Fuel Processing Technology 133 (2015) 35–42

Contents lists available at ScienceDirect

Fuel Processing Technology

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

Small addition effect of agave biomass ashes in cement mortars

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ARTICLE INFO

Article history:
Received 10 October 2014
Received in revised form 24 December 2014
Accepted 26 December 2014
Available online 22 January 2015

Keywords:
Agave
Subproduct
Characterization
Biomass

ABSTRACT

The use of industrial waste for the production of biomass is a topic that has gained increasing interest. This is due to the need to use plants that do not affect the food supply when used for power generation from biomass. *Agave salmiana* residues meet these characteristics. It has now been proposed as a possible source of bioenergy production because of its growth characteristics. Therefore, in this research, the effect of combustion temperature of the *A. salmiana* as it could happen in the energy production was studied. In addition, the characteristics of these residues were analyzed to serve as a basis for possible future applications in construction materials. Results indicate that the ashes are mainly $CaCO_3$ when calcined at below 700 °C, and CaO above this temperature. The apparent particle size was between 25 and 32 μm. However, it is observed that it consists of much smaller particles of approximately 300 nm. This reduction in size is related to decomposition at higher temperatures and is reflected in the increase of the specific area up to 70%. The compression strength at early ages was up to 90% higher than a reference, when 5% cement replacement mixes were performed.

1. Introduction

Agroindustry is a sector that mainly serves the needs of food supply, both animal and human consumption. It has been recently observed that there is a great potential for some of these industries, such as sugar, wood, and others to share part of their crops to the production of biomass for power generation [1–3]. As a result, studies of how to turn these plants into energy sources have constantly been done to increase power energy efficiency. However, once the plants have been burned to produce energy, the product of such combustion is a residue with variable content of organic and inorganic material; these residues are the biomass ashes (BA) and in most of cases those residues do not have a defined application; thus, confinement is regularly practiced. BA contains different features and their properties must be established to determine the possible uses or final disposal. Currently, a unique classification to relate the properties and/or applications of BA does not exist. However, several researches have been conducted to classify BA depending on their chemical composition and mineral phase to an extensive number of different reported BA [4]. This classification considered carbonaceous content, organic phases, inorganic material composition and fluids contained in them, and possible uses were established from the main chemical element groups that are often associated [5].

Currently, between 8 and 12% of energy is produced through biomass direct burning. The result of the widespread use of energy production from biomass will be the increase of the residues which are known as biomass bottom ashes. This form of energy production will continue growing and the amount of waste would be even comparable to the fly ash that is currently produced by burning fossil fuels [6]. This makes it urgent to establish the possible uses that these BA might have.

BA properties would depend on the characteristics of the plants used as biomass; temperature and time process; and the procedure for its final disposal. Thus, it is necessary to emphasize the need to analyze in the most elaborate way, a methodology for BA characterization, which considers chemical composition, mineral phases, size, and morphology of the BA to elucidate their potential uses or the characteristics under which they shall be confined. The chemical composition of the BA is based on the content of the main components, having regularly as main elements: O, C, H, N in the organic material; and Si, Ca, K and Mg in the inorganic material [4,7].

Among the plants that are potential sources for generating biomass with high power generation potential, is the *Agave salmiana*. Furthermore, the conditions where these plants grow are mostly arid regions; therefore vast land that is uncultivable now could be planted. So, a great potential for future energy production has been found [8,9].

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http://dx.doi.org/10.1016/j.fuproc.2014.12.041
0378-3820/

Nowadays, most of the grown *agave* is intended for the *mezcal* production industry, which is an alcoholic beverage produced in Mexico. An advantage of using this plant as a possible raw material for power generation is that it does not compete with worldwide food production and it can be grown on currently unused arid land. Arid and semi-arid areas are expanding more because of climatic changes, and it has been found that plants of the genus *agave* can grow in places where the total annual rainfall (TAR) is as low as 427 mm. However, this affects their annual productivity in 10 $Mgha^{-1}$ and increasing to 34 $Mgha^{-1}$ when the TAR is 848 mm. Thus, it can be said that the conditions of higher productivity for the production of these plants are not fully established [10] and the energy demand will develop this sector and consequently the waste generation previously mentioned. Then, because of the large amount of waste generated from biomass, some researchers have proposed to integrate high volumes of biomass residues in products such as paper, activated carbon and agglomerates, focusing mainly on the use of bagasse and not to the ash resulting from its burning as biomass. Agroresidues that have gone through this same process are olive and sugarcane, which are mostly consumed to produce food, and more recently for biofuel. The extensive use of sugarcane has led to characterize its waste and to use it in building materials. Researchers have reported the possible use of different sugarcane wastes: for the manufacture of fibers, in fiber-reinforced composite materials [11]; and ashes in ceramic matrices, such as refractory materials [12]; or the effect of the sugarcane BA addition as supplementary material in cement[13,14] as an alternative for construction in countries with emerging economies. The reactivity of the ash is limited because it contains organic residues, since the commonly used calcination temperature is not high enough to reduce the content of organics [15].

For all the aforementioned, studies have been conducted on the biomass waste decomposition conditions that would help to determine their actual use, either as a mineral filler [16], material for cement replacement [17,18], or as building materials [19–22]. In general, the agroindustrial waste of sugarcane production, has been through a process of assimilation of their capabilities and limitations to increase its use [23]. Nowadays, applications are real, and this is the same process that other agroindustrial residues, as rice husks, have been through [24,25]. Studies related to the waste of agave industry are currently focused on the characterization and use of the fibers of *agave*, and to its potential use in applications of environmental engineering, either as a source of calcium or chemical removal [24–29]. Thus, the calcination conditions for its use as fuel and how these residues can be used within different industries, must be appropriately set, considering that *agave* will be a biomass for energy production widely used in the future.

2. Material and methods

The plant leaves used in this work were obtained from Mexico in the region located at 100°23′46.793″W 25°21′53.218″N which corresponds to a semi-arid region. In this area, the plant is used for the production of *mezcal* and it corresponds to the *A. salmiana* specie. This plant has a life cycle of about 6 years and it can reach a size from 2 to 6 m depending on species. These plants were obtained by manual labor and the removal of material was not concentrated in the heart (*piñas*) of the plant, but in the leaves.

As it was mentioned above, BA has been proposed to be used potentially in building materials. However, the way agave biomass ashes (ABA) are used is rarely studied in the literature, so, according to studies consulted, a detailed description of the components of ABA will be required to determine their possible use. The first parameter to determine the feasibility of using ABA is to know their chemical composition, because the ashes of biomass are normally distinguished for having carbonaceous material, highly crystalline materials, and a higher alkali content than coal ashes [30]. Some researchers have reported that these BA classifications are first determined by their main chemical group. The chemical composition of ABA depends on the type of plant species, soil and the conditions under which they were calcined, and stored [1,31]. In this study, the combustion of dry *A. salmiana* bagasse was conducted at different temperatures, and the resulting ashes were characterized by thermogravimetric analysis (TGA), visual inspection, chemical composition, X-ray diffractometry, particle size distribution, morphology, and loss on ignition (LOI). Trying to use agroindustrial waste in building material applications suggests that a very important factor for their interaction in cement matrices is LOI content, i.e. the amount of organics it contains [4]. But, there is no agreement of how to determine the LOI in the BA ashes. The composition of the BA varies, and some of the components can be decomposed at high temperatures, so the analysis of the loss on ignition is complex because it is not only related to the carbon-based organic material, but with the decomposition of carbonates, sulfates, phosphates and other elements. In this study, recommendations of ASTM C311 standard were used to LOI measurement. The resulting ABA from the ashing process proposed was not subjected to a washing process; this to observe if the material obtained would have a direct potential use in cement matrix.

The compressive resistance is an ideal parameter to analyze whether the additions of these residues are feasible to be into the cementitious matrix. As it has been mentioned, there is a consensus that the production of energy from biomass will have an important participation in the sector, so that the residues obtained will be of concern in their final disposition. Previous experiences with other BA have proven to be feasible in the replacement and/or addition within the cementitious matrix, so, using a similar methodology will help to investigate this possibility. In this research, the compressive strength effect of the addition of ashes burnt at different temperatures was evaluated to determine the convenience of burning the ashes at high temperatures.

The procedures used to fabricate specimens and to evaluate the addition of ABA in mortars were based on ASTM C311 standard, which indicates the requirements to evaluate a fly ash and natural pozzolans that could be used in Portland cement concrete. Strictly speaking, biomass ashes are not classified according to the ASTM C618 standard, which exclude this type of ashes due to their chemical composition. Compressive strength tests in mortars were carried out according to ASTM C109 and the proportioning mixtures used are shown in Table 1, which was designed to evaluate the cement replacement by ABA for each of the different combustion temperatures, and for a mixture reference made only with Portland cement. ABA dry densities are also reported for each combustion temperature according to ASTM C188. After the 28 days of curing, samples were dried at 60 °C to constant weight. Then, they were immersed in water and constant weight was measured according to ASTM C642 to determine water absorption. From results in Table 1, it was observed that the effect of adding ABA is not very significant, and the values are very similar to the mortar reference. Water absorption is related to durability; thus, from the results it could be said that the capillary absorption effect will be similar in all test mortars. The amount of replacement was 5% mass, instead of 20% as recommended by ASTM C618 standard; because the mortar consistency measured by ASTM C1437 remarkably decreased as shown in Table 1, the consistency reduction is related to the ABA particle size and their chemical and mineralogical composition. The cement used was an ordinary Portland cement according to ASTM C150 and aggregate used was standard silica sand, according to ASTM C778. The sand cementitious ratio was 1:2.75 and a water/cement ratio of 0.484.

3. Experimental procedure

3.1. Bagasse collection and preparation

Agave leaves were removed directly from the plant and subsequently its initial weight was determined. Once they were weighed, they were subjected to a drying process during 120 h and the results show that the dry sample (dry bagasse) is about 12% of the plant weight. The drying process removes water that could interfere in the combustion process.