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Characterising long-term wet-stored fly ash following carbon and particle size separation

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HIGHLIGHTS

- Recovery of coal-derived fly ash from ponds and stockpiles.
- Low-cost wet-processing technology used to homogenize the materials.
- Microstructural, physical nature and chemistry of particle groups investigated.
- Heterogeneity reduction giving particle groups for various construction applications.
- Potential for yield optimisation for holistic use of fly ash.

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ABSTRACT

The paper describes a study carried out to characterise fly ash produced from hard-coal, following recovery from long-term pond and stockpile storage, and wet process separation. Three power station sites, representative of those in the United Kingdom, were considered and initial work examined the characteristics of recovered material from both types of storage area. Most of this had high loss-on-ignition (LOI) and was relatively coarse, with that in ponds generally having greater variability. Fly ash particles had reaction products on their surfaces and the presence of agglomerates was also noted. Methods including, pre-screening, column (hydraulic) separation, froth flotation and lamella hydraulic classifier were considered for processing. Three trials were carried out using various combinations, and it was possible to separate carbon and fly ash to give material groups ranging from carbon-rich to low LOI/high fineness, although fine fly ash particles (<5 μm) were distributed throughout these. Relatively minor changes in chemical composition and mineralogy of the separated materials were noted, except for particle groups with high LOI (reflecting fly ash dilution). Similar effects were generally obtained with both pond and stockpile storage. Mass balance calculations were made to quantify material distributions for the three processing trials carried out. Examples are given of yields achieved for potential end-uses from these, which indicate that optimisation to target particular fly ash properties should be possible.

1. Introduction

It is estimated that 100 Mt of coal-combustion residues, including fly ash, were produced from electricity generation in the European Union in 2009 [1]. However, in many markets, supply of fly ash exceeds demand and as a result much of that remaining unused is placed into storage [2]. This is normally by mixing with water and transporting to designated ponds (slurried with a solids/water ratio of up to 20%) or stockpiles (moistened up to about 15–20% by mass of solids) within or adjacent to power plants.

Storage periods can range from months to a decade or longer, depending on demand. As a result, it is estimated that more than 100 Mt of accessible fly ash of this type are available in the United Kingdom (UK) alone [3]. There is often significant heterogeneity in this material, reflecting changes at the power plant with time (e.g. coal type and/or burning conditions), as well as natural separation occurring during storage. This can be further affected by the presence of various forms of char from incomplete combustion and pyrite from coal pulverizer rejects [4].

Research examining the effects of short-term storage under moist or saturated conditions on low-lime fly ash in UK ponds and stockpiles suggests that while physical and chemical changes occur, the material can still be used as a cement component in concrete [5,6]. Homogenization of fly ash to meet various property

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Table 1
Characteristics of recovered fly ashes from UK pond and stockpile sites.

Fly ash characteristics[a]		Power plant site				
		1		2	3	
Storage type (no. of samples)		Pond (34)	Processing[b]	Stockpile/processing[b]	Stockpile (45)	Processing[b]
LOI, %		3.8–20.2 (8.2)	14.7	10.0	11.2–25.4 (15.3)	14.4
Particle size distribution, μm	D_{10}	3.2–14.3 (6.2)	7.3	12.1	3.7–7.1 (4.9)	4.5
	D_{50}	13.4–100.5 (43.7)	42.9	55.3	27.4–43.6 (34.8)	31.2
	D_{90}	54.1–521.5 (153.0)	186.6	164.7	96.5–208.5 (127.5)	113.6
45 μm ret, %		12.0–61.9 (39.8)	58.6	53.4	31.1–42.3 (36.7)	39.2
Chemical composition, % by mass						
CaO		2.0–4.3 (2.7)	4.3	4.6	1.2–3.5 (2.2)	2.7
SiO_2		40.0–52.5 (47.4)	45.7	41.7	35.8–45.8 (40.4)	40.5
Al_2O_3		24.3–31.4 (28.5)	26.1	25.9	19.5–23.6 (21.5)	21.8
Fe_2O_3		3.3–6.8 (4.9)	5.8	9.0	5.3–8.5 (6.7)	7.5
MgO		1.1–2.8 (1.6)	2.8	1.6	0.7–1.5 (1.2)	1.2
TiO_2		1.2–1.6 (1.4)	1.5	1.2	1.0–1.7 (1.1)	1.1
K_2O		0.7–1.6 (1.1)	1.4	2.1	1.7–3.1 (2.6)	2.8
Na_2O		0.3–3.8 (1.1)	0.5	0.9	0.3–2.0 (0.6)	0.5
P_2O_5		0.5–1.5 (0.9)	1.5	0.6	0.5–0.8 (0.6)	0.6
Cl^-		0.4–6.4 (1.8)	1.0	0.0	0.0–3.0 (0.3)	0.0
SO_3		0.2–1.2 (0.6)	0.3	2.0	0.2–1.8 (0.7)	0.7
Main mineral composition[c]*, % by mass*						
Quartz		3.0–13.9 (8.3)	6.3	5.3	2.4–4.7 (3.2)	2.6
Mullite		13.9–32.3 (22.3)	17.3	12.9	5.0–7.9 (6.5)	6.2
Non-crystalline content[d]		47.3–72.3 (59.1)	60.7	68.9	60.7–72.6 (67.2)	71.4

[a] Where multiple samples were taken, results are given as ranges (means).
[b] Typical properties of samples used during processing trials.
[c] For power plant site 3 stockpile, results are from 9 measurements.
[d] By difference. *Note*: this does not necessarily equal the pozzolanically reactive 'glass' content.

requirements, [e.g. 7–9], may then enable adoption in a range of applications, beyond bulk filler, whilst also reducing pressure on storage sites. Furthermore, this approach can contribute to the increasing requirements for sustainable materials in twenty-first century design and construction [10].

Several systems have been developed recently towards enabling fly ash separation and their potential is becoming recognised [11]. The research described was, therefore, concerned with investigating the characteristics of long-term stored, low-lime fly ash following recovery and processing, with a view to identifying suitability for various end-uses.

2. Sourcing of test materials

In order to examine different power plant storage conditions, fly ash from both ponds and stockpiles was considered. A survey of storage areas at UK power plants [3], enabled three representative sites for material recovery to be identified.

At Power Plant 1, material (Fly Ash 1) was stored in a 0.4 Mt pond and ranged in age up to 30 years. At the time of testing, the pond had been drained of water and some fly ash excavated, enabling access for sampling in exposed vertical faces. A total of 33 kg samples were taken at horizontal distances of approximately 75 m and depths of 1–2, 2–3 and 3–4 m, by hand auger. In addition, a 2 tonne bulk sample was obtained at a later stage for use during the processing work.

At Power Plant 2, there was a 1 Mt stockpile, where material (Fly Ash 2) had been produced in the previous few years prior to recovery. A bulk sample of approximately 3.5 tonnes was taken from this site for processing.

At Power Plant 3, the material (Fly Ash 3) was in a 16 Mt stockpile, covering about 50 hectares and of height around 50 m. This was divided into three areas according to when fly ash had been placed there, i.e. (i) recently produced material and that stored for (ii) 5–10, and (iii) 15–20 years. Samples were taken at 5 positions in these areas, with horizontal distances of about 75 m and depths of 1–2, 4–5 and 9–10 m, giving a total of 45. Two large samples of about 1 tonne were obtained from (iii) above and combined for processing.

3. Test procedures

The loss-on-ignition (LOI) of recovered and separated materials was determined to BS EN 450-1 [7]. The fineness of the fly ashes was measured in terms of (i) the quantity of sample retained on a 45 μm sieve (following wet sieving; 45 μm ret) as described in BS EN 451-2 [12] and (ii) particle size distribution (PSD) by LASER diffraction.

Pressed powder pellets of milled fly ash were analysed for oxide composition using a sequential X-ray fluorescence spectrometer with Rh Kα source. The mineralogy was examined on powder samples by X-ray diffractometer with Cu Kα source. An internal standard was used (5.0% corundum) to enable estimation of the crystalline/non-crystalline (by difference) constituents.

4. Characteristics of recovered material

The results from the tests on recovered fly ash samples are summarised in Table 1. The LOI data highlight the variability of the materials, as mentioned above, in the storage areas, which for the test sources was slightly greater in the pond than stockpile. The results indicate that the fineness (45 μm ret) and range of particle sizes were also wider in the former. In addition, the values for many of the samples were greater than the limits set for the material's use as a cement component in concrete [7].

As expected for bituminous coal sources, all fly ashes had low lime contents, with the maximum level 4.6%. The chemical composition generally corresponded to the typical ranges for UK fly ashes [13]. Differences to these, found in some cases, e.g. Fe_2O_3, alkalis and sulfate, may relate to the wet storage conditions [5]. It was also noted that some samples contained relatively high levels of chloride, which would be an issue for their application in reinforced concrete [14]. This reflects either the use of salt water to moisten/slurry fly ash, or proximity of the storage areas to coastal/estu-