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Experimental study of the mechanical effect of a clayey soil by adding rubber powder for geotechnical applications

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Abstract. At present, worrying quantities of tires are discarded due to the growth in demand for vehicles in the world, which has a direct impact on the deterioration of the environment since they normally go to landfills. Based on the background found, the use of this material for geotechnical applications can help reduce the pollution they generate and improve the physical and mechanical properties of soils. Therefore, this research seeks to evaluate a greater shear strength and capacity of support to the penetration of the clayey soil by means of the addition of 1.5%, 2.5% and 3.5% of rubber powder recycled. For this, the Atterberg limits analysis, the modified proctor compaction test, shear box and CBR were performed. For the shear box test, the results reflect that the cohesion of the mixture increased and the angle of internal friction decreased with respect to the natural soil, resulting in the sum in an increase of shear strength. On the other hand, the percentage of CBR increased, this means that the rubber helped the soil to be more rigid and have a greater resistance to penetration. These mixtures could be used in different projects within geotechnical engineering, as it presents an improvement in shear strength and an acceptable support index value (CBR).

1. Introduction

During the last decades Thailand is the leading producer of rubber worldwide, this material serves as a raw material for the manufacture of tires through an industrial process, which increases the emission of greenhouse gases that damage the environment [1]. In addition, the final disposal of this material often ends up being landfills and then burned. Experimental studies show that this process generates CO and SO_2 in high quantities, which exceeds the allowed limits [2]. It is also known that clayey soils have a deficit in their physical and mechanical properties. Therefore, there are several investigations on the improvement of these parameters making use of recycled rubber particles from disused tires, with the aim of having a soil suitable for building embankments, roads, etc. In Turkey, the influence of the addition of recycled tire rubber fibers and silica fume to clayey soils was investigated, with the aim of improving shear strength. The results showed that cohesion and friction angle increased 1.1 and 1.7 times respectively more than the clayey soil sample [3]. In the same way, the modification of clayey soils was investigated by adding tires and synthetic fibers with the aim of finding reinforced samples subjected to a shear strength. The results showed that the parameters of the shear strength increased 1.2 times to the samples of the non-reinforced soil [4]. The improvement of the California Bearing Ratio (CBR) of a clayey soil with the addition of polished rubber and lime was then investigated in order to stabilize it and thus be used as a material for road construction. In the results it was observed that the addition of this mixture increased the percentage of CBR and managed to decrease the thickness of the

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pavement [5]. In addition, researchs on this last parameter has already been taking place in India, where it was also concluded that recycled rubber does help improve the CBR of a clayey soil, up to 5% addition of rubber improves soil support properties, helping to reduce the compression rate and swelling pressure [6]. This research aims to show the feasibility of using recycled rubber powder to improve the mechanical and physical properties of a clayey soil, and then be applied to the subgrade of a road. Finally, the use of this recycled material will help reduce the environmental pollution caused by this waste in large quantities and highly polluting if they do not have an appropriate end use.

2. Experimental Program

2.1. Materials

2.1.1. Clayey soil

The clayey soil was extracted at a depth of 1.5m from the Callampampa, Cajamarca, Peru (Figure. 1) with a plasticity index of 13%, liquid limit of 34%, plastic limit of 21% and the specific gravity is 2.13. In addition, the granulometric curve shows that this soil has 28.8% thick fraction, 17.9% silt, 24.1% clays and 29.2% colloids (Figure. 3). This clayey soil is classified as CL according to SUCS and A-6(8) according to AASHTO.

2.1.2. Rubber powder

Powdered rubber (Figure. 2) used to improve the physical and mechanical properties of clayey soil, was obtained from out-of-use tires. In the granulometric distribution (Figure. 3) it was obtained that the size of its particles varies between 2mm to 0.075mm and its average size is 1,452mm. This material has a specific gravity of 0.90.

Figure 1. Clayey Soil

Figure 2. Rubber Powder

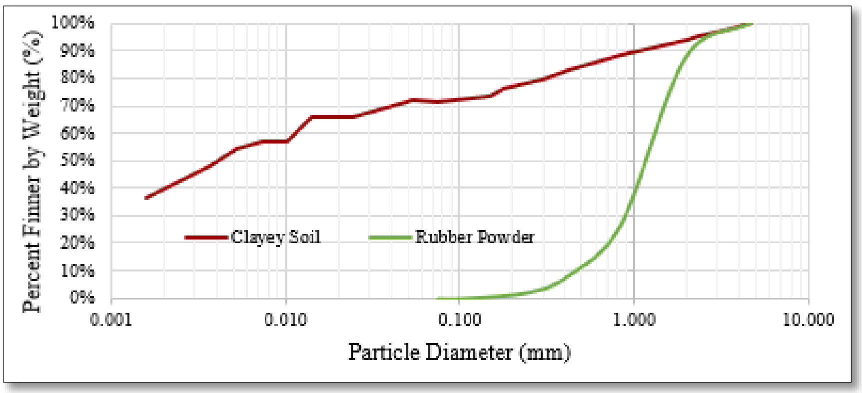

Figure 3. Particle size distribution curve of powder rubber and clayey soil

2.2. Preparation of the mixtures

The clayey soil that was used in this study was dried in an oven at 105 °C, then carefully crumbled in order not to alter the interaction between its particles. With this process a more homogeneous soil was obtained to add rubber powder in 1.5%, 2.5% and 3.5% of the dry weight of the clayey soil, the symbology that was used to denote these mixtures can be seen in Table 1.

Table 1. Symbologies to denote mixtures of clayey soil with rubber powder.

Material	Soil (%)	Rubber Powder (%)	Symbology
Clayey Soil	100	0	S100
Mixture 1	100	1.5	S100/C1.5
Mixture 2	100	2.5	S100/C2.5
Mixture 3	100	3.5	S100/C3.5

2.3. Laboratory tests

2.3.1. Physical characterization

To know the physical properties of clayey soil and mixtures, the following tests were performed:

- ASTM D422 - Standard Test for Particle-Size Analysis of Soils
- ASTM D4318 - Standard Test for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
- ASTM D854 - Standard Test for Specific Gravity of Soil Solids by Water Pycnometer

2.3.2. Mechanical characterization

To know the mechanical properties of clayey soil and mixtures, the following tests were performed:

- ASTM D1557-02 - Modified Proctor Test.
- ASTM D3080 – Standard Test for Direct Shear Test.
- ASTM D1883 - Standard Test for California Bearing Ratio Test (CBR).

The modified Proctor, method A, was carried out with the objective of determining the optimum humidity content and the maximum dry density of the natural clayey soil and of the soil samples improved with rubber powder. These parameters will be used to prepare the test specimens of the Shear Box and CBR tests.

The shear box test was carried, in order to determine the parameters of shear strength of clayey soil and mixtures. For this, we worked with test specimens of 6.323cm in diameter and 2.02cm in height. A tangential travel speed of 0.25 mm/min and a normal load of 49kPa, 98.1kPa and 196.1kPa were applied until the sample fails by shear. In addition, parameters such as cohesion and friction angle were known from the fault envelope.

For the CBR the samples were compacted, then saturated for 4 days and then the penetration test was performed.

3. Analysis and Results

The granulometric curves (Figure 4) represent the distribution of the particles of the thick portion, greater than the mesh No. 200, of the mixtures and the clayey soil. On the other hand, the results of the plasticity index (IP), liquid limit (LL), plastic limit (LP) and the classification by the SUCS and AASHTO method are summarized in Table 2.

Table 2. Physical characterization of clayey soil and mixtures.

Mixtures	Gs	LL (%)	LP (%)	IP (%)	SUCS	AASHTO
S100/C1.5	2.134	33	22	11	CL	A-6 (6)
S100/C2.5	2.142	31	22	9	CL	A-4 (5)
S100/C3.5	2.135	29	21	8	CL	A-4(4)

The maximum dry density of the mixtures will increase with respect to the S100 (Table 3), this means that there will be a lower pore index between the particles as the rubber powder content increases, achieving a more densified soil. The optimum humidity content decreases as the addition of rubber powder increases, this is because the rubber does not absorb water and the mixtures have less clayey soil content.

Table 3. Optimum moisture and maximum dry unit weight of clayey soil and mixtures.

	S100	S100/C1.5	S100/C2.5	S100/C3.5
MDS(g/cm^3)	1.535	1.543	1.56	1.562
OCH (%)	17.4	17.0	16.7	16.4

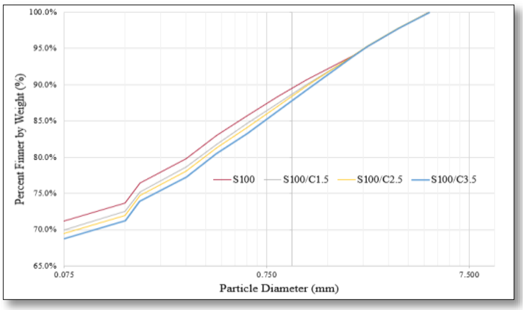

Figure 4 Particle size distribution curves of the thick portion of the clayey soil and mixtures.

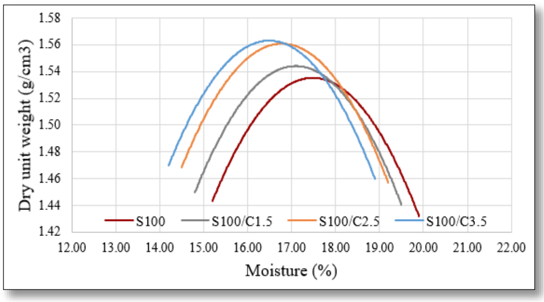

Figure 5. Modified proctor test curves for the clayey soil and mixtures.

Shear box tests showed that the addition of rubber powder improved the resistance to the shear strength of the clayey soil and that the samples tested will be more densified as the confinement effort increases. With the data obtained, the fault envelope was made (Figure. 6) where the cohesion parameters and the friction angle for each sample will be obtained. The cohesion of the low plasticity clayey soil is 0.25kg/cm^2 and the friction angle is 20.9 °, the first parameter increases as the addition of rubber powder increases and the second parameter has a behavior opposite to the first (Figure. 7). On the other hand, the ratio between the average size of the rubber powder particles and clayey soil is 1/300, this helps to improve the interaction between them. This means that a particle of rubber powder will have a considerable amount of clayey soil particles and thus achieve an improvement in the area of influence, which helps to increase cohesion and thus a greater resistance to the shear strength.

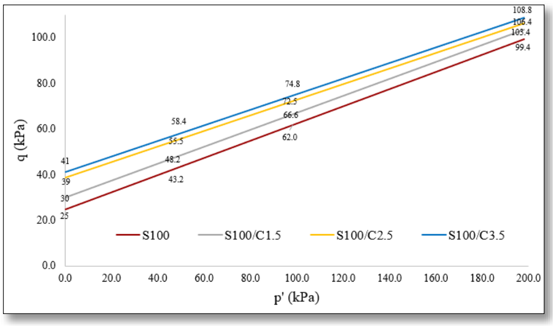

Figure 6. Strength envelopes of clayey soil and mixtures.

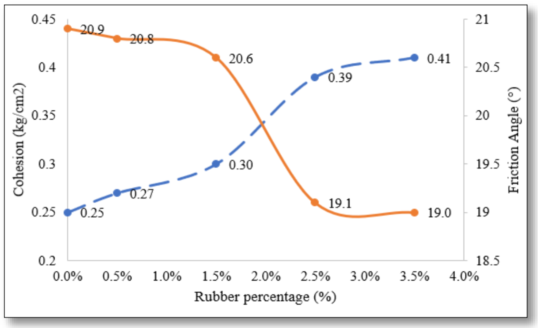

Figure 7. Variation of Cohesion and Friction Angle with respect to rubber percentages.

The CBR made to the natural clayey soil and to the samples of the soil improved with rubber powder was worked at 95% of the maximum dry density and at 2.5mm penetration. Clayey soil (S100) has a CBR of 3.2%, however, this parameter increased as the addition of rubber powder to the clayey soil increased. This is because the amount of voids in the mixtures interact with the rubber powder, which prevents water from entering, creating a larger contact surface. Table 4 shows that mixtures S100 / C2.5 and S100 / C3.5 whose CBR value is 8.7% and 9.4%, meet the conditions for an acceptable subgrade, according to AASTHO 93.

Table 4. CBR at 95% M.D.S and at 5mm penetration of clayey soil and mixtures.

	S100	S100/C1.5	S100/C2.5	S100/C3.5
CBR (%)	3.2	5.0	8.7	9.4

4. Conclusions

- The maximum resistance to the shear strength was presented when the horizontal displacement is 2.5mm. When the normal applied effort is 49kPa, the shear strength of the S100 / C3.5 mixture compared to natural soil (S100) increased from 43.2kPa to 58.4kPa, in the same way when the normal applied effort is 98.1kPa it increased from 62kPa to 74.8kPa and when the normal effort is 196.1kPa it increased from 99.4kPa to 108.8kPa.
- Cohesion increases as the addition of rubber increases, for the soil mixture plus 3.5% rubber (S100 / C3.5) the cohesion value is 0.41 kg/cm^2, which compared to the cohesion of S100 It increased by 64%. On the other hand, the friction angle has an inverse behavior of cohesion, that is, it decreases as the rubber addition increases. The S100 / C3.5 mixture has a value equal to 19 °, which compared to the friction angle of the natural soil decreased by 9.1%.
- For the CBR, it was observed that the mixtures S100 / C1.5, S100 / C2.5, S100 / C3.5 improve by 56%, 172% and 194% respectively compared to S100, with this it was possible to go from one subgrade listed as inappropriate to a regular. This allows the use of rubber powder to improve the subgrade of a road.
- The use of recycled rubber contributes to the conservation of the environment, as it has a strong impact on society, because the vast majority of disused tires are not properly recycled.

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