7 respectively (98%) (Figures 7 and 8).
Day 1, Day 3, Day 5, Day 10 and Day 15 was 0%, 6%, 32%, 83% and 90% respectively, and that in the improved soil was 0%, 5%, 35%, 75% and 90% respectively, suggesting that the seed germination of water spinach planted in the original soil and improved soil reached its maximum on Day 13 (90%) (Figures 7 and 9). The addition of FA could increase the seed germination of Chinese cabbage in the early stage (3–5 days), but it had no significant effect on water spinach.

**Growth rate of vegetables**

The growth rate of the Chinese cabbage planted in the original soil and improved soil increased gradually on Day 2, and reached its maximum on Day 5. It then decreased gradually, and later increased slightly after 15 days (Figure 10a). The water spinach planted in the original soil and improved soil grew significantly on Day 3. The maximum growth rate was reached in the original soil on Day 4, then decreased gradually, and increased slightly on Day 20 (Figure 10b). The growth rate reached its maximum in the improved soil on Day 7, then decreased gradually, and increased slightly on Day 20. Overall, the addition of FA had no significant effect on the growth rate of Chinese cabbage and water spinach.

**Conclusions**

(1) The FA is in irregular particle shape, so it has high water absorption and low activity. Its water soluble chloride ion content is as high as 0.071%, so it is inapplicable to reinforced concrete.

(2) The addition of FA reduced the hydration heat of fresh FACP greatly by 85.96–91.23%. Each addition of 10% FA prolonged the initial setting time and final setting time of fresh FACP by about 49.89% and 53.84% respectively.

(3) When the addition level of FA was 10% and 20% respectively, the hardened FACP should be cured for 28 days and 90 days respectively, so that the SAI could be greater than 75%. Therefore, the addition level of FA was recommended as 10%.

(4) The final seed germination of Chinese cabbage and water spinach in the original soil and improved soil was 98% and 90% respectively. The addition of FA could increase the seed germination of Chinese cabbage in the early stage (3–5 days), but it had no significant effect on water spinach. The original soil and improved soil had no significant effect on the growth rate of Chinese cabbage and water spinach.

**Acknowledgment**

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