Construction and Building Materials 189 (2018) 825–848

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Use of wood dust fly ash from an industrial pulverized fuel facility for rendering

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HIGHLIGHTS

- Wood fly ash is a viable component for render mortars.
- Wood dust fly ash from reducing conditions has excellent resistance to weathering.
- Wood fly ash from reducing conditions can replace a significant amount of cement.
- Wood fly ash from reducing conditions is good in mixtures for atmospheric CO_2 sinks.

ARTICLE INFO

Article history:
Received 5 April 2018
Received in revised form 23 August 2018
Accepted 5 September 2018

Keywords:
Biomass
Ash utilization
Bioenergy
Fly ash
By-products
Mortars
Renders

ABSTRACT

Wood dust II fly ash, which was generated after boiler retrofit (implementation of low-NOx burners combined with over-fire air), apparently is an enhanced quality for rendering. This is attributed to the mineral phases formed, an increase in the amount of free lime, and performance test results. After accelerated aging tests, the wood dust II fly ash showed no visible occurrence of cracks or detachment of the render base coat from the substrate. Tensile strength values met the applicable limit requirement of 8 MPa. The results contribute to a sustainable ash management for wood fly ash from pulverized fuel facilities.

1. Introduction

A growing concern for future energy supplies and reducing carbon dioxide emissions has led to an expanding interest in the use of other fuel sources, such as biomass, for the production of heat and power [1]. Thus, occurring over the last decades have been increased interests in developing bio-energy technologies worldwide due to not only declining energy supplies but also severe environmental constraints associated with fossil fuels [2]. The goal of the European Union is to increase the percentage of biomass fuels used in the primary energy consumption, offering a reasonable, acceptable option to reduce greenhouse gas emissions [2], mainly CO_2. To ensure the economic, environmental, and social benefits of biomass (renewable energy) power generation, using and managing the ash by-product are important issues connected to a power plant operation and administration [3]. Thus, it is paramount to study biomass ashes in many potential applications.

The pulverized fuel boiler is the most widely used for coal combustion to generate electricity, and the other boilers are prevalent at industrial or cogeneration facilities [4]. Thus, pulverized fuel combustion technology has a vital role in electricity production to ensure the sustainable development of society [5], and its ashes

Abbreviations: C_3A, tricalcium aluminate; C_3S, tricalcium silicate; C-A-S-H CDW, construction and demolition waste; C-S-H, nano-pours gel of calcium-silicate-hydrate (CaO-SiO_2-H_2O); H, height; L, length; OFA, over-fire air; OPC, ordinary Portland cement; Pr_{air}, primary combustion air; PSD, particle size distribution; RCA, recycled concrete aggregates; RH, relative humidity; RMA, recycled mortar aggregates; Sec_{air}, secondary combustion air; W, width.

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https://doi.org/10.1016/j.conbuildmat.2018.09.016

Nomenclature

Symbol	Value (Unit)
d	particle size (μm)
D_{10}	the diameter having 10% of the distribution as smaller particle sizes and 90% as larger particle sizes (μm)
D_{50}	the diameter having 50% of the distribution as smaller particle sizes and 50% as larger particle sizes (μm)
D_{90}	the diameter having 90% of the distribution as smaller particle sizes and 10% as larger particle sizes (μm)
$\varepsilon_{sh(t)}$	relative shrinkage of paste samples (shrinkage strain) at time of measurement, $t = days$(mm/m)
f_c	compressive strength (MPa)
f_{fl}	flexural strength (MPa)
f_t	tensile strength (MPa)
M	mass flow rate (t/h)
P	electrical power generation (MW_{el})
$\dot{V}$	volume flow rate (Nm^3/hr)
w/f	water to fly ash ratio
X_i	mass percent of indicated compound i (CaO, SiO_2, etc.) (%)
λ	stoichiometric air ratio

should be thoroughly studied when the fuel source changes from fossil fuels**.**

Fly ash and other industrial waste products must be efficiently disposed to eliminate air, soil, groundwater, etc. pollution that adds cost to the industry and society [6]. Therefore, their utilization as mineral admixtures in cement and concrete transforms a costly liability into an economic gain, minimizing or eliminating the costs and potential environmental problems [6]. The use of coal combustion by-products, to include fly ash, leads to minimizing disposal costs, decreasing disposal permitting requirements and the land is used for other purposes, offsetting processing costs, saving scarce or expensive natural resources, saving in energy, and reducing emission of pollutants [7]. It was noted that the addition of fly ash in concrete can not only reduce the total CO_2 emissions, but also reduce the energy consumption, considering that the basic performance of concrete is satisfied [8]. Cement is the most expensive conventional mortar, such as used in render base layers, and it is very energy-consuming [9]. The total energy required based on kJ/kg of material is 372 and 0 for cement and fly ash, respectively [6]. It was reported that it was shown that replacing cement with fly ash is environmentally beneficial from a greenhouse gas emissions prespective even when the transportation distance between the power plant and the cement plant are very large (e.g., more than a quarter of the way around the world by road, and much further by rail and sea [10]. Furthermore, utilization of fly ash lower construction costs [7]. For example, using fly ash in concrete that incorporates superplasticizer can offset the high cost of concrete with superplasticizer [11]. Also, metal-laden fly ash used as part of a concrete mixture does not lead to heavy metals leaching from solidified products over extended periods [7]. Thus, industrial waste residues, such as fly ash, silica fume, rice husk ash, etc. continue to become the largest source of mineral admixtures for use in cement and concrete [6]. Significant research has only been conducted with coal fly ash with high utilization figures already being reported, whereas biomass fly ash use is not widely reported, and many research efforts are underway [7].

The industrial waste known as ash is capable of polluting the environment, but it has important qualities for many utilization routes [12]. An important aspect of clean coal technology is to avoid disposal of minerals produced (e.g., fly ash) as coal combustion by-products (CCPs) and use them as valuable sources in another industry [13]. The use of coal combustion by-products, especially fly ash, may be in the form of replacing another industrial resource, process, or application [7]. Fly ash is mostly used in cement and concrete industrial applications [14]. Enhanced performance properties of cement mortar and concrete occur with the use of industrial by-products, to include fly ash, due to pozzolanic contributions [15,16]. Construction uses are attributed to physical properties of fresh cement paste and the improved microstructure (due to grain and pore refinements [16] of the paste after hardening). The paste is positively modified by mineral admixtures used as a replacement for sand and as a partial replacement of cement [6]. The use of CCPs supports sustainability in the construction and building industry [13]. Fly ash is the most important CCP, with about it constitutes 68% of the CCPs in 2008 in Europe (EU 15) [17].

Fly ash utilization is yet to be fully exploited [18]. The uses of fly ashes in many countries are also small in categories, as in India, due to a lack of cost-effective technologies [19]. Less than half of the world's generated coal fly ash is utilized with a global average use of approximately 25% [20]. There is a need of a comprehensive study of fly ash quality generated from wood dust biomass combustion in potential applications. Also, more studies with changing combustion atmospheres from oxidizing to non-oxidizing are needed, as these conditions will ultimately impact the fly ash formation and its quality for utilization.

The advent of environmental responsibility in producing heat and electricity from power plants led to measures to reduce NOx emissions, oxides of nitrogen, NO + NO_2. An initial reducing atmosphere, from the primary combustion operation of low-NOx burners and over-fire air (OFA) (introduce later for complete fuel burnout), leads to an invariably higher carbon carryover [21], which may affect the reactivity, composition, morphology, and particle size distribution of fly ash in a negative manner [22]. Mitigation measures can lead to ash quality usable in concrete and cement, fired-clay bricks and sand-lime bricks, cellular concrete, light-weight aggregates, hydrophobic soils, alkali-slag cement, and foundations of road constructions [22].

After mitigation measures, the uses noted above can be mainly attributed to the chemical make-up of the fly ash along with other characteristics, leading to beneficial effects. Fly ash can be used in fired clay bricks, saving cultivated land [23]. Incorporating fly ash in clay material is beneficial for the mechanical properties of the clay [24]. Fired clay bricks with a high volume ratio of fly ash were reported to have a high compressive strength and a low water absorption [24]. Rice husk ash and fly ash are light materials that have a high porosity and good insulation, and adding them to conventional fired clay bricks can potentially produce more voids and lower thermal conductivity [25]. Rice husk ash or fly ash added to fired clay bricks caused them to become more porous, and the heat resistance of the bricks was higher than ordinary clay bricks [25]. In regards to other brick types, construction materials like sand/lime or silica/lime bricks are based mainly on $CaO\text{-}SiO_2\text{-}H_2O$ (C-S-H) formation by the reaction of $Ca(OH)_2$, SiO_2, and H_2O [26]. In the presence of Al_2O_3, hydrogarnet, $CaO\text{-}Al_2O_3\text{-}SiO_2\text{-}H_2O$ (C-A-S-H), is also found to be formed [26]. C-S-H and C-A-S-H are the main phases that contribute to the hardening of fly ash/lime materials, as fly ash contains considerable amounts of Al_2O_3 and SiO_2 [26].

Alkali-activated cements are cementitious materials formed as a result of the dissolution-precipitation reactions of solid