Construction and Building Materials 48 (2013) 457–463

Contents lists available at ScienceDirect

Construction and Building Materials

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

Concretes containing biomass ashes: Mechanical, chemical, and ecotoxic performances

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HIGHLIGHTS

- Concrete formulations using biomass ashes were prepared.
- Concrete with 10% of fly ashes: similar/slightly higher compressive strength values.
- Similar emission levels of chemical species in marine/freshwater leaching conditions.
- Similar ecotoxicological levels under marine/freshwater leaching conditions.

ARTICLE INFO

Article history:
Received 8 March 2013
Received in revised form 11 June 2013
Accepted 16 July 2013
Available online 8 August 2013

Keywords:
Biomass ashes
Concrete
Mechanical properties
Leachability
Chemical behavior
Ecotoxicological levels
Salted and freshwater environments

ABSTRACT

The objective of this work was to assess the possibility of using biomass ashes as substitutes for cement and natural aggregates in concretes, without compromising their mechanical, chemical, and ecotoxic properties. Thirteen concrete formulations were prepared with different percentages of bottom and fly ashes produced in the power plant of a pulp and paper industry. These formulations were submitted to mechanical compressive strength assays, after 28, 60, and 90 days of cure. The reference formulation (without biomass ashes) and two formulations (with biomass ashes), were selected for further characterization. After 90 days of cure, the selected formulations were submitted to the leaching test described in the EN12457-2 (L/S = 10 L/kg, 24 h batch cycle) by using two leaching agents: a synthetic marine water (ASPM medium) and a synthetic freshwater (ISO 6341 medium). The eluates produced were submitted to chemical characterization (set of 19 metals, pH, SO_4^{2-}, F^-, dissolved organic carbon, chlorides, phenolic compounds, and total dissolved solids) and to an ecotoxicological characterization (for marine eluates: bioluminescence inhibition of the bacterium *Vibrio fischeri*; growing inhibition of the microalgae *Phaeodactilum tricornutum*; mobility inhibition of the microcrustacean *Artemia franciscana*; for freshwater eluates: mobility inhibition of the microcrustacean *Daphnia magna*; growing inhibition of the microalgae *Pseudokirchneriella subcapitata*). The substitution of 10% cement by fly ashes has promoted similar to higher levels of the compressive strength to reference formulation. The new formulations presented emission levels of chemical species similar to, or even lower than, those observed for the reference formulation. The ecotoxicological levels were reduced for all of the formulations.

1. Introduction

The production of electric energy through the use of forest residues is one of the possible ways to increase the production of renewable energy and to promote sustainable development through the reduction of the direct emission of greenhouse gases associated with the energy sector [1]. A considerable amount of the forest biomass received by pulp and paper industries is not appropriate for pulp and paper production. This biomass is considered a residue that can be valorized. The most common valorization route of these forest residues is their thermal valorization through combustion, since the energy content is high enough for energy recovery [2–5]. In the Portuguese pulp and paper sector, the thermal valorization of forest residues through combustion is widely used. Nevertheless, the combustion of biomass produces ashes that need to have an adequate management strategy. The types of ashes produced depend on the characteristics of the boiler and the treatment system of the exhaustion gases. Usually, two types of ashes are produced: bottom and fly ashes. The former type is collected at the bottom of the boilers, while the latter is collected in the treatment system of the exhaustion gases. Two main strategies have been adopted in the last years for the management of these ashes: the addition of the ashes to the forest soils (as soil

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0950-0618/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2013.07.031

conditioner) and their incorporation in cement production. The first solution has some limitations imposed by European legislation, due to the high content of biomass ashes in alkali and alkali-earth metals. The second option is also limited since the cement industries are not able to receive all fly ashes produced by the pulp and paper industry due to a low incorporation rate in the cement production process. Therefore, it is necessary to find new applications for biomass ashes.

Several studies have shown that the production of construction materials, mainly cement and concrete, is actually part of the solution for the management of biomass ashes, with a higher level of utilization, despite some technical and commercial barriers [6–8]. In fact, there are concerns about the availability and quality of biomass ashes and blends of coal and biomass ashes, when used in cement and concrete industries [6–13]. Some standards, such as ASTM C618, EN-450, EN 197-1, related with the utilization of ashes as a concrete additive, do not allow using ashes aside from those produced during combustion of the coal. Aside from this aspect, some types of biomass ashes (those from herbaceous and forestry biomass) do not comply with the criteria of EN-450, particularly for alkali and chlorides and occasionally sulfates, and loss on ignition. The standard EN 450-1 allows the utilization of co-fired ashes, with a maximum of 20% of biomass ashes, in concrete production, if the ashes fulfill some requirements, namely the content of Cl, total alkali and residual carbon.

Several tests have been performed regarding the use of coal ashes [14–16] and ash blends (coal and biomass) in concrete production and cement-based mortars (with up to 10–25% of cement replaced by ashes) [6,9,10,12,17–20]. The main conclusions were that the ash blends do not promote significant changes in the bulk cement chemistry. The materials produced in such conditions have equal or even better performances than those produced by coal ashes.

Concrete incorporating biomass ashes is a potential solution for using these ashes in coastal protection and embankment reinforcement of inland water flow systems [21,22]. Moreover, the use of concrete in the shore can reduce the eroding action of waves and promote the development of high quality waves for surf practice.

To the authors' knowledge, it is the first time that concretes incorporating biomass ashes from a pulp and paper industry are simultaneously submitted to mechanical characterization and leaching under marine and freshwater conditions. The use of both chemical and ecotoxicological parameters is a follow-up of the previous works in which the authors have stressed the need for gathering these two types of characterizations to support the eco-compatibility assessment of new materials for civil engineering works [23,24].

The main objective of this work was to produce concrete formulations by using biomass ashes as substitutes of cement and natural aggregates, without compromising their mechanical performance, the emission of chemical species and the ecotoxicological properties. Therefore, the compressive strength resistance of concretes produced with bottom and fly ashes from the combustion of forest residues was studied and the chemical and ecotoxicological properties of some selected concrete formulations was assessed. These chemical and ecotoxicological properties were assessed under marine and freshwater leaching conditions.

2. Materials and methods

2.1. Origin of biomass ashes

The fly and bottom ashes were produced in a Portuguese biomass boiler from the pulp and paper industry. This industry produces electricity through the combustion of bark from eucalyptus and pine, and other forest residues, in a bubbling fluidized bed combustor (BFBC). The bottom ashes were collected at the bottom of the combustion chamber and the fly ashes were collected in the electrostatic precipitator of the air pollution control system. The BFBC uses sand as a fluidizing agent. During the transport and conservation in the laboratory, the ashes were stored in dark airtight polypropylene containers and maintained at a temperature of 4 ± 1 °C, in the absence of light, to prevent their weathering and carbonation.

2.2. Concrete formulations

Thirteen formulations of concrete were prepared (Fig. 1). The reference formulation (F1) was composed by the usual materials: cement, sand, 10 mm calcareous gravel, and water. The composition of the reference formulation was adapted from Nawy [25].

The ratio w/c was slightly higher than that defined by Nawy [25] due to the high water absorbance by pozzolanic materials, namely the biomass fly ashes. This behavior was to be expected as it was observed by other authors [26,27].

The formulations F2 to F13 were prepared with bottom and fly ashes. Three levels of cement substitution by fly ashes were used: 10% (formulation F2 to F5), 20% (formulations F6 to F9) and 30% (formulations F10 to F13). In each of these formulations, four substitution percentages of aggregates (sand and calcareous gravel) by bottom ashes were tested: 0% (F2, F6, F10), 9% (F3, F7, F11), 18% (F4, F8, F12), 36% (F5, F9, F13).

The fresh concrete was prepared in a concrete mixer (Matest B025-SP), and then was placed in cylindrical plastic molds with 80 mm height and a diameter of 70 mm. Each mold containing the fresh concrete was submitted to a vibration process, with an amplitude of 0.3 mm, in a mechanical vibrator (Retsch AS 200 digit), in order to remove air bubbles. The molds were then capped in order to avoid air contact, and stored at 20 ± 1 °C, in a climate chamber, on the absence of light.

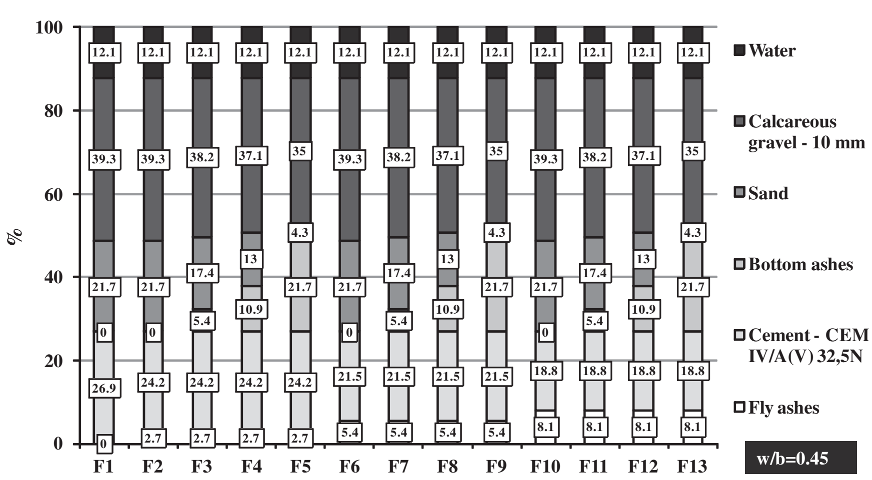

Fig. 1. Composition of the thirteen formulations of concrete (w/b: water/binder ratio; % wet basis).