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Research article

Geotechnical Characterization of Biomass Ashes for Soil Reinforcement and Liner Material

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Abstract.
Biomass ashes (BA) have been intensively studied as amendments for soil in earthworks. This paper aimed to geotechnically characterize BA from pines and olive trees compared to the soil from Castelo Branco, Portugal. Namely, granulometry, specific gravity, Atterberg limits and optimal compaction values were obtained and analyzed in order to valorize the residue incorporated into soils. This work is part of broader efforts to develop an alternative material that can be used in hydraulic barriers as liners and for soil reinforcement. Thus, BA can contribute to reductions in weight and plasticity, and filling properties. Further studies are needed, particularly mechanical and hydraulic performances tests.

Keywords: biomass ashes, geotechnical and mechanical properties, residue valorization, soil reinforcement, liner material

1. Introduction

BA are the by-product produced mostly in co-fired thermoelectrical facilities for energy production. Several processes are involved in such facilities, such as combustion, pyrolysis, and incineration, generating filter and fly biomass ashes, which are considerably different from the original biomass, as they are mixed with other products and suffer physical and chemical processes [1-2]. Therefore, as a residue that could cause contamination, BA waste has received attention due to its possible pozzolanic properties, which could indicate their use as cementitious material after alkali content reduction [3] or substituting gravel in road construction while possibly replacing fine-grained clays and soils in the construction of landfill liners due to its latent hydraulic properties [4]. Bagasse ash, rice husk ash, and palm oil fuel ash are prominent examples of such residues [5], like the, already studied cellulose and paper mill sludge which consist mainly of fibers, fillers, clays, and several other minor impurities that can have low hydraulic conductivity (k) when properly compacted, the geotechnical characteristics of the sludge in the paper mill are very different from typical clays, but in general they behave similarly. [6] analyzed the industrial potential for BA and concluded the main advantages: the concentration and recovery of valuable components - SiO_2, Al_2O_3, CaO. These components could indicate their feasibility for soft soil reinforcements, increasing friction angle while reducing the number of voids and settlements, even though BA properties vary when dealing with different types of biomasses.

As biomass ashes are originated from different natural and anthropogenic processes that take place within combustion units, they are a highly variable residue, principally when considering its large and varied origin possibilities. In addition, several types of BA, such as pines BA are not yet fully understood, requiring further investigation to understand their properties within soils. Different geotechnical characteristics can be seen among literature, which some of them have stated biomass ashes' successful approach for reinforcing soft soils, as stated in [7-8].

Thus, this paper aims to investigate and characterize biomass pine and olive ashes geotechnically searching its feasibility for soils' reinforcement and alternative liner material incorporating or substituting usual material in earthworks due to geotechnical parameters.

2. Materials and methods

The BA were collected at the industrial park of Valamb - Grupo Razão, located in Castelo Branco (Portugal), and the soil for reinforcement was collected at Castelo Branco (Portugal). Both materials were characterized to evaluate their geomechanical characteristics, as follows: specific gravity (G_S) and water content (w), according to standards [9–11]; granulometry and specific surface (SS), according to the equipment CoulterLS200 procedure, and based on standard [12]; Atterberg limits and plastic index (PI) according to standard [13]; and compaction characteristics with Normal Proctor, according to standard [14].

3. Results and discussion

The granulometry curves are presented in Figure 1 and the geotechnical parameters are presented in Table 1.

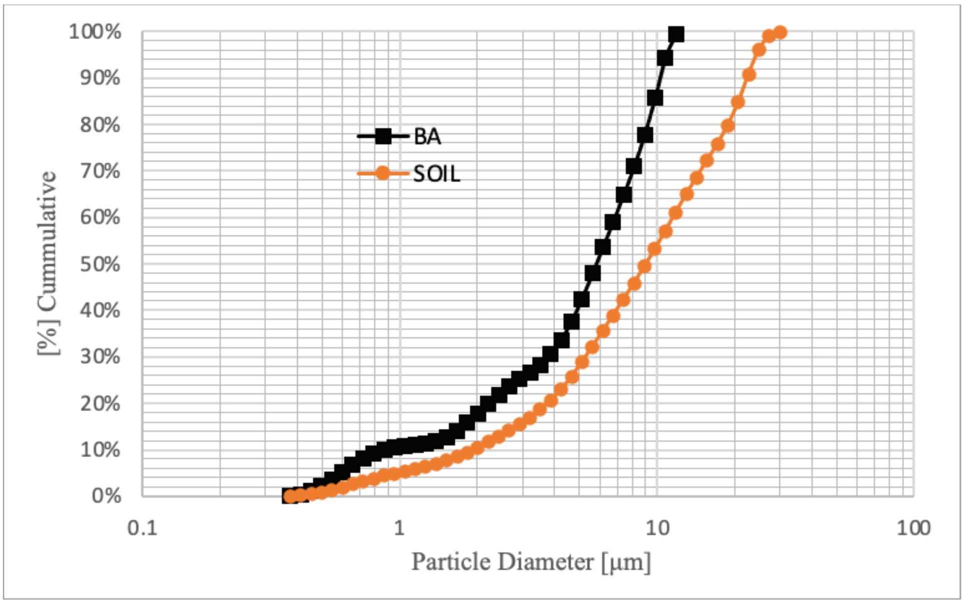

Figure 1: Particle size distribution of soil and BA.

Exposed geotechnical parameters in Table 1 have shown BA finer granulometry, non-liquid (NL), and non-plastic (NP) behavior, which could imply that their introduction into soils could reduce the mixture's plasticity, number of voids, and possibly their settlement. Also, a lower G_S value indicates weight-reduction property. Other parameters, such as mechanical and hydraulic values have yet to be investigated, although varied published studies, such as [15], have exposed BA successful introduction into residual compacted granite soil, resulting in lower soil plasticity and weight reduction while also increasing k value at higher BA rates. Thus, currently published results state BA feasibility for improving geotechnical parameters, indicating that these enhancements could be similar to the analyzed pine's BA, being required further investigation to confirm geomechanical parameters – k value, friction angle, and cohesion – and the above-mentioned important characteristics for successfully reinforcing soft soils and possibly application as liners. One possibility for BA valorization is its incorporation into the soil, based on percentages by mass, whether dry or wet and increasing the amounts of this residue in the mixtures, evaluating its characteristics and geotechnical performance analyzing above-mentioned parameters.

BA's literature [18] for hydraulic parameters found k values between 6 x 10^{-10}-1 x 10^{-9} m/s [15-16-17] meeting well the required 1 x 10^{-11}-1 x 10^{-9} m/s for a geological barrier at the base or top landfill's layer, additionally c' = 20–25 kPa and φ' = 30-45° found by [19-20] make possible soil's reinforcement while incorporating biomass ashes into soils.

TABLE 1: Geotechnical characterization for soil and BA.

	G_S (-)	W_L (%)	W_P(%)	PI (%)	W_{opt} (%)	$\rho_{d,opt}$ (g/cm^3)
Soil	2.7	38	34	4	20	1.9
BA	1.9	NL	NP	NP	26	1.2
[15]	2.3	35	25	10	20	1.6
[16]	2.5	88	NP	NP	24	1.6
[17]	1.7	41	25	16	80	1.7

4. Conclusions

Biomass ashes are a new focus of attention for clay substitutes in landfills, as studies are beginning to discover their physicochemical, mechanical, and hydraulic properties. Their characteristics and composition are highly variable and dependent on the plant's species, origin location, and collect, while combustion processes and used products/accessory materials, such as char, transform the original biomass into basically a new material. Some of the studied biomasses are bagasse ash, rice husk ash, and palm oil fuel ash, although there is a lack of research for soils reinforcement and liners application. This indicates the necessity of further investigating pines' BA into soils to test long-term performance, compaction, and strength characteristics. Primary results are optimistic and could indicate a solid path towards using this residue for the named applications, principally for weight-reduction due to lower G_s and $\rho_{d,opt}$, non-plastic behaviour, decreasing plasticity and filling properties caused by finer granulometry.

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References

[1] Vassilev SV, Baxter D, Andersen LK, Vassileva CG. An overview of the composition and application of biomass ash. Fuel. 2013;105:19–39. https://doi.org/10.1016/j.fuel.2012.10.001

[2] Loo S, Koppejan J. The handbook of biomass combustion and co-firing. Earthscan; Routledge, 2007.

[3] Salvo M, Rizzo S, Caldirola M et al. Biomass ash as supplementary cementitious material (SCM). Advances in Applied Ceramics. 2015;114(1):3-10. https://doi.org/10.1179/1743676115Y.0000000043

[4] Obernberger I, Supancic K. Possibilities of ash utilisation from biomass combustion plants. Paper presented at: Proceedings of the 17th European Biomass Conference; 2009 29 Jun – 3 Jul; Hamburg, Germany.

[5] Rubinos DA, Spagnoli G. Utilization of waste products as alternative landfill liner and cover materials – A critical review. Critical Reviews in Environmental Science and Technology 2018;48(4):376–438. https://doi.org/10.1080/10643389.2018.1461495

[6] Vassilev SV, Baxter D, Andersen LK, Vassileva CG. An overview of the composition and application of biomass ash: Part 2. Potential utilisation, technological and ecological advantages and challenges. Fuel. 2013;105:19–39. https://doi.org/10.1016/j.fuel.2012.10.001

[7] Galvín AP, López-Uceda A, Cabrera M, Rosales J, Ayuso J. Stabilization of expansive soils with biomass bottom ashes for an eco-efficient construction. Environmental Science and Pollution Research. 2020; 28:24441-24454. https://doi.org/10.1007/s11356-020-08768-3

[8] Cabrera M, Rosales J, Ayuso J, Estaire J, Agrela F. Feasibility of using olive biomass bottom ash in the sub-bases of roads and rural paths. Construction Building Materials 2018;181:266–275. https://doi.org/10.1016/j.conbuildmat.2018.06.035

[9] ISO 17892-1. Geotechnical investigation and testing - Laboratory testing of soil - Part 1: Determination of water content; 2014.

[10] ISO 17892-2. Geotechnical investigation and testing - Laboratory testing of soil - Part 2: Determination of bulk density; 2014.

[11] ISO 17892-3. Geotechnical investigation and testing - Laboratory testing of soil - Part 3: Determination of particle density; 2015.

[12] ISO 17892-4. Geotechnical investigation and testing - Laboratory testing of soil - Part 4: Determination of particle size distribution; 2016.

[13] ISO 17892-12. Geotechnical investigation and testing - Laboratory testing of soil - Part 12: Determination of liquid and plastic limits; 2018.

[14] BS 1377-4. Methods of test for soils for civil engineering purposes - Part 4: Compaction-related tests; UK: British Standards Institution; 1990.

[15] Osinubi KJ, Eberemu AO. Hydraulic conductivity of compacted lateritic soil treated with bagasse ash. International Journal of Environmental Waste Management. 2013;11(1):38–58. https://doi.org/10.1504/IJEWM.2013.050522

[16] Daud NN, Muhammed AS, Kundiri AM. Hydraulic conductivity of compacted granite residual soil mixed with palm oil fuel ash in landfill application. Geotechnical and Geological Engineering. 2017;35(5):1967-1976. https://doi.org/10.1007/s10706-017-0220-1

[17] Bajwa TM, Fall M. Mechanical characteristics and behavior of compost-based landfill cover. Paper presented at: Proceedings of 2011 Pan-AM CGS Geotechnical Conference; 2011 Oct 2– 6; Toronto, Canada.

[18] Marchiori L, Alburquerque A. Critical review of industrial solid wastes as barrier material for impermeabilization of storage waste facilities. Paper presented at: Proceedings of 5^{th} Symposium on Urban Mining and Circular Economy – SUM2020; 2020 Nov 18-20; Sardinia, Italy.

[19] Kuokkanen T, Nurmesniemi H, Pöykiö R, Kujala K, Kaakine J, Kuokkanen M. Chemical and leaching properties of paper mill sludge. Chemical Speciation Bioavailability 2008;20(2):111-122. https://doi.org/10.3184/095422908X324480

[20] Slim GI, Morales M, Alrumaidhin L et al. Optimization of polymer-amended fly ash and paper pulp millings mixture for alternative landfill liner.Procedia engineering. International Conference on Sustainable Design, Engineering and Construction. 2016 May 18-20; Tempe, Arizona, USA ; 145:312-318. https://doi.org/10.1016/j.proeng.2016.04.079