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Comparative study on soil improvement with classical binders and plastic waste materials.

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ABSTRACT: The paper presents a comparative study on soil improvement with classical binders and plastic waste materials, in our case polyethylene terephthalate (PET). In the past years the production of plastic waste materials has increased, at the same time as the price of soil improvement or stabilization with classical hydraulic binders. In Transylvanian region (Romania) some of the most problematic soils are expansive clays, therefore, our study will concentrate on the comparison between the effect on swelling pressure when clayey soil is mixed with shredded PET and hydraulic binders. Current study presents the effect of additives on the swelling pressure, but also the microstructure of the mixture.

Because plastic waste pollution has reached a worrying level in recent years and environmental issues related to the production of classical binders are commonly raised, the subject of this study could be one of great interest.

KEYWORDS: Expansive clays, Polyethylene terephthalate, classical binders, soil improvement.

1 INTRODUCTION

Traditionally, clayey soil can be stabilized by adding different percentages of lime or cement, so that to improve desired engineering properties. By mixing the soil with such materials, soil strength will increase and plasticity or swelling potential will decrease. If expansive soils treated with calcium-based stabilizers contain sulfates, the calcium from the stabilizer reacts will react with soil sulfates and alumina to form an expansive mineral (Firoozi et all, 2017). One of the objectives of this study is to observe the behavior of the expansive clays from Transylvania when mixed with lime and polyethylene terephthalate (PET).

In Romania, research on soil improvement with plastic waste is limited. Previous studies of the authors tested similar clay mixed with 2%, 4%, and 6% PET, showing that small amounts of PET can enhance shear strength. The effect depended on the percentage, shape, and distribution of the PET particles (Trimbitas et al., 2021).

When similar clayey soil was tested in a climatic cabinet (Trimbitas et al., 2023) it exhibited improvement in the behavior. At 2% PET, shrinkage cracks increased compared to untreated clay, but at 4% and 6% PET both the number and width of cracks decreased significantly. The sample with 6% PET showed the best resistance to temperature and humidity variations, with almost no shrinkage cracks and superior performance to the untreated clay. Overall, higher PET content reduced shrinkage behavior.

Some of the concerns regarding the use of plastic waste materials in geotechnical engineering applications are regarding its potential environmental impact. Urian and all, 2023, investigated the potential migration of the chemical components from PET degradation in a clayey soil. Clay–PET mixtures were exposed first in a climatic cabinet to variable humidity and temperature conditions, simulating in situ environments. Gas chromatography with mass spectrometry (GC-MS) analysis was performed on natural clay and clay mixed with 2%, 4%, and 6% PET. DIBP (1,2-benzenedicarboxylic acid, bis(2-methylpropyl) ester) was detected in all samples, with its concentration increasing proportionally to the PET content. Higher PET percentages also led to greater phthalate accumulation in the soil, along with the presence of lubricants in samples with more PET. Thermogravimetric analysis confirmed the thermal stability of the clay–PET mixtures under normal atmospheric conditions, thermal degradation of polymeric chain starting only from 200 °C. Therefore, soil mixed with PET waste is suitable for geotechnical engineering applications.

The swelling potential of expansive clayey soils is influenced by factors such as clay mineralogy, reduction of overburden stress, unloading conditions, water exposure, and increased moisture content. Civil and geotechnical engineering research established that moisture-induced swelling of expansive soils can lead to significant structural distress and even severe damage to foundations. The soils most vulnerable to swelling and shrinkage include over-consolidated clays (Khemissa and all, 2018) as well as Tertiary and Quaternary alluvial or colluvial deposits (Yilmaz, 2008).

This paper presents the effect of the treatment of the expansive clay, using lime and polyethylene terephthalate (PET). In the study different percentages of lime (3%, 4% and 5%) were mixed with soil and PET flakes and compacted at optimum water content determined by Proctor test. After a curing time of 7 days specific tests were performed and the results obtained showed that the lime has decreased the swelling pressure to very low values and the plasticity index has decreased, not by decreasing the liquid limit, but instead by increasing the plastic limit. By using plastic waste to stabilize expansive clay no noticeable improvement has been observed on swelling pressure. On the other had there was observed improvement in the shearing strength (Trimbitas et al., 2021), which might balance the results.

2 MATERIALS USED IN TESTS AND SAMPLE PREPARATION

2.1 *Material used in tests*

The clayey samples used in tests were taken from the vicinity of the city of Cluj-Napoca, at 7 km from the city center (Figure 1), an area with hill slope deposits formed by the weathering and transport downslope of older deposits of Sarmatian age (determination based on Foraminifera). Macroscopically these deposits are yellowish to yellowish-brown and consist of clays with thin laminae of silt and occasionally fine sands that are conduits for water infiltration. They have a relative uniform mineralogical composition, with quartz (20-23%), muscovite (18 - 27%), smectite (17.4%-27%) and calcite (12-14%) as main components, and with dolomite, feldspars, kaolinite and chlorite in smaller amounts. Precipitation of carbonates was noticed at several levels within the sampled interval.

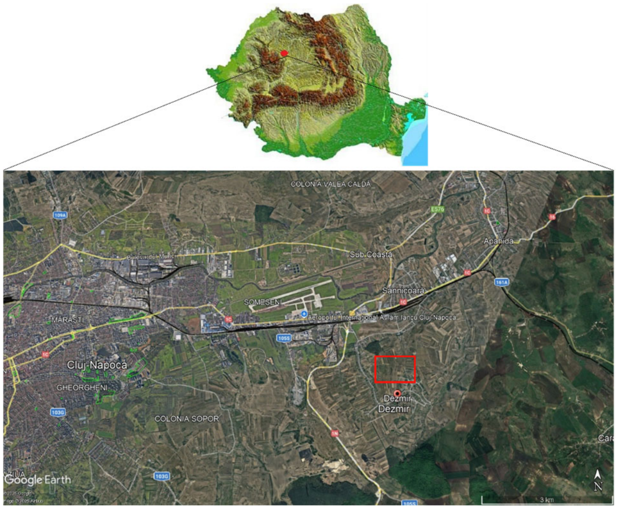

Figure 1. Location of the clay samples used in tests

The physical and mechanical properties were determined for all the samples collected from the field in their natural state. These tests include water content, grain size analysis, free swelling index, Atterberg limits (Table 1), natural bulk density, compressibility-settlement and direct shear tests, and swelling pressure test.

Table 1. Average values of Atterberg's limits.

Atterberg limit	Value
Liquid limit [%]	43.08
Plastic limit [%]	22.64
Plasticity index [%]	20.44

The mineralogical composition was determined by X-ray powder diffraction (Moore and Reynolds 1997; Marat et al. 2022). The analyses were performed with a Bruker D8 Advance diffractometer with CuKα radiation (λ = 0.15418 nm) at 40 kV and 40 mA, using a Ni filter and a LynxEye detector (Figure 2). Quantitative analyses of the bulk samples were performed through Rietveld refinement using the Profex software (Doebelin and Kleeberg 2015).

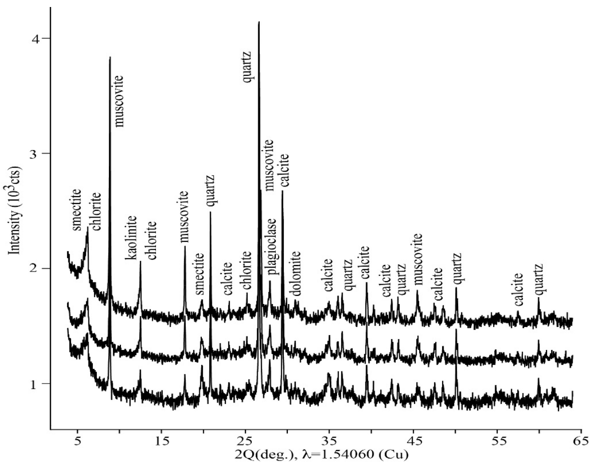

Figure 2. X-ray diffraction patterns of the samples mixed with lime and the main minerals identified

On average, the sample used in tests is composed of clay in proportion of 69% and 31% of silt. The total carbonate content of sample was determined by using the reaction of the sample with diluted hydrochloric acid and measuring the pressure of CO_2 released. By this method, it was established that the total carbonates present in sample was 14.98%, in good agreement with the carbonate content determined by Rietveld analysis (13.3% - 15.8%) for calcite and dolomite.
The free swelling index was determined by the sedimentation of a volume 10 cm^3 (12 g) of oven dried sample, ground to pass 0.2 mm sieve, in a volume of 50 cm^3 distilled water for 4 hours and after shaking in a volume of 100 cm^3 for 24 hours. The free swelling index is calculated as the final volume minus the initial volume divided by the initial volume. The free swelling index ranges in values from 110-140, with average value of 123.
The swelling pressure was determined according to ASTM D 4546-03, method A. In general, it was observed that the swelling pressure increased as the water content of the specimen decreased (Table 2). The initial water content of the samples collected in the field was between 23.7-26.97%. Some specimens were tested after losing some of initial water content to observe the difference in swelling pressure.

Table 2. Swelling pressure at different starting water content

Swelling pressure [kPa]	Water content [%]
60	25.00
190	24.76
35	23.00
190	22.76
190	22.00
195	21.77

The lime used in tests was in powder form, with 95% finer than 0.2mm (Table 3).

Table 3. Lime composition used in tests.

Composition	Value
CaO +MgO [%]	Min. 70
CaO average [%]	Min. 55
MgO [%]	Max. 5
CO_2 [%]	Max. 25
SO_3 [%]	Max. 2

The Polyethylene terephthalate flakes used in test had irregular shapes with average length between 6-8mm (Figure 3). The average density of PET is approximately 1.38 g/cm^3, and the thickness of typical recycled bottles ranges from 0.25 to 0.89 mm. The flakes used in this study were sourced from a recycling center that shreds standard PET bottles for reuse, following the principle of ensuring easy and accessible material procurement.

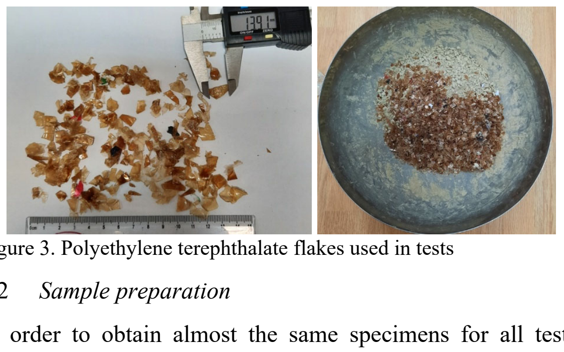

Figure 3. Polyethylene terephthalate flakes used in tests

2.2 *Sample preparation*

In order to obtain almost the same specimens for all tests, Standard Proctor test in accordance with ASTM D 698-12, was first conducted on the clay sample without additives, and the optimum water content was determined as 19.5% (Figure 4). The clay sample mixed with 3%, 4%, and 5%by mass with lime and Polyethylene terephthalate (Figure 5), were compacted before tests by using Standard Proctor compaction effort at optimum water content determined. The specimens prepared by admixture of lime were allowed to be cured for 7 days.

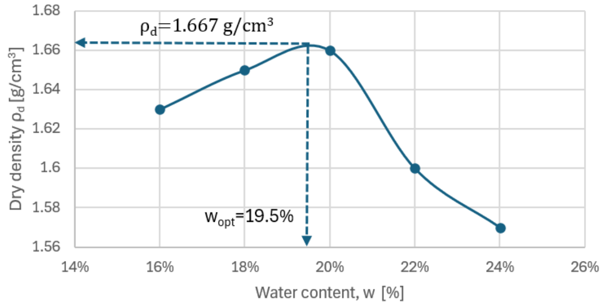

Figure 4. Optimum water content and dry density for sample without additives

Figure 5. Admixture preparation

3 TESTING PROCEDURE

In order to determine the swelling characteristics of expansive clay one-dimensional swelling pressure test was performed for all the sample analyzed. Also, free swelling index and plasticity limits were determined for the samples mixed with lime powder.

3.1 *One-dimensional swell determination*

The swelling pressure was determined according to ASTM D 4546-03, method A. The radius of the oedometer ring used in tests was 71.4 mm. The sample was placed between two porous stones, loaded with 10 kPa and the cell was inundated using distilled water. After completion of swell under 10 kPa pressure, the specimen was loaded with different increments usually 25, 50, 100, 200, 300, 500 kPa with each pressure maintained constantly until the vertical displacement between two readings was smaller than 0.01 mm at two hours interval. The pressure necessary to recompress the specimen to its original void ratio/height was considered the swelling pressure. The small increase in vertical height Δ_h, due to swelling upon absorption of water, did not cause extrusion of specimen between the porous stone and the metal ring.

3.2 *Atterberg's limits*

The liquid limit was determined by using the "Fall cone method" with 60g/60° cone and the plastic limit by using the "rolling method".

4 RESULTS

The swelling pressure of the cohesive soil may be modified by the mechanical disintegration of particles involved in compaction. Therefore, several specimens without any additives were tested after they were compacted using Standard Proctor at the determined optimum water content. These tests produced significantly lower swelling pressure than the one on the specimens in their natural state even though the starting water content was lower. The swelling pressure determined on specimens compacted at optimum water content without any additives was between 100-150 kPa, with an average of 125 kPa. The initial carbonate content of the sample can also be of some importance, as the carbonates were not distributed evenly throughout the samples collected, but following the compaction, the material was mixed together.

Following the determination of swelling pressure on specimens compacted using Standard Proctor and without any additive, swelling pressure was determined on sample mixed with 3%, 4%, 5% lime and PET, respectively. Lime lowered the swelling pressure in all the mixtures that were tested as presented in Table 4. Plasticity index has also decreased following the mixture with lime powder (Table 5).

Table 4. Swelling pressure of sample mixed with lime powder

Mixture with	Swelling pressure [kPa]
3 % lime powder	25
4 % lime powder	25
5 % lime powder	0

Table 5. Atterberg's limits of sample mixed with lime

Property	3% lime	4% lime	5% lime
Liquid limit [%]	43.105	47.51	47.06
Plastic limit [%]	29.30	28.29	29.90
Plasticity index [%]	13.805	19.22	17.16

In comparison, the mixture containing plastic waste only marginally lowers the swelling pressure (Table 6).

Table 6. Swelling pressure of sample mixed with plastic waste

Composition	Swelling pressure [kPa]
3 % PET	105
4 % PET	85
5 % PET	90

In Figure 5, the difference in the effect the lime and the plastic waste produced on the swelling pressure is obvious.

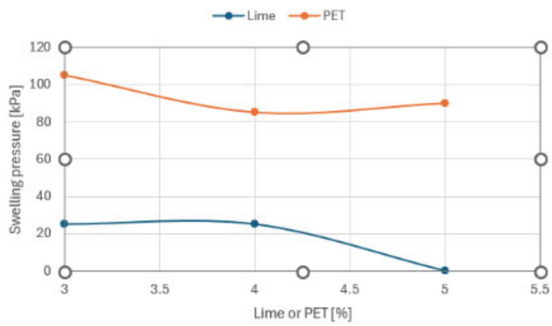

Figure 5. Comparison of swelling pressure of sample mixed with plastic waste and sample mixed with lime powder

In general, specimen deformation under the same axial stress was considerably smaller for the sample mixed with lime than for the sample mixed with plastic waste (Figure 6).

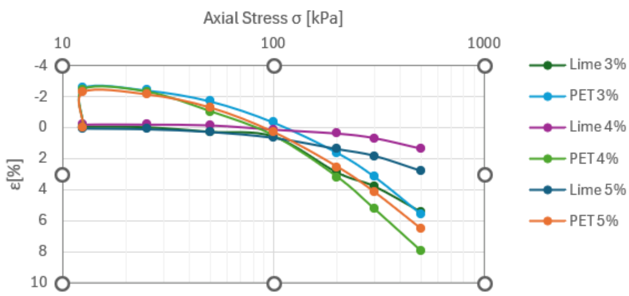

Figure 6. Specimen deformation under the same axial stress for lime and PET mixtures.

5 CONCLUSIONS

Using lime as additive to stabilize expansive clay from Cluj-Napoca neighborhood has proved useful in our laboratory experiments. Lime has decreased the swelling pressure to very low values. The plasticity index has decreased, not by decreasing the liquid limit, but instead by increasing the plastic limit. By using plastic waste to stabilize expansive clay no noticeable improvement has been observed to lower the swelling pressure. It is possible that by shredding the PET flakes to smaller size to observe some reduction in the swelling potential of expansive clay. Swelling pressure has decreased by breaking the intricate fabric of the clay by using the Standard Proctor test, as compared to swelling pressure in the natural state. The sulfate content of the natural clay was unimportant, and the mineral ettringite was not identified following the mixing of the sample with lime.

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