Eurasian Journal of Civil Engineering and Architecture
EJCAR, Vol. 3, Issue 2, pp. 32-40, December 2019

ISSN 2602-3865, TURKEY
Research/Review Article

EFFECT OF LIME ON UNCONFINED COMPRESSIVE STRENGTH OF A LOW PLASTICITY CLAYEY SOIL

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Received: 28/08/2019 **Accepted:** 17/09/2019

ABSTRACT
The performance of the superstructure in the transportation structures (railway, highway etc.) is directly affected by the characteristics of subgrade. However, it is not always possible to find the desired quality subgrade soil in the areas where both highway and railway routes. In such cases, it is an option to improve the problematic soils in place by using additives (lime, cement etc.). The aim of this study is to investigate the effect of lime on the unconfined compressive strength (UCS) of a low plasticity clayey soil under different curing time (0, 1, 7 and 28 days) and different curing conditions (in a desiccator and soaked). Firstly, geotechnical tests (classification and compaction) were conducted to determine properties of soil. UCS test samples at five different lime contents (2%, 3%, 4%, 5% and 6% by weight) were prepared and cured in desiccator. Then UCS test was conducted immediately at the end of the curing time. On the other hand, the optimum lime content by weight was determined as 4 % by using the pH method. After curing time in the desiccator, the samples prepared with optimum lime content were soaked in water for 4 days and then UCS test was carried out. As a result, with the addition of lime, maximum dry density values decreased, optimum water content values increased. UCS significantly increased with both lime content and curing time. For 28 days, soaked UCS of the samples prepared with 4% optimum lime content decreased by approximately 50% according to unsoaked condition.

Keywords: *Lime, Subgrade, Stabilization, Unconfined Compressive Strength*

1. INTRODUCTION

The performance of the superstructure in the transportation structures (road, railway, etc.) is directly affected by the characteristics of subgrade on which it was built (Little and Nair, 2009; Athanasopoulou, 2014; NLA, 2004). However, in the areas where the route is passed, there are not always subgrade soil with the required engineering properties for the project criteria. In such cases, there are several different alternative solution methods. These methods include changing the route or the project area, excavating the existing soil and bringing the soil to provide sufficient strength, redesigning the project according to the soil conditions and improving the subgrade soil using various methods (Nicholson, 2014). However, due to many reasons such as economic, technical and topography, the first three options are not preferred. Therefore, in the regions where the route is passed, the option of in situ improving the soil by using various methods presents a more suitable solution compared to other options in terms of being economical, rapid and sustainable. By using various additives (lime, cement, fly ash etc.) from these methods, in situ improvement of the engineering properties of soil is widely applied.

Stabilization of soils with lime as the additive material is one of the most widely used improvement techniques in the world (Bell, 1996; Kavak and Akyarlı, 2007; Robin et al., 2014; Little and Nair, 2009). Lime improves its performance by converting the soils which do not have sufficient engineering properties and which can create problems for the superstructure and cannot be used, into chemically usable materials (NLA, 2004; Consoli et al., 2011; Dash and Hussain, 2012; Bell, 1989). It is possible to stabilize clayey soils with a very small amount of lime (Bell, 1989). However, the effectiveness of the improvement depends on the mineralogical structure of the soil as well as the amount of lime (Al-Mukhtar et al., 2010). The researches indicate that four different mechanisms are formed by adding lime to clayey soils. These are cation exchange, flocculation/agglomeration, carbonation and pozzolanic reaction (Little and Nair, 2009; Bozbey and Garaisayev, 2010; Diamond and Kinter, 1965; Al-Mukhtar, 2014). Cation exchange and flocculation/ agglomeration occur in the short term. In this process, a rapid change in the plasticity, volume change potential, workability and strength properties of the soil occurs. The pozzolanic reaction is time dependent and continues for longer periods. In this process, cemented products are formed and strength gains are clearly observed (Little, 1999; Bozbey and Garaisayev, 2010; Little and Nair, 2009). In the literature, there are many studies investigating the effect of lime on the various engineering properties (strength and durability) of soils. (Kavak and Akyarlı, 2007; Qian et al., 2014; Dash and Hussain, 2015; Consoli et al., 2014; Al-Mukhtar et al.,2012; Al-Mukhtar et al., 2010; Jha and Sivapullaiah, 2015; Khattab et al., 2007; Cuisinier, et al., 2011; Ghobadi et al., 2014; Rao and Shivananda, 2005; Stoltz et al., 2012). Tuncer and Basma (1991) investigated the strength and stress-strain behavior of a cohesive soil with a lime additive. They performed laboratory experiments for curing time of 0, 7, 14, 21 and 28 days with different lime percentage (3%, 6% and 9%). They determined that the plasticity index decreases with the increase of the lime content and the compaction characteristics are not significantly affected. At the same time, they determined that UCS increased as the lime content and curing time increased. Kavak and Baykal (2012) investigated the long-term behavior of lime stabilized kaolin clay. While the UCS of the kaolin clay without lime was 125 kPa, the UCS of 4% lime added kaolin clay was determined as 1015 kPa after 1 year and 2640 kPa after 10 years.

In this study, UCS of a low plasticity clayey soil for different lime content (2, 3, 4, 5, and 6% by wieght of dry soil), different curing period (0, 1, 7 and 28 days) and different curing conditions (in desiccator or soaked) was investigated. At the same time, the changes in the microstructure of the soil without lime and soil with 4% lime at the end of the 28 days curing period were examined by scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) analysis.

2. MATERIAL AND METHODS

2.1. Material

The soil used in the study was obtained from the region where Torbalı-Tepeköy-Selçuk railway line passes. The soil was taken from the depth of about 1-1.5 m after the topsoil was removed. In order to determine the classification and basic characteristics of the soil, sieve analysis/ hydrometer (ASTM D422, 2007), specific gravity (ASTM D854, 2014), atterberg limits (ASTM D4318, 2017) and compaction tests (ASTM D1557, 2012) were performed according to the test standards. The basic characteristics of soil classified as CL according to ASTM D2487 are given in Table 1.

Table1. Basic characteristics of soil

Properties	Value
Optimum Water Content (%)	16
Maximum Dry Unit Weight (kN/m^3)	17.1
Liquid Limit (%)	41
Plastic Limit (%)	24
Plasticity Index (%)	17
Specific Gravity	2.77
Percentage passing No. 200 sieve (%)	99
Silt (%)	44
Clay (%)	55
Soil Classification, USCS	CL

Hydrate lime ($Ca(OH)_2$) was used as additive material (ASTM C977, 2018). 25 kg packed lime were stored in a dry environment to prevent loss of features. The physical and chemical properties of the hydrate lime used in the study are given in Table 2.

Table 2. Physical and chemical properties of hydrate lime

Properties	Value
Active $Ca(OH)_2$, %	89.54
Total CaO+MgO, %	≥90
Humidity, %	0.49
Relative Humidity, %	19.87
CO_2, %	3.44
MgO,%	0.46
SiO_2+AÇM,%	2.10
R_2O_3, %	0.36
S, %	0.23
SO_3	0.58
Fineness,%	7
Density (Kg/dm^3)	0.45-0.50

2.2. Methods

The soil was firstly pulverized for use in the experimental study and was used by sieving through the 40 sieve.

Five different lime content (0%, 2%, 3%, 4%, 5% and 6% lime by weight of dry soil) were used as additive material. pH test is also performed to determine the optimum lime content for the soil used (Eades and Grim, 1966). The test was carried out in accordance with ASTM D6276 standard. For this purpose, solutions were prepared by using different amounts of lime, soil and distilled water. Then the pH values of these mixtures were measured.

Compaction tests were performed to determine the optimum water content and maximum dry unit weight of the mixtures prepared for each lime content. Experiments were carried out with modified proctor compaction energy (2710 kJ/m^3) due to close to the compression energy of existing modern equipment (Connelly et al. 2008; ASTM D1557, 2012).

Specimens were prepared using the harvard miniature compaction test instrument to determine the UCS. The test specimens prepared have a diameter of 33 mm and a height of 70 mm (Figure 1). While samples without lime were directly compacted, the mixtures prepared by adding different lime content and optimum water were compacted after standing for 1 hour. For the 0, 1, 7 and 28 days curing periods, three specimens were prepared for each lime content. Specimens prepared for all lime ratios were kept in desiccator for curing time and then UCS test was performed (Figure 1). At the same time, in order to evaluate the effect of the curing conditions, only the specimen with the optimum lime content were taken from the desiccator at the end of the curing time and soaked in water for 4 days and then the test was carried out. In order to be able to compare, soil specimen without lime was soaked in water for 4 days immediately after preparation and then tested. UCS test were carried out according to the procedures specified in ASTM D2166.

Fig. 1. Specimen preparation, desiccator curing and soaked specimen.

SEM-EDS analysis was performed on the specimen prepared with both the without lime and the optimum lime content (28 days cured) in order to evaluate the changes in the microstructure.

3. RESULTS AND DISCUSSION

3.1. Optimum Lime Content

The solutions were prepared by adding different lime content (1, 2, 3, 4, 5, 6, 7, 8, 9 and 10% by weight) and distilled water to natural soil and the pH values of these solutions were measured. As the lime content increased, the pH value increased and reached to 12.4% with 4% lime. The measurement results are given in Figure 2. The optimum lime content for the soil used in the study was determined as 4%.

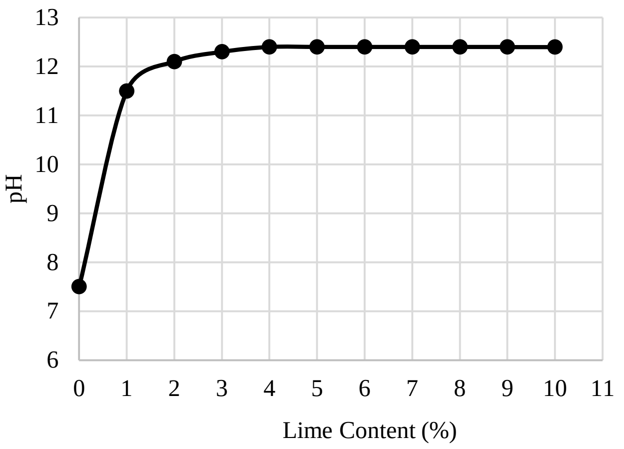

Fig. 2. pH values at various lime contents

3.2. Compaction Test Results

The results of the compaction test performed with modified proctor energy for different lime ratios are given in Figure 3. As seen from Figure 3, as the amount of lime increased, the maximum dry unit weight decreased and the optimum water content increased. While maximum dry unit weight of soil without lime were 17.1 kN/m^3 and optimum water content 16%, the maximum dry unit weight and optimum water content of 6% lime added specimens were determined as 16.1 kN/m^3 and 18.5%, respectively.

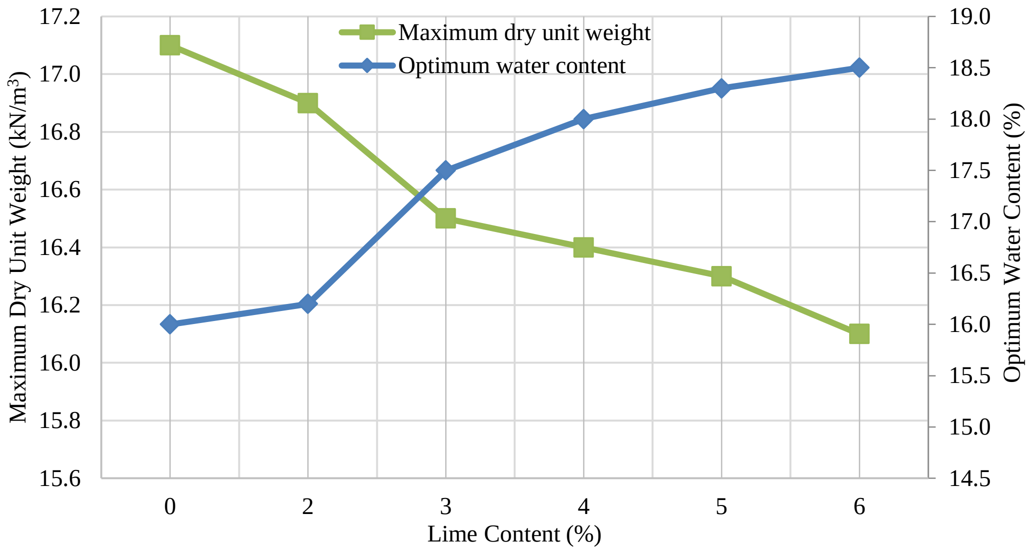

Fig. 3. Maximum dry unit weight and optimum water change for different lime percentages.

3.3. Unconfined Compressive Strength Test Results

A total of 84 UCS test specimens with five different lime content and without lime were prepared for the four different curing times and tested. The experiment was repeated three times for each case and the results were averaged. The UCS test results of specimens which are kept in desiccator for different curing time are given in Figure 4. As seen from Figure 4, the UCS values for all lime ratios increased with curing time. While UCS value of soil without lime was 428.50 kN/m^2, this value increased to 1126.9 kN/m^2 even at the end of 28 days curing time with 2% lime addition. 28 days UCS values of specimens with 4%, 5% and 6% lime reached 1400 kN/m^2. There was no significant increase in UCS value for 28 days curing time at rates above 4% optimum lime percentage.

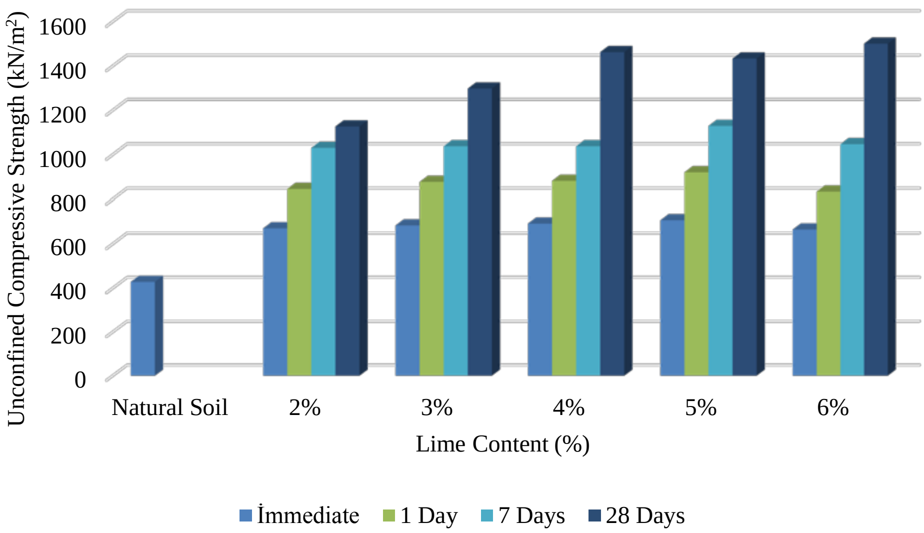

Fig. 4. Unconfined compressive strength change with curing time for different lime percentages

To determine the effect of curing conditions, specimens with 4% lime by weight (optimum lime content) and without lime were prepared and then soaked for 4 days after kept in desiccator. UCS values of the soaked specimens are given in Figure 5. UCS values of the soaked specimens prepared for the most adverse situation decreased significantly. The UCS value of soil without lime was obtained as 428.50 kN/m^2 for condition in the desiccator and 20.75 kN/m^2 for in soaked condition. Similarly, the UCS value of soil with %4 lime by weight after 28 days curing time was obtained as 1462.46 kN/m^2 for condition in the desiccator and 668.90 kN/m^2 for in soaked condition.

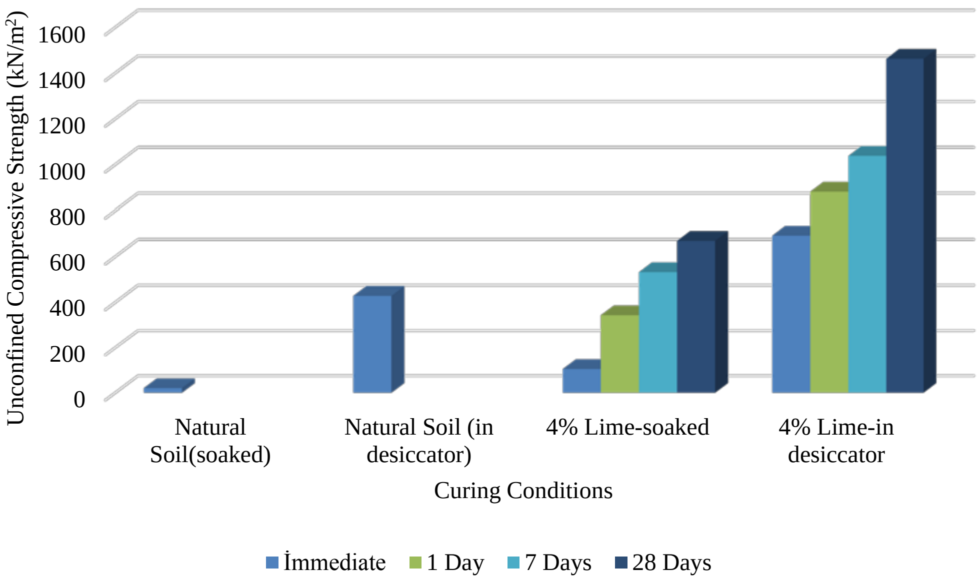

Fig. 5. Unconfined compressive strength change with curing time for different curing conditions.

For both curing condition, UCS test results of specimens prepared with 4% optimum lime content are given in Figure 6 and Figure 7. In both cases, it was observed that the strength increased significantly with the increase in the curing time but it is seen that more brittle behavior of the specimen.

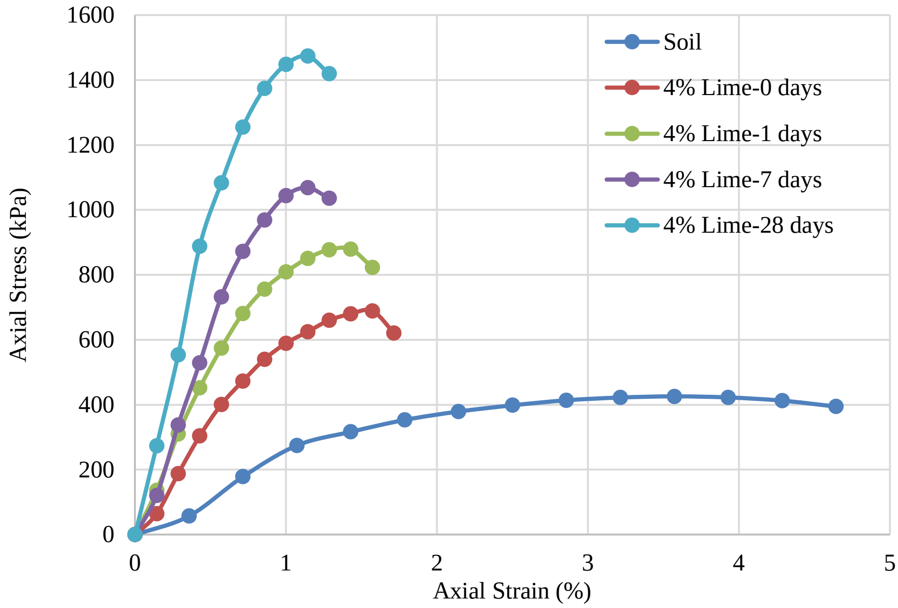

Fig. 6. Unconfined compressive strength change of soil prepared with %4 lime by weight for kept in desiccator.

As seen from Figure 7, soaked specimen without lime have very high axial strain and the unconfined compressive strength decreased from 428.50 kN/m^2 to 20.75 kN/m^2.

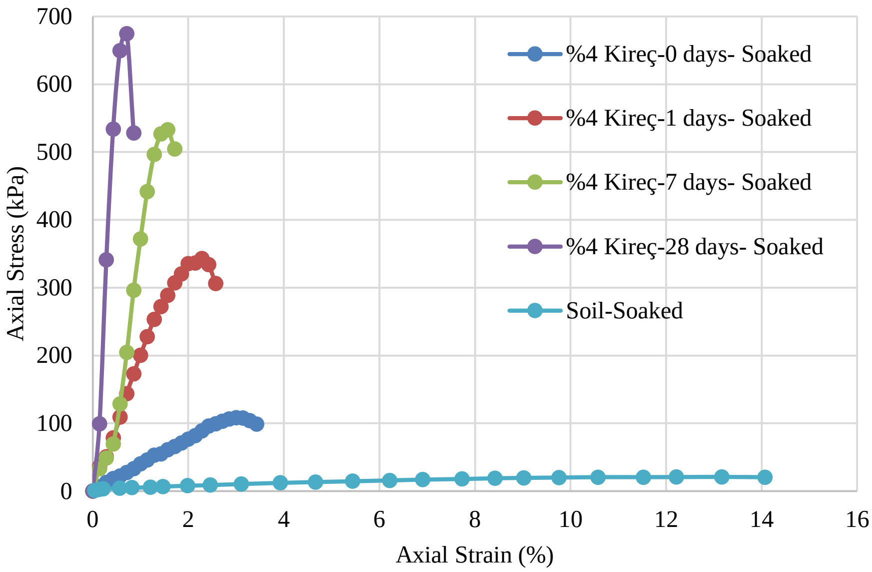

Fig. 7. Unconfined compressive strength change of soil prepared with %4 lime by weight for soaked

3.4. SEM-EDS Test Results

SEM-EDS analyzes were performed on sample without lime and sample with 4% lime at the end of 28 days curing period. Results are given in Figure 8 for sample without lime.

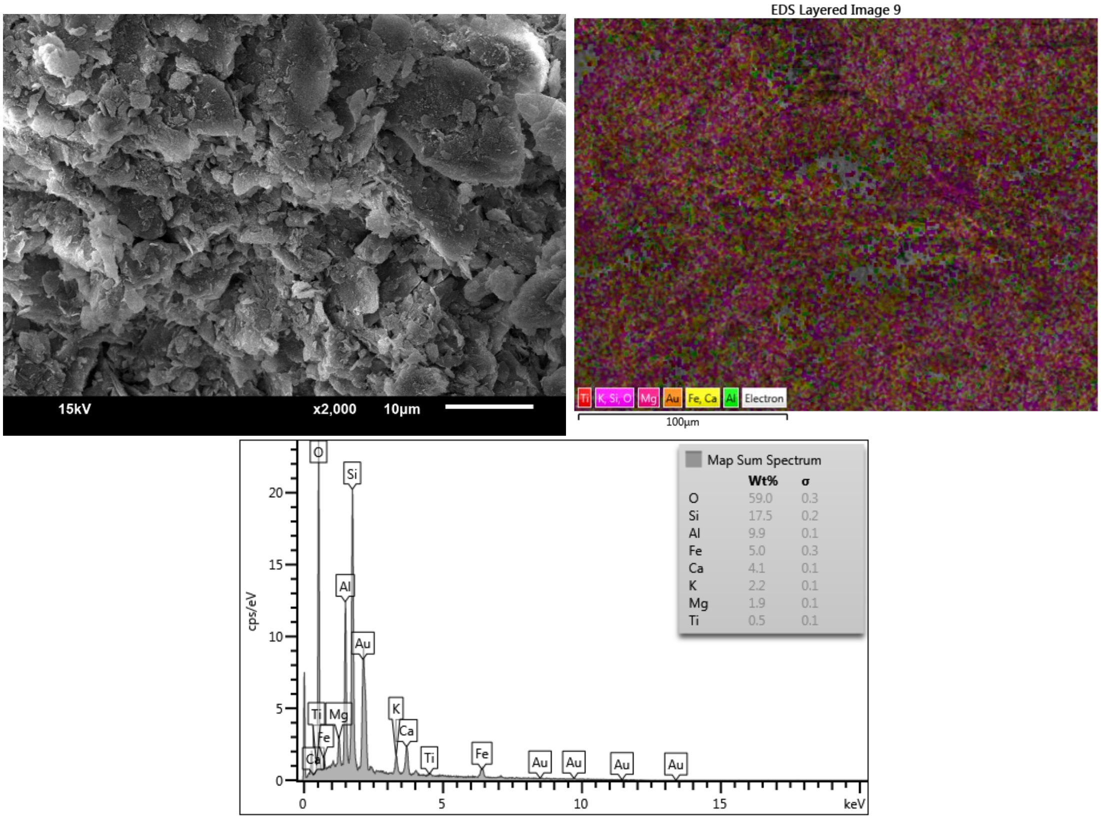

Fig. 8. SEM image, EDS spectrum, EDS mapping images for soil without lime

SEM-EDS analysis results of sample with 4% lime for 28 days cured are given in Figure 9. When SEM images are examined, it can be seen that the cementation in the microstructure is prominently formed.

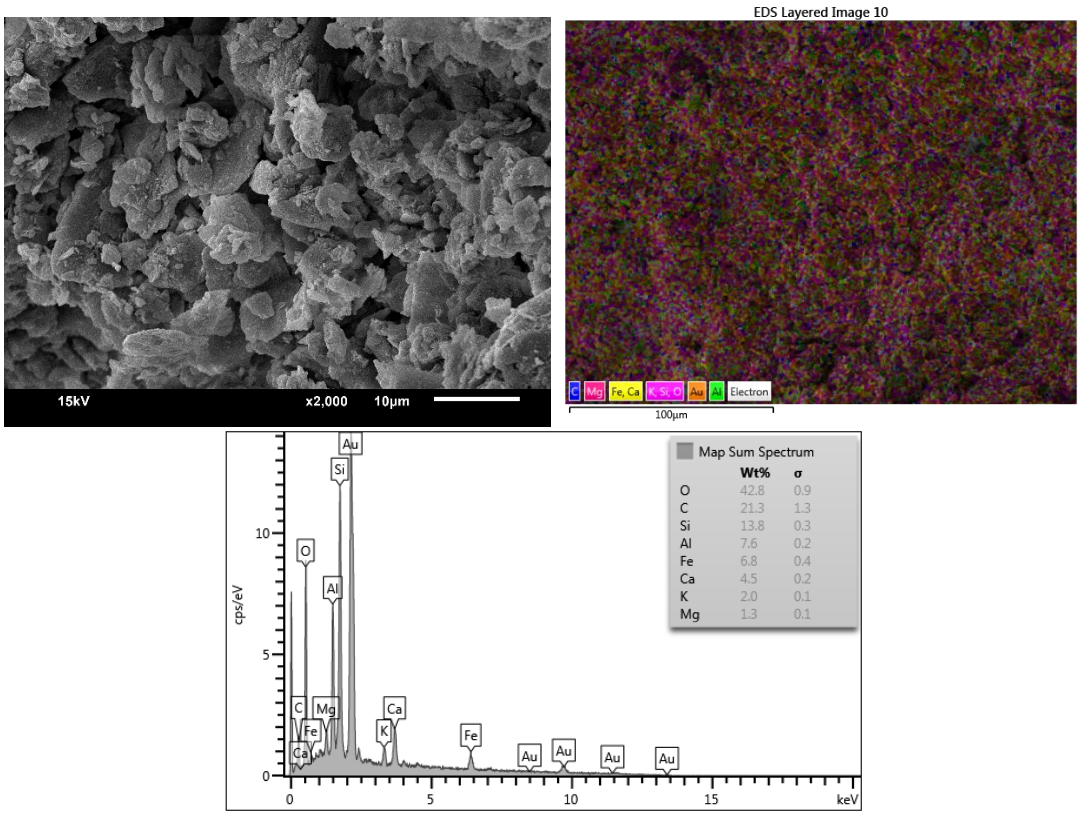

Fig. 9. SEM image, EDS spectrum, EDS mapping images for soil with 4% lime (for 28 days curing period)

4. CONCLUSION

- With the addition of lime, the optimum dry water content increased and the maximum dry unit weight decreased.
- The optimum lime content was determined as 4% for low plasticity clayey soil used in the study.
- As the lime content increased, the UCS increased significantly. However, there was no significant change in the 28 days UCS values for lime ratios higher than the optimum lime content.
- For 28 days, soaked UCS of the samples prepared with 4% optimum lime content decreased by approximately 50% according to unsoaked condition.
- It was observed that the strength increased significantly with the increase in the curing time but it is seen that more brittle behavior of the specimen.
- According to SEM/EDS analysis results, cementation was observed in 28 days samples with 4% lime additive.
- As a result, a very small amount of lime, such as 4%, improves the strength of a low plasticity clayey soil.
- Therefore, stabilization of soils in place with lime will reduce the use of natural resources in terms of sustainability. It will convert the unsuitable soils for engineering projects into usable construction materials.
- However, it would be appropriate to investigate the effect of lime soil stabilization on long-term performance and durability in more detail.

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