Physical-chemical upgrading and use of bio-energy fly ashes as building material

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Introduction

Coal-combustion fly ash (CCFA) from the incineration of coal in power plants has been already used for decades as a filler in concrete mixtures. Owing to its pozzolanic activity, CCFA can be used as a binder, e.g. to partly replace cement. The increasing worldwide concern of the CO_2 emissions and dependency on fossil fuels advances the complete replacement of coal in power plants by biomass. However, the use of biomass leads to the production of bio-energy fly ashes (BFA) with different properties, compared to that of CCFA and require certain treatment in order to be applied in concrete mixtures.

The aim of this research is to classify the physical and chemical properties of the BFA and formulate requirements to produce a material that can be used as cement or CCFA replacement. Furthermore, treatments are performed, validated (to meet the stated requirements) and finally mortars are made for testing the mechanical performance.

Methods

The samples of BFA used in this study are collected from a bio-energy power plant (The Netherlands). The following types of BFA (Twence-Hengelo) are examined: boiler fly ash (TB) and cyclone fly ash (TC).

Table 1: Requirements of EN-450 concerning coal-combustion fly ash. Values in bold do not fulfil the stated requirements

	EN-450 (m/m)	TB (m/m)	TC (m/m)
Loss on ignition (LOI)	≤ 5%	**18.7%**	1.2%
Chloride content	≤ 0.10%	**0.52%**	**0.43%**
Sulfate content	≤ 3%	2.5%	1.6%
Free calcium oxide	≤ 1.0%	**4.0%**	**6.7%**
Residue on 45 µm sieve	≤ 40%	**83%**	**75%**

Although there is no regulation describing the use of BFA, EN-450 for CCFA states fly ash properties that need to be fulfilled for a binder or a filler, such as the chemical composition and particle size distribution (Table 1).

From the chemical analysis, BFA is found to contain high amounts of chlorides. Furthermore, due to an insufficient burning process, the particle size is too coarse and the loss on ignition (LOI) is too high. In order to fulfil the requirements stated in Table 1, certain treatments are required. First, XRD analyses are performed to determine the type of chlorides (calcium chloride, sodium chloride) and define its solubility in water. Second, a washing treatment is performed to remove the chlorides from the solid. It is found that the chloride amount is reduced not as sufficiently as expected because large amounts of chlorides are trapped into the coal particles. It seems that the soluble chlorides are bound to the surface of the carbon particles preventing them from dissolving into water. Hence, the carbon content is the reason for the high loss on ignition content and needs to be reduced. Therefore, the treatment process illustrated in Figure 1 is proposed.

In order to remove the large carbon particles from the bio-energy fly ashes, a 500 μm sieve is used. Subsequently, two possible treatments are performed for the size fraction below 500 μm: 1) electrostatic filtration, 2) thermal treatment at 750 °C. One of the two methods is chosen depending on the possibility of the occurrence of a phase change during the thermal treatment. This should be avoided due to its negative effect on the pozzolanic reactivity of the fly ashes. Nevertheless, the electrostatic filter has the negative influence of removing light particles consisting not of coal only.

The washing treatment is performed at room temperature, in a 1-liter bottle with an L/S ratio of 2 using demineralised water. The bottle is placed in a horizontal direction on a shaking table for 60 min with a shaking speed of 240 rpm. After the treatment, the water is separated from the fly ash using a filter paper (8-12 μm) and flushed with demineralised water. Finally, the material is dried in an oven and, afterwards, ground with a ball mill to reduce the particle size.

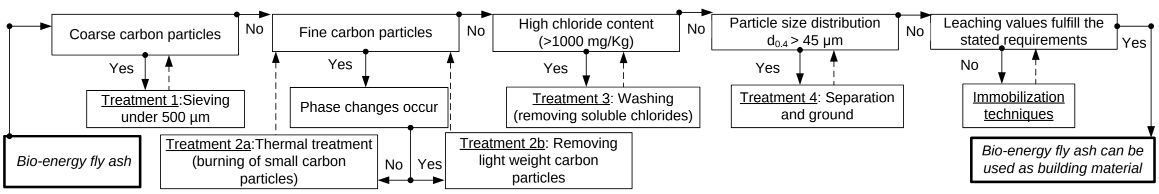

Figure 1: Treatment methodology

The chloride content in water is measured using a Metrohm 785 DMP Titrino with a 0.01M solution of silver nitrate. To determine the mechanical properties, standard mortar mixtures are produced according to EN-196 and cured under water for 28 and 90 days.
The particle size distribution of the bio-energy fly ashes is measured using a Mastersizer 2000 Ver. 5.60 with the laser diffraction method.

As this study addresses the suitability of BFA as cement or CCFA replacement, the water demand is kept the same. However, this is less favourable in case of replacing CCFA. It is known that while using CCFA, the water demand can be reduced because of the spherical particles that improve the workability. Hence, this could lead to higher mechanical strength properties due to lower amount of capillary pores.

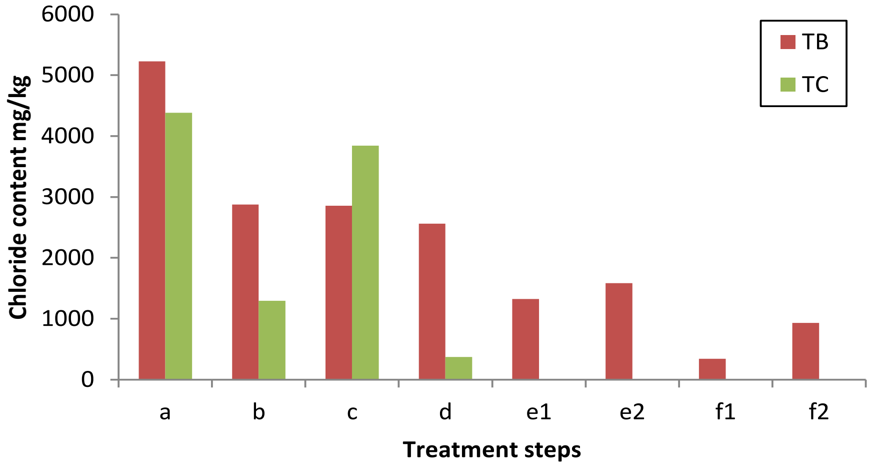

Figure 2: Effect of treatment steps on the chloride concentration of the samples, (results of step e1 and further are only addressed to TB). a) original BFA without treatments, b) water treated BFA, c) sieved BFA < 500 µm, d) step c and afterwards water treated BFA, e1) step c and afterwards small carbon particles are removed by means of electrostatic filter, e2) step c and afterwards small carbon particles are removed by means of thermal treatment, f1) step e1 and afterwards washing treatment, f2) step e2 and afterwards washing treatment.

Results

Chloride content

The influence of different treatments on the chloride content is illustrated in Figure 2. Because of the high carbon content in TB, large carbon particles and extra treatments (e1 or e2) to remove the small carbon particles is necessary before the fly ash could be successfully washed. TC could be successfully washed only after removing the large carbon particles. After removal of carbon particles, washing treatment and grinding the material in a ball mill for 30 minutes, BFA fulfils the minimum requirements of EN-450.

Mechanical properties

The strength is tested for original (O), carbon removal plus water treatment (CR-WT) and finally grinding (CR-WT-G) of the material at the replacement levels of 5%, 10% and 20% by mass of CEM I 42.5N. Results show that up to 10% of BFA as cement replacement can be used providing sufficient mechanical strength. Table 2, presents the replacement level of 20% and shows that that the mechanical strength is lower but still close to that of the reference cement (compressive strength of > 42.5 MPa) and CCFA replacement (compressive strength of 41 MPa) after all treatments. Therefore BFA can in final form be used as CCFA or CEM I 42.5N replacement. Finally, owing to the pozzolanic activity, the strength in all of mortar spies is increased during time. For TC and TBe replacement, after complete treatment the 90 days strength is increased with 8-10 MPa compared to their 28-day strength.

Table 2: Mechanical strength properties of 20% replacement by mass of cement for original bio-energy fly ashes without treatment (O), after carbon removal and water treatment (CR-WT) and after treatments and grinding (CR-WT-G). Due to different treatments tested for TB, TBt refers to thermal treatment and TBe refers to electrostatic treatment.

Strength		**28 days Flexural**			**28 days Compressive**			
Fly ash type	CCFA	TC	TBt	TBe	CCFA	TC	TBt	TBe
O	7.2	5.6	5.4	5.4	41	26	24	24.4
CR-WT		6	5.7	6		36	31	30.6
CR-WT-G		6.6	6.7	6.9		41	40	39.5
Strength		**90 days Flexural**			**90 days Compressive**			
CR-WT		6.4	6.6	6.3		40	39	36.2
CR-WT-G		7.6	7.2	7.6		49	41	49.6

Discussion and conclusion

After treatments, BFA fulfils the EN-450 regulation, and can be considered as a potential replacement of both CEMI 42.5N and CCFA up to 20%. Furthermore, it is believed that the water demand can be reduced, still maintaining a proper workability with the benefit of reducing the capillary pores. However, due to the coarser particle size, the water demand cannot be reduced as significantly as with CCFA.