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Research article

Effect of particle size distribution on the self-hardening property of biomass-peat fly ash from a bubbling fluidized bed combustion

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ABSTRACT

An increasing amount of biomass fly ash is produced because of the increased usage of renewable energy sources. Therefore, novel applications in which biomass fly ashes can be utilized efficiently are required. One interesting option is to use biomass fly ashes in hardening applications, such as earth construction. In this study, the self-hardening of ground fly ash from a Finnish power plant with a bubbling fluidized bed boiler that burns forest industry residuals and peat was investigated. Fly ash was ground with three different mills, namely, tumbling ball mill, impact mill, and jet mill, to different particle size distributions. Results showed that the amount of reactive components for ground fly ash samples was more or less the same with the original sample, but the particle size distribution was different. Moreover, the water requirement for self-hardening samples was completely different depending on the grinding mechanism. When particle size distribution was wider (after ball and impact milling), the water requirement was much lower due to the better packing of the particles. A smaller water requirement also led to greater compressive strength even the fly ash samples were chemically and mineralogically the same. After ball milling, obtaining four times higher self-hardening compressive strength, from 5 MPa to 20 MPa, was possible. For jet milled fly ash, the particle size distribution was narrow due to the classifier in the mill, and the water requirement was high. Therefore, the packing and self-hardening compressive strength of jet milled fly ash was lower than that of impact and ball milled samples.

1. Introduction

Biomass energy can be considered sustainable when the consumption of the biomass is less than its rate of growth and if the biomass intakes more carbon dioxide (CO_2) during its lifetime than it releases during firing [1]. Biomass fly ash is generated as a by-product of the combustion of biomass in power plants, pulp and paper mills, and other biomass burning facilities. About 7 million tons of biomass fly ash is produced in Europe annually, and the amount is increasing because of the EU 20-20-20 energy policy target [2] and the increase in incineration of sewage sludge. Despite the fact that biomass fly ash may be recycled in many ways (e.g., forest fertilizer [3] and foliar fertilizer [4]) and that the disposal costs due to taxes are increasing, most of it is still landfilled. Therefore, novel applications in which biomass fly ashes can be utilized efficiently are needed.

A special characteristic of fly ash that originates from a fluidized bed combustion is its self-hardening or self-cementitious property that enables fly ash to react in water and to produce reaction products similar to hardened ordinary Portland cement (OPC) [5–8] or calcium sulphoaluminate (CSA) based cement [9,10]. The main observed hydration products in self-hardened fly ashes are ettringite ($Ca_6Al_2(SO_4)_3(OH)_{12}\cdot 26H_2O$ or $6CaO\cdot Al_2O_3\cdot 3SO_3\cdot 32H_2O$), aluminium hydroxide ($Al(OH)_3$), calcium silicate hydrate (C–S–H) gel, portlandite ($Ca(OH)_2$), and gypsum ($CaSO_4\cdot 2H_2O$) [5–8,11–12].

Hardening due to ettringite formation is typically most prominent for fly ashes containing reasonable amounts of anhydrite ($CaSO_4$) or gypsum as well as some reactive calcium and aluminium oxides or hydroxides or calcium aluminates [8,13]. Ettringite is a calcium sulphoaluminate hydrate produced by the reactions of gypsum or anhydrite with calcium aluminates and water during the early hydration of OPC [14]. In the case of the CSA cements ettringite is responsible from the initial strength development and generated from the hydration of calcium sulphoaluminate phase ye'elimite ($Ca_4Al_6(SO_4)O_{12}$) [10,15].

This self-hardening property makes fly ash an interesting raw material for soil stabilization [16–19], soil amendment [20], earth construction [21], mine backfilling [22], acid mine drainage treatment [23], and concrete applications [24–27], for instance, as a replacement for OPC or other calcium-rich primary materials. The use of waste materials in concrete materials as a substitute for primary Portland cement contributes to lower CO_2 emission and to the saving of primary materials. However, the use of fly ash in applications in which self-hardening plays an important role is only occasional, as the properties of biomass fly ash,

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Table 1
Chemical and physical properties of the studied biomass fly ash (FA).

	FA
d_{50} [μm]	23.6
BET surface area [m^2/g]	3.1
CaO [%]	29.5
SiO_2 [%]	29.2
Al_2O_3 [%]	10.5
Fe_2O_3 [%]	15.4
Na_2O [%]	1.5
K_2O [%]	1.5
P_2O_5 [%]	3.4
SO_3 [%]	5.2
Free CaO [%]	8.5
Reactive CaO [%]	23.5
Reactive SiO_2 [%]	4.5
Reactive Al_2O_3 [%]	2.9
Reactive Fe_2O_3 [%]	2.7

and thus its reactivity, vary depending on the origin and the properties of fuel and combustion conditions [8,28–31]. The self-hardening properties of biomass and peat fly ashes from fluidized bed combustion have been studied earlier [8,31], and the high amount of reactive CaO, SiO_2, and Al_2O_3 has been found to play an important role to achieve high self-hardening compressive strength. However, how particle size distribution affects the self-hardening property of biomass and peat fly ashes is not known. Studies have been conducted on the effect of fineness of coal fly ash [26,32] and the different slags from the iron-making industry [33] on self-hardening strength, and it has been observed to increase with the decrease in fly ash particle size. Moreover, the compressive strength of mortar increases by mixing ground fly ash particles with cement [34,35] because of more effective packing of the particles [36,37]. The present study aims to investigate the effect of the particle size distribution of biomass-peat fly ash from bubbling fluidized bed combustion (BFBC) on the self-hardening property. The original fly ash was ground with three different mills (ball, impact, and jet mill), and then the chemical and physical compositions, as well as the reactive components, of fly ash samples were analysed. The self-hardening strength of the original and the ground fly ashes was studied after 28 days of hydration. The mineralogical changes after ball milling and hydration were also measured.

2. Materials and methods

2.1. Materials

Fly ash (FA) from a Finnish power plant with 240 MW bubbling fluidized bed boiler was studied. The fuel composition was 60% of peat and 40% of forest industry residuals. FA sample was collected from the first electrostatic precipitator (ESP A) unit.

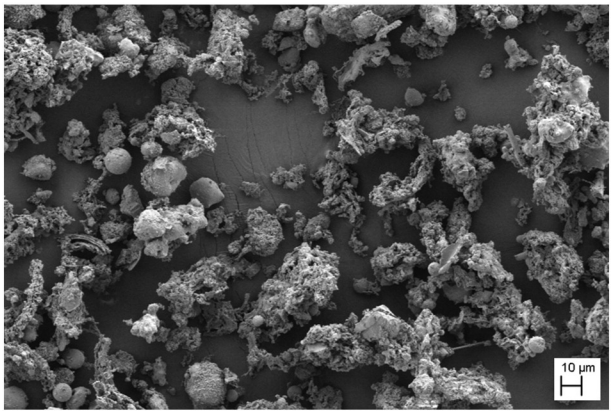

Fig. 1. FESEM image of a studied original FA.

2.2. Methods

2.2.1. Analysis of fly ashes

The particle size distribution before and after the grinding experiments was measured with the laser diffraction technique (Beckman Coulter LS 13320) using the Fraunhofer model and wet procedure reported as a volumetric median size (d_{50}). A specific surface area

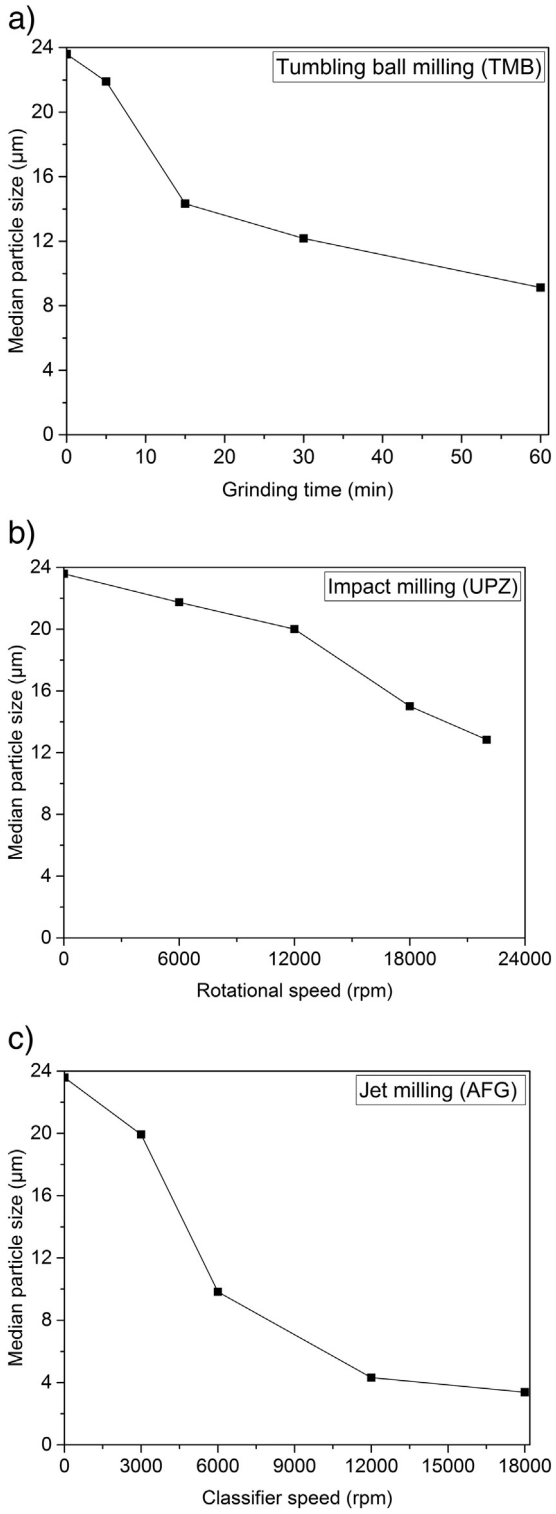

Fig. 2. The achieved median particle sizes as a function of a) different grinding times for ball milling, b) different rotational speeds for impact milling, and c) different classifier speeds for jet milling.