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Effects Of Ground Glass Powder In Silty Soil Stabilization

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ABSTRACT

The article presents the stabilization of soil with glass waste and Portland cement. For this, sedimentary soil originating from the Guabirotuba Formation (Curitiba, Brazil) was used, adding three cement contents in relation to the dry mass of the soil: 3, 6 and 9%. Additionally, 15% of powdered glass residue was the content chosen to add to the soil-cement mixture. The samples were cured in times of 7, 28 and 90 days and submitted to simple compression tests (q_u). The results showed that adding the following factors increased the quality of the soil-cement-glass mixtures: cement content, molding dry specific weight and curing time. On the other hand, all strengths are controlled by the porosity/cement ratio (η/C_{iv}) for each curing time. Finally, equations for dosage and estimation of q_u were proposed using the η/C_{iv} index adjusted to an exponent of 0.20.

Keywords: Powdered glass waste; Soil stabilization; simple compression.

1. INTRODUCTION

Recycling powdered glass waste represents a significant problem for urban areas in developed and developing countries (Turgut 2013). Using recycled powdered glass waste in the production of geopolymers is a new technology considered in construction projects, especially in concrete. However, it has been little investigated for soil stabilization. Arulrajah et al. (2017) analyzed recycled glass (RG) as a supplemental filler in spent coffee bean geopolymers (GC) using fly ash and slag.

Fly ash and slag at 30% by weight were used as precursors to induce geopolymerization in RG-CG mixtures. RG was added to geopolymer mixtures in proportions of 25%, 50% and 75% by weight. The authors concluded that a liquid alkaline ratio of 70% Na2SiO3 and 30% NaOH was used to induce geopolymerization in the obtained mixtures UCS (unconfined compressive strength) with a value of 10 MPa in 28-d of curing, and the RG- CG, FA and Slag are alternative building material and indeed promote a sustainable future for the construction industry. Pourabbas Bilondi et al. (2018a) investigated the feasibility of using a geopolymer based on recycled glass powder (RGP) to improve the mechanical behavior of clayey soils. They used a low plasticity clayey soil mixed with various percentages (0-25% by weight) of RGP and sodium hydroxide as an alkaline activator. The alkaline activator was prepared with a different concentration of NaOH (1, 2, 3, 4, 5, 6, 7 and 8 M, M = Molar) and then added to the soil-RGP mixture. The authors studied the influences of curing temperatures of 25 and 70°C and various curing periods (7, 28 and 91 days) in UCS. They concluded that the UCS values of all specimens stabilized with a geopolymer and NaOH concentrations were increased compared to the unstabilized soil sample. The UCS values were higher when the specimens were cured for 91 days and the results confirmed that a rich source of silica (in an amorphous phase), such as glass powder, was necessary for better soil stabilization and formation of gel-geopolymer. Recently Pourabbas Bilondi et al. (2018b) employed calcium carbide residues (CCR) as an alkaline activator for clay-RPG mixtures. The effect of different factors such as CCR content, glass powder content (0-25%), initial synthesis temperature and curing time was investigated. The UCS of CCR-RGP samples improved significantly by increasing the CCR and RGP content to the optimal values of 7% and 15%, respectively. The authors also concluded that the UCS values of the geopolymeric specimens increased with increasing the initial synthesis temperature from 25°C to 70°C for both curing times (7 and 28 days). However, the effect of the high initial temperature of synthesis on the UCS of the specimens was less effective for 28 days of curing.

In agreement with the above, the use of cement together with recycled glass powder was not investigated in the stabilization of soils of the Guabirotuba Formation. Thus, this study evaluates the potential of combining two binders: recycled glass powder (in powder form) and Portland cement of initial strength, as a possible geopolymer partially replacing Portland cement to improve the behavior of a sedimentary soil of the Guabirotuba Formation.

2. EXPERIMENTAL PROGRAM

The experimental program was divided into two stages: the first was to carry out the characterization tests of the soil, glass powder residue and Portland cement: soil and glass powder granulometry according to the American standard ASTM D2487 (ASTM, 2011), soil Atterberg limits according to Brazilian standards NBR 7180 (ABNT, 2016) and NBR 6459 (ABNT, 2016), the actual specific mass of soil grains according to ASTM D854 (ASTM, 2014) and actual mass specification of cement grains and powdered glass according to the Brazilian standard NBR 16605 (ABNT, 2017); and the second stage consisted of molding, curing and breaking the soil-glass-cement specimens submitted to simple compression tests at different curing times.

2.1 Materials

The present research used four materials: soil, high initial strength cement, powdered glass residue, and water.

The soil used is a soil characteristic of the metropolitan region of Curitiba belonging to the Guabirotuba Formation. The soil is mainly composed of sedimentary silt, yellow in color, and was collected on a road slope 2.5 meters deep from the natural ground level in the municipality of São José dos Pinhais (southeast of Curitiba). Table 1 presents the soil properties. It is noted [according to the Brazilian standard NBR 6502 (ABNT, 1995)] that 60% of the particles are silt (0.002 mm < diameter <0.06 mm), 25% are sand and a small portion of 5% clay was also found during the sedimentation test. According to the Unified Soil Classification System (SUCS), the soil is classified as elastic sandy silt (MH) with an average plasticity index of 14.86%.

Table 1. Physical properties of soils and ground glass

Properties	Soil	Ground glass
Liquid Limit, %.	50.82	-
Plasticity Limit, %.	35.96	-
Plasticity index, %	14.86	-
Actual grain density	2.62	2,40
Coarse sand (0.6 mm< diameter<2 mm), %.	5	-

Medium sand (0.2 mm< diameter <0.6 mm), %.	12	-
Fine sand (0.06 mm< diameter <0.2 mm), %.	18	-
Silt (0.002 mm < diameter <0.06 mm), %.	60	95
Clay (diameter < 0.002 mm), %.	5	5
Effective diameter (D_{10}), mm	0.003	0,0035
Average diameter (D_{50}), mm	0.038	0,015
Coefficient of uniformity (C_u)	12.67	5,43
Coefficient of curvature (C_c)	0.88	1,09
Classification (SUCS)	MH	ML
Color	Yellow	Branco

The cement was of high initial strength, with a high percentage of calcium oxide (CaO). The cement density was calculated to be 3.11. Table 2 presents the properties of the cement used in this study.

Table 2. Physicochemical properties of cement

Properties	Value
% MgO	4.11
% SO_3	2.99
% CaO	60.73
%Al_2O_3	4.38
%Fe_2O_3	2.83
%S_iO_2	19.9
% Insoluble residue	0.77
Compressive strength for 7 days (MPa)	42
Compressive strength for 28 days (MPa)	53
% Fineness	0.04
Gs_C	3.11

The powdered glass residue was collected in a glass shop in Curitiba and dried in an oven at 70°C for 42 hours. The residue was subjected to milling using a ball mill for 4 hours. Finally, the ground product was sieved using a diameter of 0.075 mm, thus obtaining the powdered product. The powder residue was characterized, and the results are shown in Table 1. In addition, mineralogical tests were carried out, finding an amorphous formation with 98% silica content. Finally, the glass powder was classified as silt (ML) with a density of 2.40 g/cm^3.

Distilled water was used to characterize materials, perform compaction tests, prepare compression-tensile-durability test specimens and saturation the samples, thus avoiding unwanted reactions.

2.2 Cement percentages, glass residue and curing times.

Three cement contents were used in relation to dry soil mass: 3, 6 and 9%, according to local experience in stabilizing the soils of the Guabirotuba Formation with cement (Moreira et al. 2019). Additionally, 15% of glass was chosen relative to the soil's dry mass. Finally, the simple compressive strength of the compacted mixtures was evaluated after 7, 28 and 90 days of curing.

2.3 Molding points

For this research, 3 specific dry molding weights were chosen: 13.50 kN/m^3 (A1), 14.50 kN/m^3 (A2) and 15.50 kN/m^3 (A3). A battery of tests was carried out previously, compacting specimens at point A2, adding 6% cement, 15% glass, curing in 28 days and varying the moisture content from 20% to 38%. It was found that 26% moisture is the value where the mixtures obtain the highest value at simple compression, as seen in Figure 1. Thus, all samples were compacted with 26% moisture content, varying the specific molding weights and cement percentages.

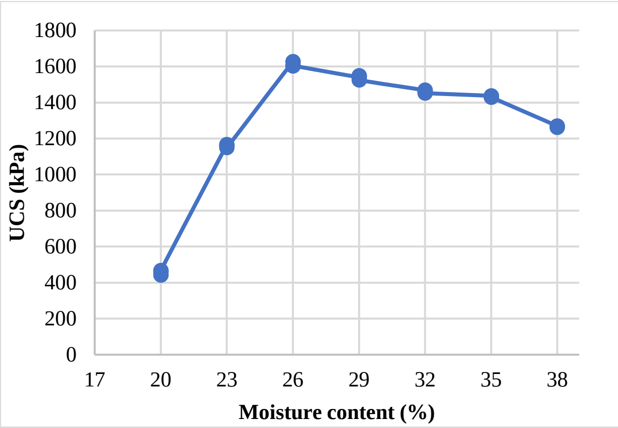

Figure 1. Influence of moisture content on the simple compressive strength of soil-glass-cement mixtures

2.4 Simple compressive strength tests

Specimens of 50 mm and 100 mm in diameter and height were molded, respectively. First, the soil was entirely dried in an oven and added the amount of cement and powdered glass residue. The dry mixture of soil+cement+glass was carried out until homogeneous. The amount of water necessary to reach 26% moisture of the mixture was weighed and added. A second homogenization was performed by hand until uniform. The amount of mixing required to achieve the molding densities was calculated. Next step, the specimens were compacted using 3 layers using stainless steel molds and a manual hydraulic press with a capacity of 10 ton. Finally, the specimens were extracted from the molds and were weighed and measured. The samples had to respect the following maximum errors to be used in the simple compression tests: dimensions of the samples with a diameter of ±0.5 mm and a height of ±1 mm, specific dry weight γ_d) of ±1% and moisture content (ω) of ±0.5%. For each molding point and cement content, 3 specimens were molded.

An automatic press with a capacity of 10 kN was used to carry out the simple compression tests. The tests were carried out with an automated system, measuring mainly the applied force and the deformation with a sensitivity of 0.01 mm, with a test speed of 1.10 mm/min. The simple compression test procedures followed the Brazilian standard NBR 5739 (ABNT, 2018).

3. RESULTS AND DISCUSSIONS

Figures 2-4 present the results of the influence of cement content on the simple compressive strength of compacted soil-glass waste mixtures for 7, 28 and 90 days of curing, respectively. There is an increase in the mechanical strength of the mixtures when the amount of cement powder is increased. It is also verified that the growth of UCS related to the cement content occurs linearly. On the other hand, the UCS strength also increases when the dry molding density is increased (from A1 to A3). So. molding points A1, A2, and A3 show how the mechanical strength increases linearly regardless of the curing time.

Comparing Figures 2-4, strength increases with curing time. In 7 days, the maximum strength obtained is 2.5 MPa, while in 90 days of curing, the strength is 10.5 MPa, an increase of 320%. Additionally, comparing mold points from 7 days to 90 days, the increases average 300%.

The results of Figures 2-4 can be expressed in terms of compaction and amount of cement using the porosity/cement index (η/Civ). Where η represents the voids and Civ represents the unit volume of cement. Thus, Figure 5 shows the results of UCS-η/Civ for the compacted mixtures and equations that potentially control UCS for 7 (Eq. 1), 28 (Eq. 2) and 90 days of curing (Eq. 3), given by the following expressions:

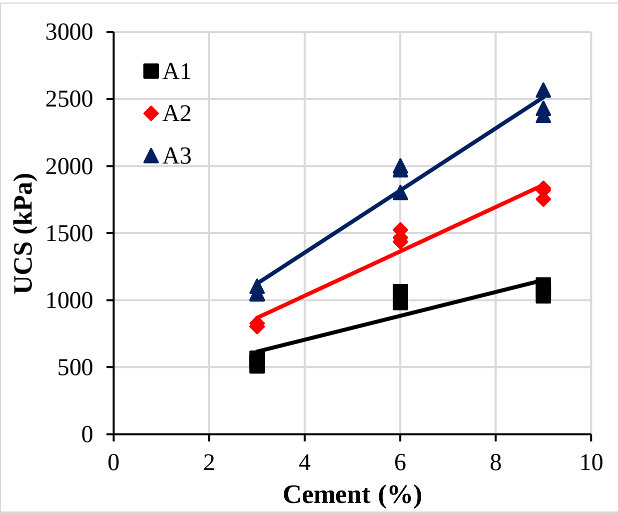

Figure 2. Influence of cement content on UCS strength of soil-glass mixtures for 7 days of curing

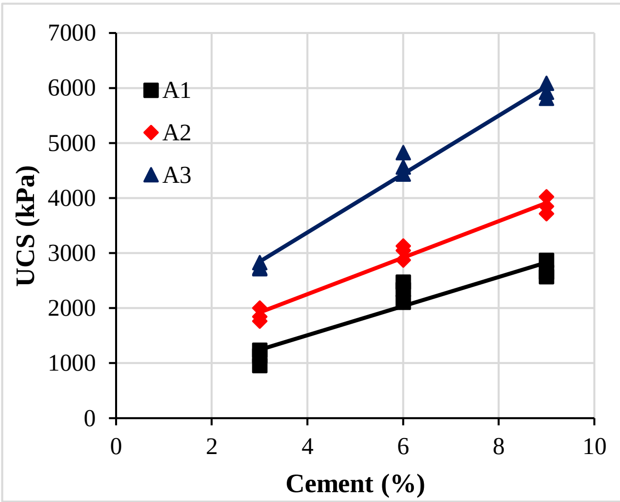

Figure 3. Influence of cement content on UCS strength of soil-glass mixtures for 28 days of curing

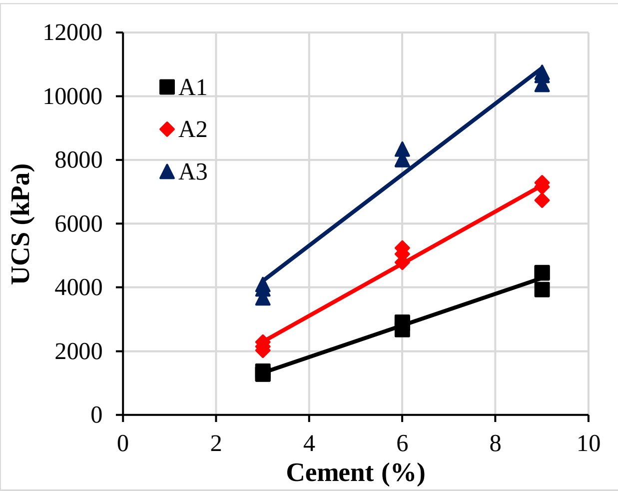

Figure 4. Influence of cement content on UCS strength of soil-glass mixtures for 90 days of curing

$$q_u=1565{,}4\times10^6\left[\frac{\eta}{(C_{iv})^{0{,}20}}\right]^{-3{,}87}\ (R^2=0{,}98) \quad (1)$$

$$q_u=3644{,}8\times10^6\left[\frac{\eta}{(C_{iv})^{0{,}20}}\right]^{-3{,}87}\ (R^2=0{,}99) \quad (2)$$

$$q_u=6102\times10^6\left[\frac{\eta}{(C_{iv})^{0{,}20}}\right]^{-3{,}87}\ (R^2=0{,}94) \quad (3)$$

To make UCS-η/C_{iv} compatible, the C_{iv} values had to adjust to an exponent of 0.20. This exponent added the coefficient values of determination of the equations and depended on the type of soil.

Figure 5 shows how UCS strength potentially increases with increasing cure time. The decrease in η/Civ adds the values of q_u and vice versa due to the decrease in voids and increase in cement and glass powder volume. The increase of q_u with the addition of glass can be compared with the soil-cement strength. For example, for 28 days of curing, soil-cement mixtures with 3% cement, compacted at a density of 14.5 kN/m3, obtain a UCS=500 kPa. By adding 15% glass, the strength increases to 2000 kPa. The same goes for the other mixtures. When adding the glass powder, the pozzolanic reactions increase, causing the formation of higher percentages of C-S-H. Thus, the improvement of the bond between the soil particles by the geopolymeric gel of the cement with the glass powder has been the main factor for the increase in the resistance of the specimens. This factor was responsible for the increase in strength of geopolymer materials in previous studies carried out by Pourabbas Bilondi et al. (2018a, 2018b).

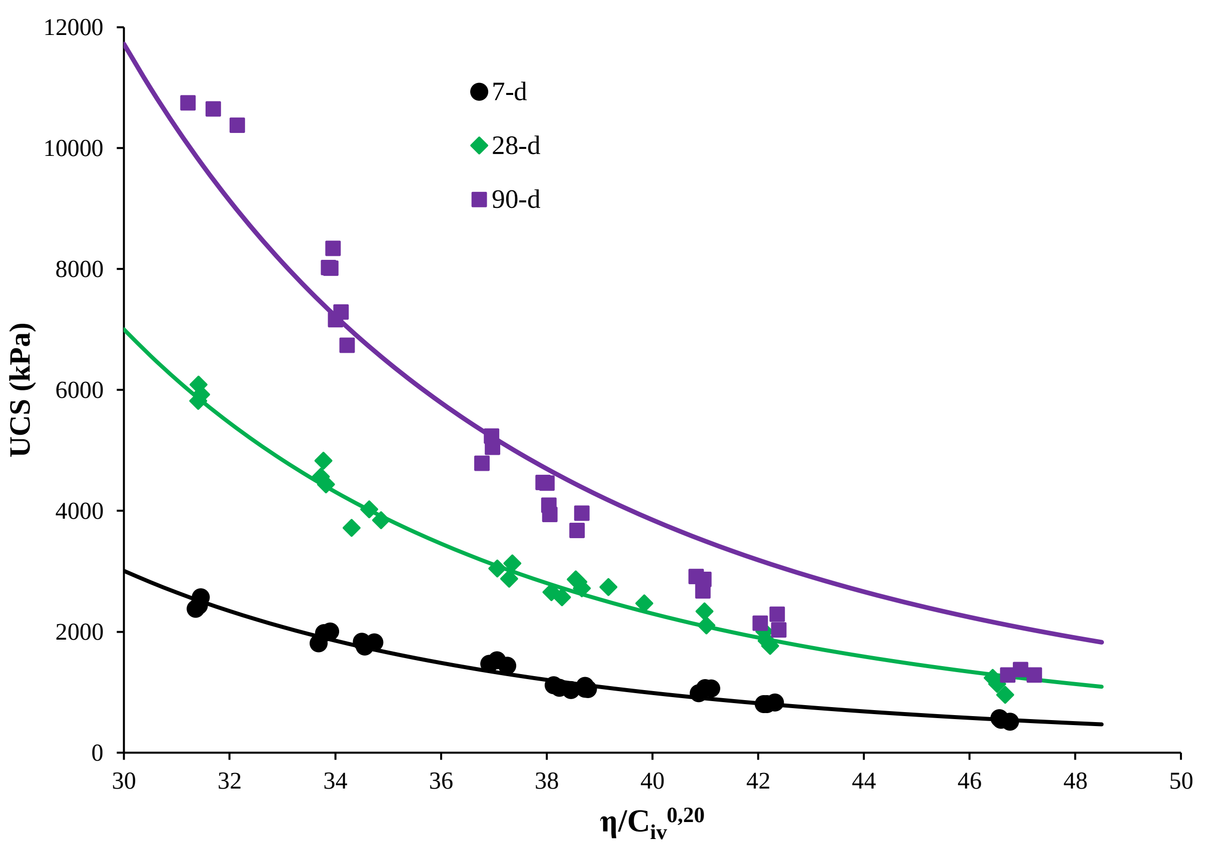

Figure 5. Influence of the porosity/cement index (adjusted with 0.20) on the simple compressive strength of soil-glass mixtures considering curing times of 7, 28 and 90 days.

4. CONCLUSION

This work presented the mechanical behavior of soil-cement-glass mixtures. The porosity/cement index was used to describe the growth of q_u. According to the results, the following conclusions can be attached:

– The simple compressive strength of the specimens of soil-cement mixtures increased with the addition of 15% glass powder content and the dry molding density. Furthermore, a linear trend was the best way to represent the growth of q_u with the variation of cement content from 3 to 9%. On the other hand, the decrease in the porosity of the samples also increased q_u.

– The porosity/volumetric cement content ratio (η/C_{iv}) proved to be an efficient parameter for studying soil-cement-glass powder mixtures' mechanical behavior. An exponent of 0.20 over the volumetric cement content ($\eta/C_{iv}^{0.20}$) provided a better fit of the samples tested under simple compression.

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