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TECHNICAL AND ENVIRONMENTAL ASSESSMENT FOR SOIL STABILIZATION USING COAL ASH

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In most Latin American countries, low-volume roads are composed of unpaved roads; this is considered a problem of economic, social and environmental interest. There are different stabilization alternatives for this type of roads with traditional materials, i.e., Portland cement (OPC) and lime (L), both of which have a high environmental impact due to anthropogenic CO_2 emissions. This paper presents the results of the environmental assessment of an industrial residue Coal Ash (CA) with pozzolanic characteristics. The residue was alkaline activated with $Ca(OH)_2$ from commercial lime (L). The binary system (CA+L) is called (CLM) and forms a material with cementing properties, and when it is mixed with soil, it increases the capacity to support loads. The CLM as a soil stabilizer is proposed along with the modification of some construction processes associated with lime technology and Portland cement. Finally, a technical and environmental comparison is made for conventional stabilizers and the binary system CLM. The results showed that stabilization of a silty soil with CLM can achieve a reduction of 58% and 75% in CO_2 emissions when compared with L and OPC, respectively.

Keywords: Sustainability, Pozzolans, CO_2 emissions, Latin America.

1 INTRODUCTION

Soil characteristics such as resistance and durability can be improved through a stabilization process (Hossain and Mol 2011, Zhang *et al.* 2015). The energy industry, metal manufacturing and other similar industries generate large quantities of industrial by-products such as those obtained from coal combustion (García-Lodeiro *et al.* 2007) blast furnace slag (Provis 2015), biomass ash (Zelaya *et al.* 2017) and construction and demolition wastes that cause a high degree of pollution on landfills (Chowdhury *et al*. 2010). These non-conventional materials may in some cases be combined with highly alkaline materials, such as lime, and create materials with cementitious characteristics "pozzolanic" (Duxson *et al.* 2007) or alkali such as NaOH (Hoyos-Montilla *et al*. 2018) contributing to sustainable development in the construction sector, partially replacing OPC (Zhang 2015) and other calcium-based soil stabilizers.

Currently, there are not universal specifications to address the environmental impacts of the use and application of by-products in road construction. To meet this challenge, the use of methodologies to quantify impacts in different stages of the life cycle is proposed, contributing to the reduction of gas emissions into the atmosphere compared to traditional materials; OPC industry being the second largest producer of greenhouse gases and occupying the third place (after aluminum and steel) in energy consumption (Rashad 2014). According to reports, the production of 1.0 metric ton of OPC releases between 0.73 - 0.99 metric tons of gaseous carbon dioxide CO_2(g) (Hasanbeigi *et al.* 2012). The calcination processes of limestone $CaCO_3$, dolomite Mg_2CO_3 and the impurities thereof can theoretically represent 0.785 CO_2(g) per tons in the production of calcium oxide and 1.092 CO_2(g) in the production of magnesium oxide. Emissions associated with energy use depend on the efficiency of the process, the use of fuel and the emissions that are indirectly produced by electricity generation (IPCC 2014). Colombia has a limited road network when compared to other Latin American developing countries. Its tertiary road network was estimated at more than 142,284 km and, despite information gaps, only 18.74% is considered to be in good conditions, while 40.13% is in poor conditions and the remaining 41.13% is under regular conditions (DNP 2016).

2 METHODOLOGY

2.1 Materials

Fine granular soil of high plasticity from a region of western Colombia was used to improve its bearing capacity, see Table 1. The soil was dosed with two stabilizers of conventional use: Common Purpose Ordinary Portland Cement (OPC) and commercially quicklime (L), and an alternative stabilizer composed of a binary mixture of calcium hydroxide and coal ash (CLM). The stabilizing residue is composed of commercial grade slaked lime and residue from coal combustion in Medellin- Colombia, with 25% and 75% of mass, respectively.

Table 1. Characteristics of natural soil.

ASTM D 4318-10			**ASTM D 854-10**		**ASTM D 1557-10**	**ASTM D 2487-11**	**ASTM M 145-91**
LL %	PL %	PI %	Specific gravity	Dry-density kN/m3	Opt. Moisture content %	Classification USC	Classification ASSHTO
66	48	17	2.71	14.65	26	MH	A-7-5

The chemical composition was obtained by means of XRF on a Phillips PW 2400 X-ray fluorescence spectrometer. The test was carried out on pressed powder ash and soil. See Table 2.

Table 2. FRX of waste (%) in mass.

Material	***SiO₂***	***Al₂O₃***	***Fe₂O₃***	***CaO***	***MgO***	***Na₂O***	***SO₃***	***TiO₂***	**loss on ignition 110°C to 1000°C**
Coal Ash	41.9	31.1	6.4	7.4	1.5	5.6	1.1	1.3	2.1
Silt	41.2	33.6	9.2	0.1	0.4	0.1	0.1	1.4	13.6
Lime	1.5	1.0	0.1	65.6	0.1	0.1	0.3	1.1	30.3

The mineralogical content of the materials was determined by X-Ray Diffraction (XRD) on a PANalytical X´Pert MPD PRO equipment, between 5° to 60° with a step size of 0.02° and counting time of 56 seconds. A CuKα1 (λ=1.54059 Å) source was used. Figure 1-a shows the diffractograms for the coal ash and soil evaluated. The particle-size distribution (PSD) of ash and soil are shown in

Figure 1 (b) was measured in Master Sizer 3000 equipment. A D80 of 49.1 μm for Coal Ash and 40.89 μm for soil is presented. During the soil mechanical stabilization, every product: OPC, L, and CLM, were incorporated in mass with a dosage ranging from 0% to 24%.

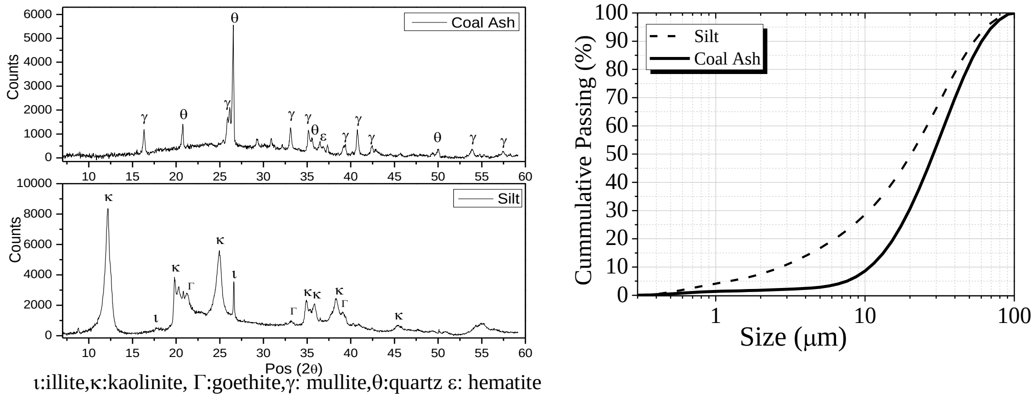

Figure 1. (a) Mineralogical phases of silt and coal ash (b) Particle size distribution of silt and coal ash.

2.2 Methods

2.2.1 *Soil stabilization*

Modified Proctor trials were performed on OPC, L and CLM stabilizers, considering standard Invias 142 de (INVIAS 2012), which is derived from ASTM D 1557-09. The results show that, in all cases, the increase of the stabilizer percentage also increases water demand, being more noticeable for dosages above 14%. See Figure 2.

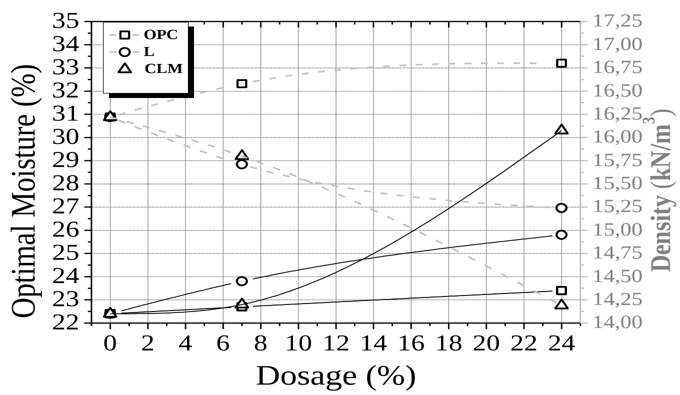

Figure 2. Modified Proctor for stabilized soil.

2.2.2 Emissions quantification

The CO_2 emissions quantification is performed in three stages: stage one, take theoretical values from a stoichiometric balance, see Eq. (1) and Eq. (2), the theoretical CO_2(g) emissions can be determined obtaining one metric ton of Lime (L) and Ordinary Portland Cement (OPC).

$$1C_a\,CO_3 \xrightarrow{\Delta \approx (950^\circ C} 1C_a\,O^* + 1CO_2 \tag{1}$$

$$Ca\,CO_3 + 1Al_2O_3\,SiO_2 + Fe_2O_3 \xrightarrow{\Delta \approx (1450^\circ C)} \frac{C3S + C3A + C4AF}{Clinker^*} \tag{2}$$

According to Eq. (1), the carbonate contains 56.03% CaO and 43.97% $CO_2(g)$ by weight from which an estimated 0.44 tons of $CO_2(g)$ is obtained. For the OPC case, a ton of clinker was considered, it contains 0.65 tons of CaO coming from $CaCO_3$ (IPCC 2014). The amount of $CaCO_3$ needed to obtain 0.65 tons of CaO is equivalent with 1.1601 tons of $CaCO_3$, therefore, the amount of $CO_2(g)$ released by calcination of $CaCO_3$ in the process of producing a ton of Clinker is 0.5101 tons, see Eq. (2). Stage two includes the values reported in the literature to generate the brute product and established that the CO_2 emissions for obtaining these products can vary as a function of the raw material extraction and their purity, considering a carbon footprint above the theoretical one, this can vary depending on the source. Table 3 based on theoretical sources presents the CO_2 emissions in kilograms per ton of cement and lime respectively, without including the emissions by energy or fossil fuel needed to make the burnt. For the lime, the dissociation of limestone produces up to 0.75 tons of CO_2 per ton of quicklime. In stage three, we used reports like IPCC (2014) when the fossil fuel is included from the cement and lime production processes, and the emissions oscillate between 0.785 and 1.092 CO_2 metric tons for lime (L), and 0.730 to 0.935 CO_2 metric tons for Ordinary Portland Cement (OPC).

Table 3. World cement production and CO_2 emissions in 2015.

Region	**North America**	**CIS**	**Eur.**	**Asia+ oceania****	**Middle East**	**Africa**	**China Korea Japan**	**Brazil**	**South America***	**Central America**	**India**
Emission kg CO_2/t Gross	1000	910	815	805	800	790	780	780	760	750	715
Emission kg CO_2/t Gross Lime*** (For the all-region 750)											

Notes: specific emission does not include emissions from the use of electricity. *Excl. Brazil, **Excl. CN, India, CIS, and Japan. Source: Adapted from GNR 2015 ***(CSC 2018, European Commission 2001).

3 RESULTS AND DISCUSSIONS

3.1 Effect of the Stabilizer on the Soil

In all cases, with a gradual increase of the stabilizers in the soil, an increase of the mechanical stabilization occurred. See Figure 3. When defining the optimum value of 9.0% for the stabilizer L, it was found that to obtain the same conditions of compression strength with OPC and CLM, additions of approximately 17% and 15% are required.

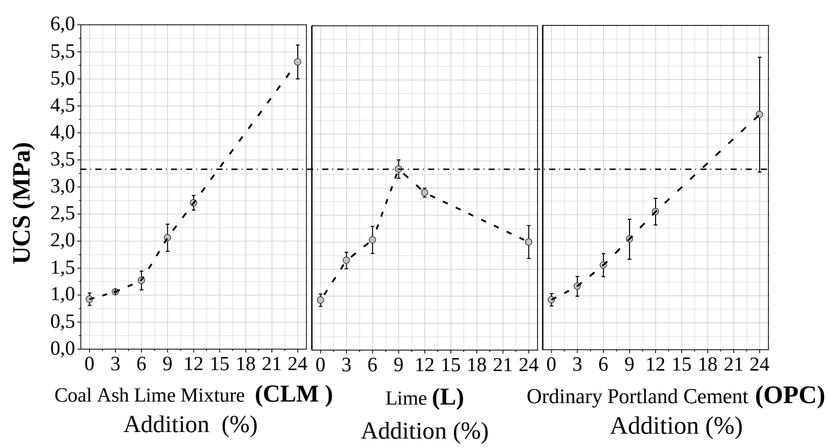

Figure 3. UCS for different dosages of the stabilizer.

3.2 Emissions Quantification

Table 4 presents the average values for CO_2(g) emissions for stabilizers OPC, L and CLM determined. The stabilizers OPC, L, and CLM environmental assessment was addressed using 3.3 MPa in the soil's bearing capacity, corresponding with a UCS value defined from the maximum obtained experimentally for L (see Figure 1). Therefore, the silty soil stabilization A-7-5 requires dosing of 9% L, 17% OPC, and 15% CLM to obtain the same mechanical performance.

Table 4. CO_2 emissions.

	Stoichiometry emissions			**Gross emissions (extraction & purity)**			**Gross + energy & fuel emisions**		
	Lime	*Cement*	*Coal Ash/lime*	*Lime*	*Cement*	*Coal Ash/lime*	*Lime*	*Cement*	*Coal Ash/lime*
	100%	100%	75%/25%	100%	100%	75%/25%	100%	100%	75%/25%
Emission Max	-	-	-	-	0.733	-	1.092	0.73	0.273
Emission Min	-	-	-	-	0.549	-	0.785	0.935	0.196
Average	0.44	0.51	0.11	0.75	0.638	0.188	0.939	0.833	0.256
Deviation	-	-	-	-	0.062	-	0.217	0.145	0.054
	Stabilizer emissions for soil CO_2 /tone								
	Lime	*Cement*	*Coal Ash/lime*	*Lime*	*Cement*	*Coal Ash/lime*	*Lime*	*Cement*	*Coal Ash/lime*
	9%	17%	14%	9%	17%	14%	9%	17%	14%
Average	0.04	0.087	0.015	0.07	0.108	0.026	0.084	0.142	0.036
Deviation	-	-	-	-	0.011	-	0.02	0.025	0.008

According to the stoichiometric analysis, the emissions generated by the use of CLM are 61.11% and 82.24% lower than when using L and OPC, respectively. Similarly, the analysis considering industrial production indicated a reduction of 61.11% and 75.80% with respect to L and OPC. When including the energy processes for the use of fuel or energy for burning, the decrease was around the order of 57.53% and 74.66% with respect to L and OPC. The results show that under conditions of productivity in stage three the system with the highest CO_2 emissions is represented by OPC, followed by L and finally the CLM. See Figure 4.

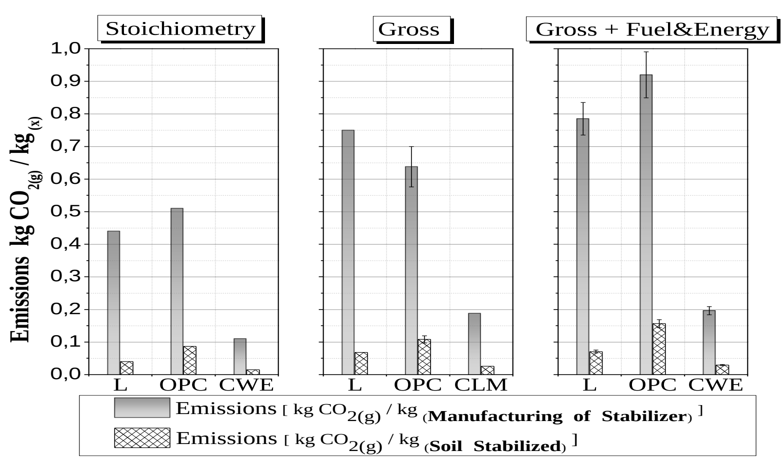

Figure 4. CO_2 emissions for different soil stabilizers.

4 CONCLUSIONS

It is possible to achieve improvements in the bearing capacity of the Lime clayish soil at 7 days of curing by incorporating stabilizers such as OPC, L, and CLM, in mass percentages of 17%, 9%, and 15%, respectively, achieving increases of UCS of an order of 366% with respect to the soil without a stabilizing product. Independently of the three stages evaluated in the environmental aspect the results obtained show how the use of industrial waste with coal ash lime (CLM), when applied to soil stabilization, can decrease the CO_2 emissions in constructive processes based on L and OPC for soils stabilization. Thus, they obtained the closest conditions to the productive chain decreases of 75% and 57% with respect to OPC and L in stage 3. OPC and L are the ones causing more damage, including the extraction process as it entails: fuel consumption, the use of machinery, transportation of the material, among others. This reveals that the use of alternative materials in the construction sector may reduce the impacts on human health, the soil and other ecosystems.

Acknowledgments

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