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

M. Cabrera, G. Rosales, F. Agrela

Area of Construction Engineering, University of Cordoba

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 (Maestro & Ibáñez 2009). 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 (Attoh-Okine 1999). Previous works have proved the feasibility of reusing industrial residues from different origin which have been applied in road construction (Croft 1967, Basma & Tuncer 1991).

Soil stabilization is the process of alteration of geotechnical properties to satisfy engineering requirements (Sherwood 1993). 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 (Bell 1996, Miller Azad 2000, Nalbantoglu, & Gucbilmez 2001, Rao et. al 2001, Ramadas 2011).

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.

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 (Cabrera et al 2014, Cabrera et al 2016). 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 (Rosales et al 2016). 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 (Andrade et al 2007, Hinojosa et al 2014).

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 (Melotti et al 2013).

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

2.1 Biomass bottom ash

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 (Huang et al 2007). 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 (Andrade 2004, Forteza et al 2004). 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 (Shvarzman 2002). 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 abundant element, followed by Ca and K (in similar amounts). Due to the nature of the material, the BBA sample tested contained 4.89% organic matter.

Tab. 1: Summary of the main physical and chemical properties

	Particle size distribution (%)		Specific density of the solid particles **(g/cm^3)**	Water absorption **(%)**	Chemical compounds **(%)**		Organic matter content **(%)**	Loss on ignition **(%)**	Total sulphur content **(%S0^3)**
	UNE-EN 933-2		UNE-EN 1097-01		UNE 80-215		UNE 103204		EN-1744-1
BBA	10 mm	97.0	2.46	20.11	Si	25.14	4.89	15.50	0.39
	8 mm	95.1			Ca	16.78			
	4 mm	84.8			K	14.28			
	2 mm	65.2			Mg	3.09			
	1 mm	39.0			Fe	1.64			
	0.5 mm	23.1			Al	0.76			
	0.25 mm	13.1			Na	0.35			
	0.063mm	5.40			Ti	0.12			

2.2 Quicklime

Hydrated lime is obtained when quicklime reacts chemically with water. Hydrated lime (calcium hydroxide) reacts with clay particles and permanently transforms them into a strong cementitious matrix. The plasticity and chemical properties are summarized in Table 2.

2.3 Expansive clay soil (ECS)

The expansive clay soil analysed was stockpiled on the premises of the University of Córdoba. The maximum aggregate size was 2 mm. Chemical analysis highlighting the elemental content of elements (Table 2) and the organic matter content was 1.20 wt%, as determined according to standard UNE103 204.1993.

Tab. 2: Physical and chemical properties

		Quicklime	ECS
Liquid limit (UNE 103-103-94)		-	59.2
Plastic limit (UNE 103-104-93)		-	39.9
Plasticity (LL-PL)		-	26.3
Organic matter (%) (UNE 103-204)		-	1.2
Elemental content (%) (UNE 80-215)	Si	<0.01	23.48
	Ca	52.9	16.8
	K	<0.01	0.74
	Mg	0.15	1.17
	Fe	0.03	2.93
	Al	0.03	3.44
	Na	0.02	0.23
	Ti	<0.01	0.45

2.4 Mixtures

In this study, four different percentages of BBA were added to the expansive material, 0, 15, 50 and 100%; furthermore, the expansive material was mixed with 5 wt% quicklime. Table 3 shows the mixes obtained in the laboratory as well as the name used for the different mixes.

Tab. 3: Dosages of the mixtures

Nomenclature	ECS	BBA	Quicklime
ECS	100%		
BBA		100%	
ECS+BBA(50/50)	50%	50%	
ECS+BBA(85/15)	85%	15%	
ECS+5% QL	95%		5%

3 Experimental Methods and Results

3.1 Modified Proctor

The Modified Proctor compaction test, in accordance with UNE 103-501-94, consists of compacting soil samples with given water content in a standard mould with standard compaction energy. Figure 3 shows the graphical representation of the results of the Modified Proctor test, it is possible to observe that all the materials presented curves very insensitive to changes of moisture content, making it necessary to ensure that the moisture content was close to the optimum value during compaction.

In previous research (Cabrera et al 2014), these results were confirmed for BBA. The plane curves shown indicate that these materials do not exhibit high sensitivity to changes in moisture for compaction.

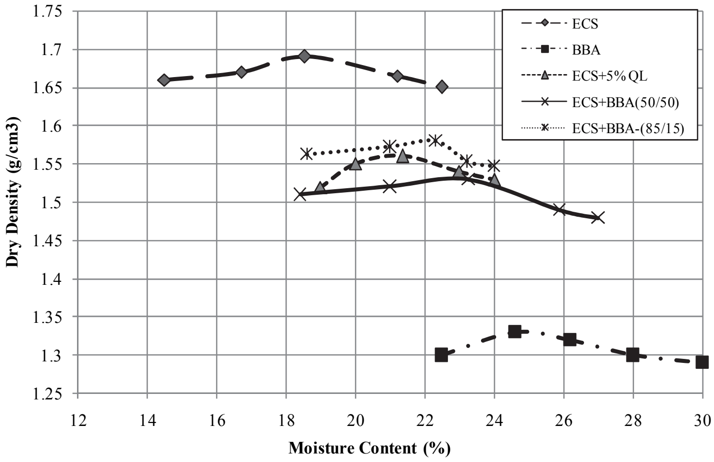

Fig. 1: Moisture-density relationships

3.2 California bearing ratio (CBR)

This test method is used to evaluate the potential strength of sub-grade, sub-base and base course material, including recycled materials for use in road and airfield pavements. The CBR value obtained in this test forms an integral part of several flexible pavement design methods. This test is performed according to UNE 103 502-95, which describes the process for determining the resistance index of soils called CBR.

This study was conducted with 25% Modified Proctor (MP), 50% MP and 100% MP value tests. The evolution of the tested specimens was examined under different external conditions and over time. The four test conditions were un-soaked CBR, 4-day soaked CBR, 90-day soaked CBR and 90-day in dry chamber camera CBR(Table 4).

Tab. 4: CBR Values

	Un-soaked CBR			4-days soaked CBR			90-days soaked CBR	90-days dry chamber camera CBR
	25% MP	50% MP	100% MP	25% MP	50% MP	100% MP	100% MP	100% MP
ECS	3.24	8.15	13.05	1.2	1.4	2.3	1.31	58.89
BBA	13.96	21.53	35.09	11.66	17.62	28.01	38.69	44.98
ECS+5% Q	8.12	14.62	22.31	2.24	3.58	4.67	36.81	69.19
ECS+BBA (50/50)	15.64	22.89	25.84	12.45	23.11	33.70	41.71	63.64
ECS+BBA (85/15)	10.89	18.22	21.39	6.48	15.22	19.75	30.55	54.31

3.3 Triaxial compression test

The triaxial test is performed according to UNE 103 402-98, which determines the strength parameters of a material sample in CU test mode: consolidated and undrained, with a pore pressure measurement assay. The specimen is saturated, consolidated under isotropic conditions and the test proceeds until compressive failure. The interpretation of those curves allowed us to calculate Mohr-Coulomb parameters with the aid of the s´-t diagrams, as seen in Figure 2.

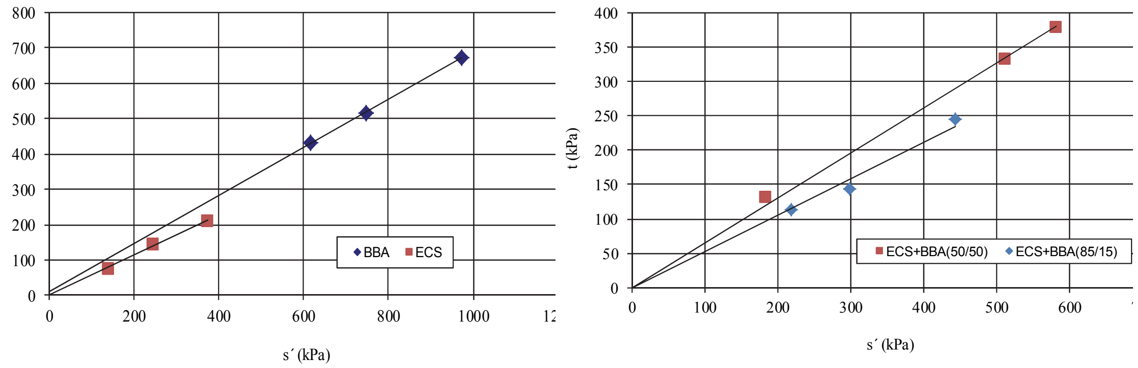

Fig. 2: Tests performed with ECS and BBA (Left) and tests performed with ECS + BBA (50/50) and ECS + BBA (85/15) (Right)

It can be observed that the relevant points fit very well on lines that can be interpreted as representative of the Mohr-Coulomb failure criteria. The values of friction angle obtained with these tests are summarized in Table 5.

Tab. 5: Triaxial strength parameter values

	Strength Parameters (Effective) Φ'
ECS	34.6
BBA	43.7
ECS+5% QL	27.5
ECS+BBA (50/50)	40.7
ECS+BBA (85/15)	31.9

All the materials seem to exhibit non-cohesive behaviour. ECS has a friction angle of 35° (a bit large for its clayish nature) that increases to 41° once mixed with 50% BBA. The mix of 85% ECS with 15% BBA seems to have strength similar to that of the original ECS.

From this point of view, the strength of all of these materials, and their combinations, can be considered high and sufficient to build any type of embankment.

3.4 Free-swelling

A series of free-swell tests were conducted on specimens compacted with optimum water content and to a density equivalent to 100% of standard Proctor compaction.

The apparatus used for free-swell testing was an odometer, according to UNE EN 103 601-96.

Tab. 6: Swelling test values at four days

	% Free-Swelling
ECS	6.74
BBA	0.06
ECS+5% QL	0.02
ECS+BBA (50/50)	0.04
ECS+BBA (85/15)	0.18

As shown in Table 6, the ECS sample showed a high percentage of free swelling. When the ECS was mixed with 50% bottom ash from the biomass (i.e. ECS + BBA at 50/50), the free swelling was reduced by 99.5%. This reduction was similar to that achieved with the mixture manufactured with 5% lime (ECS QL + 5%). It can be concluded that the use of BBA reduces the expansion of expansive soils to the same extent (percentage) as lime. This demonstrates economic and environmental benefits from using this industrial by-product in this way.

4 Conclusions

Based on the results obtained, we present the following conclusions:

- The addition of BBA in all the mixtures improved the bearing capacity, mainly due to the high calcium content that increased the pozzolanic activity.

- When the ECS was mixed with 50% bottom ash from biomass, the free swelling was reduced by 99.5%. This result is similar to those reported for the mix with 5% lime.

- Regarding the values of Mohr-Coulomb failure criteria obtained in the tests, the strength of all of these materials (and their combinations) can be considered high and sufficient to build any type of embankment.

- It can be concluded that the use of bottom ash from biomass combustion reduces the expansion of expansive soils to the same extent as from treatment with lime, providing an economic and environmental benefit of using this industrial by-product.

The present work has proved, at least for certain dose percentages, the benefits of BBA for improved mechanical ability and stabilization when used for material construction in civil infrastructure.

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