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Contaminated biomass fly ashes – Characterization and treatment optimization for reuse as building materials

G.C.H. Doudart de la Grée [a,*,1], M.V.A. Florea [a,*,1], A. Keulen [a,b], H.J.H. Brouwers [a]

[a] Department of the Built Environment, Unit Building Physics and Services, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands
[b] Van Gansewinkel Minerals, Flight Forum 240, Eindhoven, The Netherlands

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ABSTRACT

The incineration of treated waste wood generates more contaminated fly ashes than when forestry or agricultural waste is used as fuel. The characteristics of these biomass fly ashes depend on the type of waste wood and incineration process parameters, and their reuse is restricted by their physical, chemical and environmental properties. In this study, four different fly ash types produced by two different incineration plants were analysed and compared to Dutch and European standards on building materials. A combined treatment was designed for lowering the leaching of contaminants and the effect of each treatment step was quantified. A pilot test was performed in order to scale up the treatment. It was found that chlorides (which are the main contaminant in all studied cases) are partly related to the amount of unburnt carbon and can be successfully removed. Other contaminants (such as sulphates and chromium) could be lowered to non-hazardous levels. Other properties (such as particle size, LOI, oxide and mineralogical compositions) are also quantified before and after treatment.

1. Introduction

Worldwide increased concern of the CO_2 emissions and dependency on fossil fuels leads to an increasing use of renewable energy sources in order to decrease the greenhouse emissions. One of the possible renewable energy sources is 100% biomass that can be used as a replacement of coal in power plants. These bio-power plants use mainly 'waste' or residue wood streams as fuel to produce heat, which is then consumed in steam turbines to generate electricity to be supplied to the electricity grid. The generated combustion fly ashes are collected and mainly disposed of at landfill sites. However, those responsible for the disposal of fly ash are regularly seeking potential ash utilization options because of high landfilling costs and the increasing banning of these on landfill sites. Nowadays, pulverised coal fly ash is mainly applied in cement- and asphalt-based concrete mixtures due to its physical and chemical properties. Fly ash is a fine material that can be used as filler in concrete mixtures. Also, due to its pozzolanic activity, it can be used as a binder to partly replace cement and therefore reduce the use of natural resources. In the Netherlands the majority of coal combustion fly ash is applied (Vliegasunie, 2008).

The use of biomass as fuel in power plants leads to the production of fly ashes which are different from the 'conventional' coal combustion fly ash. These ashes created from burning biomass have different characteristics and properties in comparison to coal combustion fly ash. It has become important to find new ways for the reuse of biomass fly ashes, e.g. in concrete mixtures. The fly ash obtained from the incineration of waste forest wood, agricultural waste and co-firing of biomass and other fuels has been investigated previously (Berra et al., 2015; Cheah and Ramli, 2011; Jaworek et al., 2013; Li et al., 2012; Lima et al., 2008; Pöykiö et al., 2009; Rajamma et al., 2015, 2009). However, the fly ash generated from the burning of contaminated wood has been studied less (Berra et al., 2015) and its reuse has not started because of the following reasons:

1. biomass fly ash is a chemically and physically variable product, which makes its combination with cement more challenging. Its particle size distribution, loss on ignition, density, specific surface area, leaching, as well as pozzolanic/cementitious properties need to be tested to confirm its suitability;
2. biomass fly ash contains contaminants like lead, zinc and chromium and large amounts of chlorides that may have negative influences on the hydration of cement;

* Corresponding authors.
E-mail addresses: G.C.H.Doudart.de.la.Gree@tue.nl (G.C.H. Doudart de la Grée), m.v.a.florea@tue.nl (M.V.A. Florea).

[1] Equal contributors.

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3. as replacement of cement, its slow pozzolanic activity influences the hydration process, consequently lowering the properties of concrete at early ages;
4. so far there is no certified treatment method to sufficiently remove the contaminants and increase the reactivity of contaminated fly ash, which could make its utilization more cost-efficient and sustainable.

The biomass fly ash created from burning biomass has different characteristics and properties in comparison to coal combustion fly ashes because of the different combustion input and therefore, additional research is needed to establish its applicability as building material.

The first concern of such by-products is their environmental impact, and how it is evaluated based on the legislation (Landfill Ban Decree, 2012). In the case in which the fly ashes are considered hazardous or unfit for landfilling, a treatment must be envisaged before their disposal can take place. Furthermore, in order not to just lessen their environmental impact, but also to render such secondary materials useful, a number of other factors need to be taken into consideration. A number of utilization routes can be envisaged for these fly ashes, by comparison with the uses of coal combustion fly ash and other secondary building materials in concrete mixes. A first of these routes is application in concrete mixes as inert filler. A second application route is as secondary binder, in which case the chemical interactions between the bio energy fly ashes and water and/or cement becomes of interest. In this case, the bio energy fly ashes must comply with the environmental laws (Soil Quality Regulation, 2013) which define a building material (see Section 3), but a pozzolanic or hydraulic activity is not needed on its part.

In this research different types of fly ashes from two power plants are investigated. Each power plant has its own technology of biomass fly ash generation, which is known to be a factor influencing the quality of the obtained fly ashes (Lima et al., 2008; Rajamma et al., 2009). However, one thing they have in common is that the generated biomass fly ashes cannot be reused as they are because of their concentration of unburned components and harmful substances (metals and salts). To get more insight about these fly ashes in general, background information about the origin of the material and production is very important.

Waste wood can be divided into three different classes, namely A-wood, B-wood and C-wood (National Waste Management Plan, 2010). Not all these types of timber are suitable as fuel for the bio-power plants because of their components. The wood waste used in the bio-power plants considered in this study consists mainly of B-wood, which includes painted, varnished and glued wood, or wood-wool composite boards. Other compositions, such as paper sludge residue or organic municipal waste residues, are also used as fuel.

There are different types of combustion chambers available for the incineration of waste. The two mainly used types are the grill oven (furnace) and the fluidized bed incinerator (Doudart de la Gree, 2012).

The grill oven

The grill oven consists of the following devices: moving tiles for the transport of waste materials; combustion zones; a water basin and an air suction system. The transport tiles can shift and tumble under an angle over each other. The waste undergoes various stages of the combustion process, like drying, degassing, and finally burning under temperatures around 850 °C. After a combustion time of around one hour, the solid combustion residues left on the grate (bottom ash) are water-quenched.

In general, a sufficiently high temperature (above 850 °C), the presence of oxygen (residual content of at least 6% in the flue gases), sufficient stand time (at least two seconds) and thorough mixing of the flue gases should provide a complete burning of the wood.

The fluidized bed incinerator

In this type of incinerator, the biomass is fed to the fluidized bed, which contains a large amount of sand (an inert, non-combustible material). A cyclone separates the solid and unburnt particles from the flue gases and carries it back to the bed.

There are two main types of fluidized beds. In the first one, the velocity is chosen so that the sand and the fuel just perform a bubbling motion. This can be called a stationary fluidized bed or a bubbling fluidized bed (BFB). In the second type, the speed of the airflow is further increased creating flows that are carrying sand and fuel. Such an installation is called a circulating fluidized bed (CFB). Compared to a BFB, the CFB has the advantage that by the greater turbulence the heat transfer will be higher, which means a lower flue stream resulting in a highly efficient system. The disadvantages of the CFB are the higher use of electric power due to the need for an increased airflow and the higher dust concentration in the flue gas. Most of the ashes, however, are simply separated from the flue gas in the cyclone. Unburnt particles from the flue gases are going back to the combustion chamber. That process is controlled by the cyclone. After this, there is another cyclone that captures red-hot ash particles and ash particles greater than 10 μm. The fly ash that is removed by the cyclone is stored in closed fly ash silos.

In general, fly ashes in the grill oven are collected in the following way: coarser particles in the boiler, finer particles in the electrostatic filter and in the cloth filter. In the fluidized bed incinerator, fly ash is collected as follows: coarser particles in the cyclone and finer particles in the electrostatic filter.

2. Materials

The biomass fly ashes used in this study were collected from the cyclone and electrostatic precipitators of two different power plants in The Netherlands. The reason for this approach is that fly ashes generated in power plants are inherently variable materials, because of several factors. Among these are the type and mineralogical composition of the fuel, degree of pulverization, type of furnace and oxidation conditions including fuel ratio and the manner in which fly ash is collected, handled and stored before use.

Since no two installations or plants have all of these factors in common, fly ash from various power plants are likely to be different. The following types of bio-power plant fly ash are examined (Table 1): boiler fly ash (BF1) and cyclone fly ash (BF2) from a plant in Hengelo, in the Netherlands and cyclone fly ash (BF3) and filter fly ash (BF4) from a plant in Alkmaar, in the Netherlands. Using several types of fly ash, a more general approach of treatment and application can be sought.

For example, in the Alkmaar plant, 170,000 t of waste wood (dry biomass) are incinerated every year, compared to 140,000 t of waste wood incinerated by the Hengelo plant. The power plant

Table 1
Terminology of all fly ashes used in this study.

Fly ash name	Fly ash type	Type of incineration bed
BF1	Boiler ash	Grill oven
BF2	Cyclone ash	Grill oven
BF3	Cyclone ash	Fluidized bed
BF4	Filter ash	Fluidized bed
Fly ash	Pulverised coal combustion fly ash	

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