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Feasibility of using olive biomass bottom ash in the sub-bases of roads and rural paths

M. Cabrera [a,*], J. Rosales [a], J. Ayuso [a], J. Estaire [b], F. Agrela [a]

[a] Area of Construction Engineering, University of Cordoba, Cordoba, Spain
[b] Geotechnical Laboratory (CEDEX), Madrid, Spain

HIGHLIGHTS

- We show the use of biomass bottom ash for soil treatments.
- Different mixtures of expansive soils were applied, with different BBA rates.
- The use of BBA as stabilizer material in road was proved.
- The addition of BBA in all the mixtures improved the bearing capacity.
- BBA reduces the expansion same as treatment whit lime.

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ABSTRACT

Clay soils are widely distributed throughout the world and are the source of multiple technical problems in their application for the construction of sub-grade and sub-road bases. These types of soils are found in areas where civilian infrastructure such as roads and rural roads must be built. Therefore, in many situations it is necessary to use stabilized expansive soils, in the formation of the foundation and structural layers of linear infrastructures.

Soil stabilization is used to increase the load capacity of the soil, and mixtures of lime and cement are generally used as binders.

In recent years, interest in the recycling of industrial products and by-products has increased. One example of this is the use of biomass combustion in power plants. The management of significant amounts of waste (biomass bottom ash) from biomass power plants remains a problem.

This paper presents the results of an experimental study for stabilizing expansive soil to determine its bearing capacity and mechanical properties via a triaxial test of the addition of biomass bottom ash. A double objective was targeted: reduction of the problems in using this type of soil and provision of a use for this type of waste. The results showed significant improvements in the mechanical. Therefore, herein is proposed the use of biomass bottom ash as a stabilizing agent for expansive soils, to improve the efficiency of the construction process by incorporating this product into a second life cycle as road bases.

1. Introduction

In road and rural-path construction, it is essential to minimize the use of additional materials, and eliminate earth moving as much as possible, for environmental and technical considerations.

The soil treatment techniques contribute to the competitiveness and sustainability of road engineering [1]. The engineering properties of construction materials determine their potential use and application in civil works. The material characteristics must satisfy the engineering functions that contribute to the durability and quality of the entire road structure [2]. Previous works have proved the feasibility of reusing industrial residues from different origin which have been applied in road construction [3,4].

Soil stabilization is the process of alteration of geotechnical properties to satisfy engineering requirements [5]. Extensive studies have been carried out regarding the treatment of expansive soils using various additives, such as lime, cement, fly ash, industrial waste products, potassium nitrate, calcium chloride and phosphoric acid [6–13]. Traditional techniques of soil stabilization are

* Corresponding author.
E-mail address: manuel.cabrera@uco.es (M. Cabrera).

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often used to obtain geotechnical materials improved through the addition into soil of such cementing agents as Portland cement, lime, asphalt, etc. However, the traditional cementitious stabilizers like cement are under discussion, not only for their negative environmental effects during manufacture but also for their cost.

Those types of additives have been used in soils to improve their engineering properties, and to modify physical and chemical reactions with soil elements in the presence of water [14–18]. For this reason, this work seeks the feasibility of using new by-products with pozzolanic characteristics for use as a soil stabilizer. Based on previous studies in which fly ash is used as a stabilizer due to its high CaO content, hydrates forming cementitious pozzolanic products similar to those formed during the hydration of Portland cement or lime [19–21]. This research demonstrated the possibility of removing cement as a stabilizing material, replacing it with ash from the combustion of biomass for the generation of energy in combination with lime.

In addition to cement, lime is one of the most used materials for soil treatment. Lime is a very caustic, pure white substance that results from the calcination of limestone. The common lime is calcium oxide CaO, also known as quicklime, which is widely used in construction.

Lime can usually be obtained via thermal decomposition of materials such as limestone, which contains calcium carbonate ($CaCO_3$), extracted from sedimentary deposits called caliche. It is subjected to very high temperatures (900–1200 °C), for a period of three days in a rotary kiln or in a special furnace called a lime kiln. However, if not managed, the process is reversible: while cooling, the lime begins to absorb CO_2 from the air again; after a while, it once again becomes $CaCO_3$ (calcium carbonate).

The long-term operation of any construction project depends on the quality of the underlying soils. Unstable soils can create significant problems in built structures and pavements. With appropriate design and construction techniques, unstable soils can be chemically transformed into usable materials. In addition, the structural support provided by lime- or cement-stabilized soil can be exploited in pavement design.

In general, the good results obtained from treatment with lime or cement, as applied in the construction of roads and esplanades, have extended this technique to any type of geotechnical problem and to esplanades with low bearing capacity [22]. The use of stabilized or treated soils, even with marginal and contaminated soils, avoids the reduction of natural resources by reducing the need for better quality soil. Moreover, clearance operations and transportation to a landfill are avoided, along with the extraction and transportation work conducted to replace the soil. It is a technique clearly focused on achieving greater sustainability.

One of the biggest drawbacks of stabilization using lime or cement is their small particle size. Dust can be a problem, and its management is generally inadequate in populated areas. In addition to the high volumetric weight of such additives, which makes them more expensive to transfer, the dosage is altered in places where it is very windy. Moreover, the hydration process is more expensive when done in a plant rather than doing it at the site of application.

Biomass is a term with many definitions. For the purposes of this paper, biomass is considered as any organic (non-fossil) material burned as fuel to generate electricity or produce heat.

Biomass-based products produce solid residue (ash) a result of thermochemical degradation. Thermochemical processes include combustion, pyrolysis, and incineration of woody biomass.

Currently, research is being conducted regarding the use of biomass ashes for civil works. In Spain, Andalusia leads in its scope of power generation from biomass, with 18 biomass combustion plants and a total installed capacity of 257.48 MW [23,24]. The waste biomass in Andalusia from grapevines, olives, fruit trees, and poplar, is used as a source of renewable, sustainable energy to provide heat in homes. Biomass ashes are the solid by-products that remain after complete or incomplete combustion of organic matter. Industrial biomass ashes consist of biomass bottom ash (BBA), or slag, and biomass fly ash (BFA).

BBA and BFA have been extensively studied, with focus on several applications. BFA has typically been used in agriculture due to its nutrient mineral content, including calcium, potassium and phosphorus [25]. Because of the increased production of this by-product, BFA has been investigated regarding its use in building materials. While fly ash utilization has been extensively studied, similar studies on the effective management and utilization of bottom ash have been scarce. BBA is traditionally disposed of in landfills.

In recent studies, biomass bottom ash from wood combustion and agricultural olive residues was used as filler material in road embankments, as well as in the manufacture of cement-treated recycled materials and as additive in the manufacture of lightweight recycled concrete [26–28].

Therefore, it would be interesting to study the possible application of bottom ash biomass for soil stabilization or treatment, and more specifically, for its use in the region of Andalusia in southern Spain. This region has problems related to expansive soils and has an abundance of European combustion power plants as well as higher concentrations of available biomass.

The goal of the present work was to evaluate the possibility of using BBA as a soil treatment to stabilize the sub-bases of roads and rural paths according to the technical specifications for road works imposed by Spanish regulation [29].

This article discusses the experimental results of improvement of the properties of an expansive soil when it is treated with biomass bottom ash. Thus, the treatment or stabilization of expansive soils has been considered from the standpoint of civil engineering. These experiments have been based on tests to evaluate the use of these types of soil as building materials.

To these ends, the following parameters were measured to physically and mechanically characterise the samples: granulometric composition, absorption, density, compactability according to the modified Proctor test, bearing capacity based on the CBR index, plasticity and the triaxial compression test, X-ray fluorescence spectrometry and scanning electron microscopy analysis with X-ray spectroscopy.

The potential for using BBA mixed with clays at certain percentages of dosage. This BBA valorisation could avoid a large amount of the waste currently being sent to landfills, providing economic and environmental incentives.

2. Materials and methods

2.1. Biomass bottom ashes (BBA).

In this work Olive Biomass Bottom Ash (BBA) was studied and applied in the formation of granular materials to be applied in road structural layers.

Based on the data, a power plant burned approximately 40% olive cake and 60% wood biomass (poplar, olive and pine).

The biomass sample analysed in this study was collected after combustion at the plant BioLinares, as characterized in specific studies performed previously [26,30]. A summary of the physical and chemical characterization of this sample material is shown in Table 1.

According to the results, BBA is composed of extremely porous particles with rough surface textures. The size of these particles varies from sand to fine gravel. The water absorption and saturated surface-particle density were measured. Absorption is an important factor to consider because many physical parameters of bottom ash are altered in the presence of excess water [31,32]. Low dry-surface particle densities (SSD) were calculated for the BBA sample. Compared to traditional natural aggregates, low densities were obtained for BBA because it is composed of particles with low specific weight [33,34]. The chemical composition of BBA indicated that BBA primarily consists of Si, Ca and K, while the measured amounts of Mg, Fe, Al, Na and Ti (minor elements) were <5%. Thus, Si is the most