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Application of Glass and Fan Shells to a Clay Soil to Increase its Mechanical Properties

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Abstract. Improving the mechanical properties of a clayey soil is one of the best options to avoid future structural failures in buildings and is cheaper than replacing all the material. Therefore, this article proposes the use of recycled glass and fan shells as reinforcement materials. This article presents an experimental study to evaluate the mechanical properties of a pure and mixed soil. The clay soil was mixed with 7% of glass (PV) and with 3%, 6%, 10%, 12% and 15% of Fan Shells (PCA) duly crushed and passed through sieve #100. Tests of sieve granulometry, sedimentation granulometry, Atterberg limits, modified proctor and drained consolidated direct cut were performed. This allowed comparing all the data obtained and defining the optimal percentage of the mixture in which the clay improves its mechanical properties. According to the tests carried out, the proportion that has 7% glass and 6% Fan Shells has better results because there is an improvement in its dry density from 1,784 g / cm3 to 1,847 g / cm3, its moisture content increases from 9.4% to 12.1%. In addition, its friction angle improves from 28.9 ° to 32 ° and cohesion from 0.05 kg / cm2 to 0.1 kg / cm2. These results verify that the properties of the clay soil are improved.

1. Introduction

Clayey soils turn out to be one of the problems with the highest incidence in construction, because the increases in volume and the mechanical properties of this land where it is built are not announced in a uniform way, on the contrary, they cause growth in different areas and at the moment of contracting they produce settlements, which can severely damage the structures.

In Peru there are several areas with clay soil problems, and we refer to the province of Talara that presents large tracts of land with the presence of this soil and this adds to the lack of alternatives to control the expansive behaviour and low resistance of the mechanical properties that this soil presents in buildings.

Building on these clayey soils, which by their nature have a low bearing capacity, means that the requirements necessary to carry out civil works projects are not met. This implies an increase in costs to try to stabilize these problematic soils with different alternatives.

Geotechnical engineering offers solutions for various problems that occur with clayey soils such as pile construction and soil improvement. In the improvement alternative, there are several

investigations that present the technique of stabilization and improvement of mechanical properties with the application of mollusk valves and crushed glass, as evidenced by their results:
D. Koteswara Rao [1] did his research in India testing a soil mixture with mollusk valves and ferric chloride. The proportion of the mollusc shells was from 0% to 15% and the Ferric Chloride was from 0.5% to 2.5%. Atterberg limits, specific gravity, compaction and CBR tests were performed. The results showed improvements in the mechanical behaviour of the clay soil with 10% of mollusk valves and 1.5% of ferric chloride.

Maheshwari G [2] carried out an investigation evaluating the effect of mollusk shells that are naturally available materials on the coasts of the sea and bitumen emulsions that act as a binder between the clayey soil particles, which prevent the entry of water into the soil. Uniaxial compression and CBR tests were performed. With a 16% addition of mollusk shell powder, it significantly reduces its plasticity indexes and the CBR values of the soil samples increased considerably.

Al-Hassnawi [3], carried out a study with the intention of improving the plasticity, support, consolidation and cut resistance of clay when interacting with glass. The residual glass was used as an additive material that passes through the # 200 sieve in percentages of 3, 5, 7 and 9%. Tests of consistency limits, unconfined compression and CBR were performed. It was concluded that the additive had a positive impact on the soil and had improved properties. The liquid limit, the plastic limit and the plasticity index decreased with a 7% increase in glass powder.

H. Canakci [4], did a study with the intention of observing improvements of the clayey soil due to the addition of residues of glass powder of soda and lime (WSLGP). The soda lime glasses were crushed and sieved through the # 200 mesh (75 μm) and were also mixed with clay at 3%, 6%, 9% and 12%. The strength and consistency test were carried out on the mixed samples after curing. The test results indicated that the addition of 12% WSLGP to the clay has a significant effect on the strength and consistency properties of the clay.

In all these previous investigations positive results were seen such as the improvement of the plasticity index, the capacity to support the load, an increase in maximum dry density and an increase in CBR. In order to solve this problem, in this research, stabilization using two external agents such as mollusk shells (PCA) and crushed glass (PV) is proposed as an alternative for improving the mechanical properties of clay soil.

2. Experimental program

2.1. Materials

2.1.1. Clay *soil.* The clay soil used to improve its mechanical properties is found in the town of Piura, Peru; its coordinates are: 4 °35'19.0 "S 81 °16'15.3" W. The physical properties of the clay soil were identified and investigated according to technical standards (ASTM). The tests carried out were: sieve granulometry, sedimentation granulometry and consistency limits.

The soil studied is made up of 98.1% fines and 1.9% sand. This clay has a CL classification (low plasticity sandy clay) according to SUCS and for AASHTO A-7-6 (26) [5]. Table 1 shows the characteristics.

Table 1- Characteristics of natural soil

Soil Properties	Results
Consistency limits	
Liquid Limit (LL)	47%
Plastic Limit (LP)	23%
Plasticity Index (IP)	24%

SUCS classification	CL
AASHTO classification	A-7-6(26)
Soil composition	
Gravel	0.00%
sand	1.90%
fine particles	98.10%

2.1.2. Fan shells. The scallops used for this research were extracted from the fishing dumps in the area. This element was used, since one of its predominant chemical components is calcium carbonate (CaCO3) [6], these are the same minerals that Cal contains. See figure 1.

Figure 1. Fan shells.

2.1.3. Glass (recycled bottles*).* The glass used was collected from junkyards in the area. This material was used because it contains calcium carbonate (CaCO3) and Silica sand (SiO2) [7], elements that work well with fine soils. See figure 2.

Figure 2. Glass bottles.

2.2. Preparation of mixtures

For the preparation of the mixtures, references from previous academic articles and theses were taken. This allowed defining the sample percentages for each test. The particle size with which we worked for the mixtures of PV (glass powder) and PCA (fan shell powder) was retained on the N °100 sieve, this size was used because as the fine soil is granular, it can better grip the particles and thus have better soil stabilization. A nomenclature was assigned for each mix. See table 2.

Table 2. Mix Design.

Mixture	% Soil	% Mollusk Shells	% Glass Powder	Symbology
Natural Soil	100	0	0	NS
Mixture 1	90	3	7	M1
Mixture 2	87	6	7	M2
Mixture 3	83	10	7	M3
Mixture 4	81	12	7	M4
Mixture 5	78	15	7	M5

2.3. Laboratory tests

The tests were carried out for the mixtures defined in table 2 according to the ASTM standard, which were:

2.3.1. Atterberg limits test. This test allows determining the different states of the soil such as liquid limit (LL), plastic limit (LP) and plasticity index (IP). With the mixtures already defined in table 2, the tests were carried out according to ASTM D4318 [8].

2.3.2. Modified Proctor Test. It aims to achieve maximum dry density for optimum humidity in order to improve the soil [8]. Being a repetitive compaction process, the objective is to reduce the volume of voids, generating an increase in density. With the mixtures already defined in table 2, the tests according to ASTM D-1557 were carried out.

2.3.3. Drained Consolidated Direct Shear Test. This test determines the resistance to the shear stress of the soil and determines the resistance parameters such as cohesion and friction angle [8]. The test was carried out applying a normal force to the ground of 0.5 kg/cm2 (49 kPa), 1.0 kg/cm2 (91.1 KPa) and 2.0 kg/cm2 (196.1 KPa). The vertical movement is read by placing a deformmeter on top. The applied deformation speed was 0.00492 in / min, since it must be slow to guarantee drainage conditions equivalent to zero pressure. Compaction was carried out with the humidity and unit weight conditions obtained from the control test. In addition, the specimens were allowed to cure for approximately one day.

3. Analysis and results

A comparative analysis of the results obtained in the Atterberg limit tests, modified proctor and drained consolidated direct cut was performed on the natural soil and on the mixtures defined in table 2.

3.1. *Atterberg* limits test

Carrying out the tests, figure 3 was obtained, where the results of the test for natural clay and the mixtures are summarized.

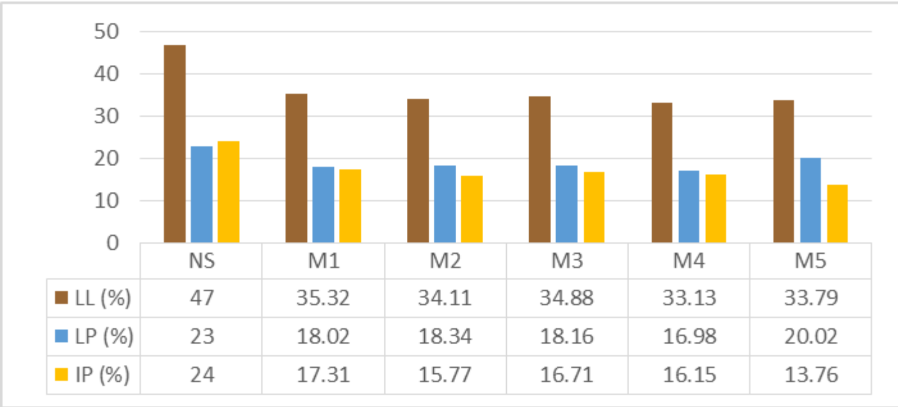

Figure 3. Atterberg limits tests.

It is evident that natural clay has a higher liquid limit and tends to decrease when adding the percentages already defined in table 2. This is generated, since the additive used for the study has a particle size of 150 µm, all that is retained in mesh # 200. Furthermore, by reducing the percentage of water (LL), a reduction in the volumetric variation of the soil is generated.

3.2 Modified proctor test

From the tests performed, a summary of all modified Proctor tests was developed. See figure 4.

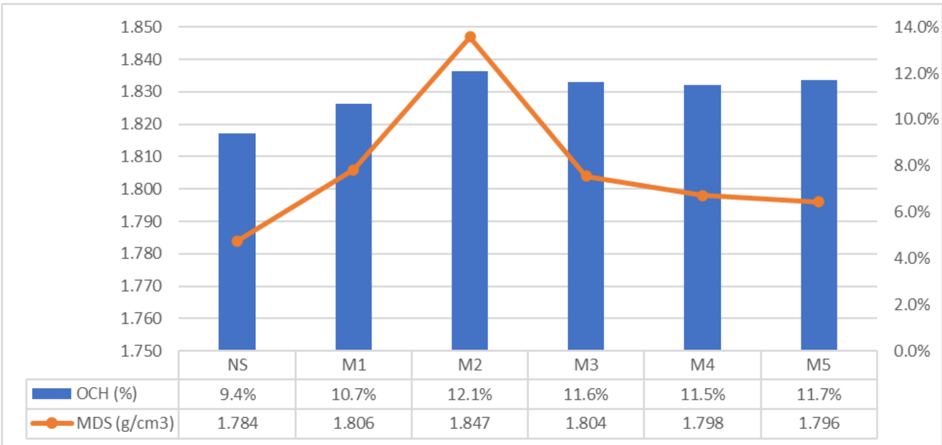

Figure 4. Summary of modified proctor results.

It is observed that the maximum dry density increases compared to natural clay. This has a maximum dry density (MDS) of 1,784 kg / cm3 and a maximum moisture content (OCH) of 9.4%. When the percentage is increased to 6% PCA-7% PV (M2) there is a peak increase in MDS of 1,847 kg / cm3 and an OCH of 12.1%. When 10% PCA-7% PV (M3) is added, it begins to have a decreasing trend in MDS and OCH.

3.3 Direct cut test consolidation drained

In the direct shear tests, the Tangential Deformation vs. Shear Stress graphs were performed at different normal stresses already defined in the experimental program. See figure 5, 6 and 7. This will allow us to identify the maximum shear stresses and find the parameters (see table 3) of friction and cohesion angle.

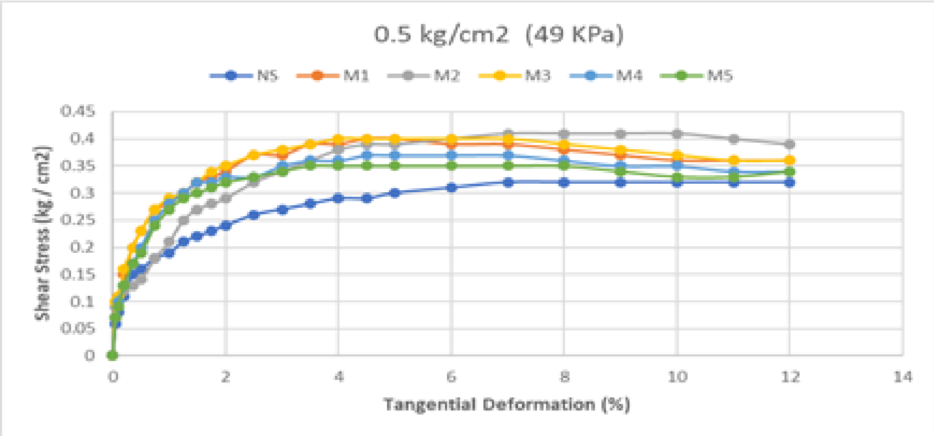

Figure 5. Tangential Deformation (%) vs Shear Stress (kg / cm2) of all the mixtures at 0.5 kg / cm2.

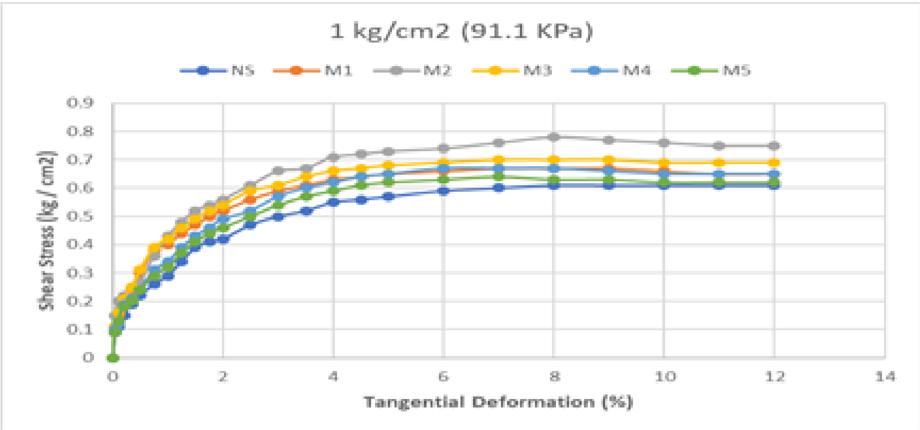

Figure 6. Tangential Deformation (%) vs Shear Stress (kg / cm2) of all the mixtures at 1 kg / cm2.

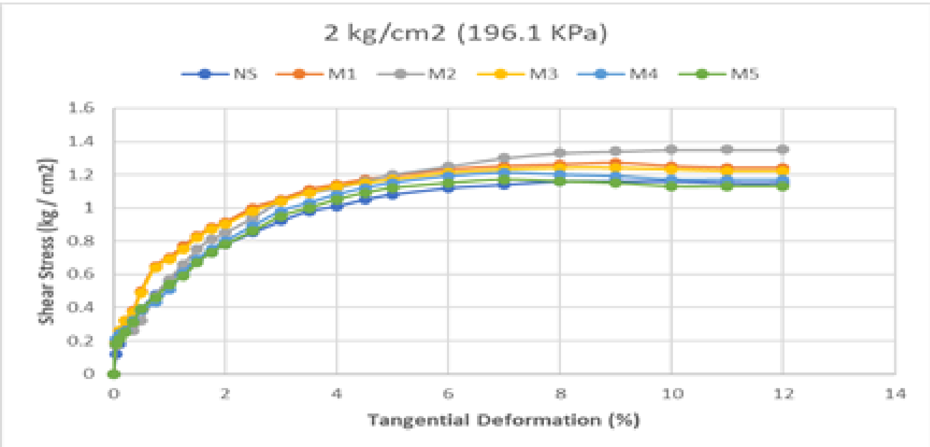

Figure 7. Tangential Deformation (%) vs Shear Stress (kg / cm2) of all the mixtures at 2 kg / cm2.

Table 3. Maximum shear stress.

Normal effort (kg / cm2)	Maximum Shear Stress (kg / cm2)					
	NS	**M1**	**M2**	**M3**	**M4**	**M5**
0.5	0.32	0.4	0.41	0.4	0.37	0.35
1	0.61	0.67	0.78	0.7	0.67	0.64
2	1.16	1.27	1.35	1.24	1.21	1.17

Identifying the maximum shear stresses, the failure envelope of each sample was plotted with the Mohr circle. See figure 8 and table 4.

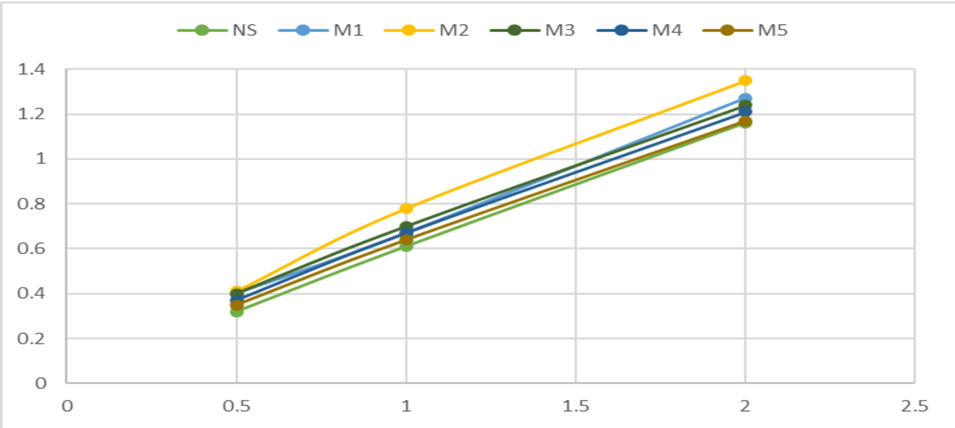

Figure 8. Normal Effort vs. Cut Effort of all mixes.

Table 4. Summary of resistance parameters.

	NS	M1	M2	M3	M4	M5
Ø	28.9	30.5	32	29.8	28.6	28.3
Cohesion	0.05	0.07	0.1	0.08	0.08	0.06

It is evident that there is a trend of increasing resistance parameters in the design mixtures, but then it begins to decrease with increasing percentages of PV and PCA. The M2 mix is the one that has the best results, since the natural clay soil has a friction angle of 28.9 °and a cohesion of 0.05 kg / cm2 and increases in M2 its friction angle to 32 °and its cohesion to 0.1 kg / cm2.

4. Conclusions

• The liquid limit of the natural soil is 47% and when adding the first mixture, M1 decreases to 35.32% and this tendency to decrease for the other mixtures continues.
• In DMS, the highest result obtained from all the mixtures was M2, since it increases by 0.063 g / cm3 with respect to natural soil (NS). This occurs because the scallop behaves as a binder.
• In the consolidated direct cut drained it is observed that the M2 mix has better results. When the applied normal tension is 0.5 kg / cm2 (49 KPa), the shear resistance of the natural soil compared to the M2 mixture increases from 0.32 kg / cm2 to 0.41 kg / cm2, in the same way for the applied normal tension of 1 kg / cm2 (91.1 KPa) the cut resistance increases from 0.61 kg / cm2 to 0.78 kg / cm2, and when the applied tension is 2 kg / cm2 (196.1 KPa) the cut resistance increases from 1.16 kg / cm2 to 1.35 kg / cm2.

• The friction angle of M2 increased by 10.7% with respect to the natural NS soil and its cohesion increased by 100%, going from 0.05 kg / cm2 to 0.1 kg / cm2.
• The use of fan shells and glass contribute to the environment, since they are recycled elements. In addition, there is an incentive to discover new stabilization methods for clay soils.
• With this research it was shown that the stabilizing elements for clay soil achieve a significant increase in mechanical properties, thus achieving an improvement in the soil for constructions.

5. References

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