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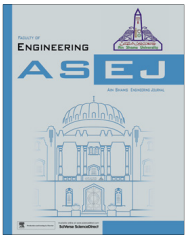

CIVIL ENGINEERING

The incorporation of wood waste ash as a partial cement replacement material for making structural grade concrete: An overview

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Abstract With increasing industrialization, the industrial byproducts (wastes) are being accumulated to a large extent, leading to environmental and economic concerns related to their disposal (land filling). Wood ash is the residue produced from the incineration of wood and its products (chips, saw dust, bark) for power generation or other uses. Cement is an energy extensive industrial commodity and leads to the emission of a vast amount of greenhouse gases, forcing researchers to look for an alternative, such as a sustainable building practice. This paper presents an overview of the work and studies done on the incorporation of wood ash as partial replacement of cement in concrete from the year 1991 to 2012. The aspects of wood ash such as its physical, chemical, mineralogical and elemental characteristics as well as the influence of wood ash on properties such as workability, water absorption, compressive strength, flexural rigidity test, split tensile test, bulk density, chloride permeability, freeze thaw and acid resistance of concrete have been discussed in detail.

1. Introduction

In the current years, the concern of our global environment and increasing energy insecurity has led to an increasing demand in renewable energy and their sources. Among these resources, biomass resources (forestry and agricultural wastes) and power plants fueled by them are a promising source of renewable energy with an economically low operational cost and continuously regeneration of the fuel. Also it is considered a CO_2 neutral energy resource as consumption rate is lower than growth rate. Additionally, the use of forest and timber industry by products such as sawdust, woodchips, wood bark, saw mill scraps and hard chips in the production of power

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presents an efficient method for the disposal of the aforementioned industrial by products. The thermal incineration significantly reduces the mass and the volume of the waste thus providing environmentally and economically safe solid waste management [1]. It is a common practice in the timber product manufacturing industry to draw power for the industrial processes from the wood wastes by developing small scale boilers units and using wood wastes as chief sources of energy. Moreover in the presence of proper emission controls such as electrostatic precipitator, there is virtually little or no emission, thus rendering it an environmentally safe fuel. Wood wastes' fuels are preferred more than other biomasses (herbaceous and agricultural) due to reduced fly ash and other residue production [2].

Among the technologies available for power and heat production, solid biomass combustion is a proven technology in which technologies of fluidized bed and grate furnace combustion are mainly used [3,4]. But a major problem arising from regular use of forestry and timber biomass is the production of ash as a by-product which is a major environment pollutant and health hazard in the absence of emission controls, most of which are also very expensive. Thus, increasing the number of biomass fueled thermal power plant will lead to the generation of vast amount of wood ash which would need proper monitoring and sustainable management of the ash. In the current trend, approximately 70% of wood ash is land filled, 20% tends to be used as a soil supplement in agriculture and 10% are employed as other uses mainly in metal recovery and pollution control [5,6]. The characteristics of ashes from the biomass may differ and chiefly depend on (1) biomass characteristics such as herbaceous or wood or bark (2) combustion technology such as fixed or fluidized beds (3) and the location where collection of ash is done [7]. Combustion of wood produces less ash whereas agricultural wastes and bark have more ash content and thus produce more ash content. Also, the biomass combustion technology controls the properties and amount of ash produced. In a grate furnace, the biomass are subjected to high temperature which volatizes the organic species such (salts and heavy metals), thus reducing their content in the ash [3,7,8,].The difference in operating temperature of the furnace characterizes the degree of fouling and slagging in the ashes. The hydro dynamics of the furnace control the biomass ash fractions collected in the grate furnace and the amount of bottom ash is dominant compared to multi cyclone or filter whereas fly ash is quantitatively larger in case of fluidized bed.

Most of the biomass ash generated in thermal plant is either disposed of in a landfill or recycled in open agricultural fields without any control. But in recent days, land filling is becoming limited due to scarcity of waste land, increasing environmental concerns and the ever increasing volume of ash. Contamination of ground water resources is a major problem due to leaching of heavy metals from the ash or by seepage of rain water in case of land filling. Moreover, the use of wood ash as a soil supplementary material is getting increasingly restrictive due to significantly high metal content in ashes, especially wood ash, which may cause hazards in case of groundwater contamination and infertility of agricultural fertile land. In this regard many researches and studies are being carried out to use wood ash, especially in construction materials to develop a sustainable way of its disposal.

The current boom in the construction industry has caused an exponential increase in the demand of cement, which is the primary constituent in the production of concrete. The production of cement needs a massive amount of raw material and energy, and at the same time releases carbon dioxide into the atmosphere. Researchers have shown that for every 600 kg of cement, approximately 400 kg of CO_2 is released into the atmosphere. The increasing demand of cement leads to higher rate of environmental degradation and more exploitation of natural resources for raw material. The use of wood ash as partial cement replacement in concrete reduces the requirement of hydraulic cement to a large extent [9]. Researchers [10–13] have conducted tests which showed promising results for wood ash being suitably used to replace cement partially, in concrete production. These results solved twofold problems by providing a solution to the waste management problem of wood ash and by minimizing the usage of energy extensive hydraulic cement. Thus incorporating usage of wood ash as replacement for cement in blended cement is beneficial for the environmental and leads to a sustainable and symbiotic relationship.

2. Factors affecting the quantity and quality of wood waste ash

There are several factors which influence the qualitative and quantitative aspects of wood ash produced from its combustion. This facilitates the need of proper characterization of wood ash before employing it to partially replace cement. These factors include combustion temperature, types and hydrodynamics of the furnace and the species of trees from which the wood is derived.

The combustion temperatures of the wood waste influence both the yield and chemical composition of the wood ash. Combustion of the wood waste at higher temperature leads to the production of lower amount of ash. It was observed that wood ash production reduced by 45% when the combustion temperature was raised from 538 °C to 1093 °C. Combustion at higher temperatures, above 1000 °C causes decomposition of carbonates and bicarbonates and thereby decreases the alkalinity of the ash due to their reduction in the ash, being chemical species contributing to the alkalinity of the wood ash. At an incineration temperature of below 500 °C, carbonate and bicarbonate compounds, especially calcite ($CaCO_3$), are predominant in wood ash [2] whereas at higher incineration temperatures like 1000 °C, oxide compounds such as quick lime (CaO) are in majority, in the chemical phase of wood ash. Moreover, the presence of light metallic elements such as potassium, sodium and zinc decreases upon increasing the combustion temperature [13].

Different types of combustion technologies affect the physical properties of ash and varying the thermal temperature causes corresponding variation in the chemical composition of wood ash. Generally, wood ash produced in a grate fired furnace has a tendency to be coarser in nature and settle inside the chamber as bottom ash whereas in more efficient fluidized bed furnaces, the ash produced is finer, with a very low fraction of coarse particles.

The chemical characteristics of wood ash, which govern its credibility to be used as a replacement for cement, such as silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3) and quicklime (CaO) differ significantly from one species of trees to another.