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Improving of the Subgrade Soil using Chemical Additives

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Abstract

Chemical additives were used in this research to improve the properties of the road subgrade layer. Cement, lime, and ferric chloride were used. Laboratory tests such as unconfined compressive strength, consistency limits, and wheel truck test were conducted. The results showed that adding these chemicals to the soil increases the ability of the soil to work, its resistance, and its durability. The optimum percentage of chemical additives that is suitable for the addition to the soil of Al-Nasiriya city were 9 %, 10 %, and 2 % corresponding to cement, lime, and ferric chloride, respectively. According to the unconfined compressive strength test and with increase curing period, which gave good results in improving the strength of the soil.

As for the consistency limits, all additives reduced the liquid limit and plasticity index and increased the plastic limit, according to the wheel track test, at 10,000 passes the Rutting depth was 32 mm for natural soil, also the depths were (14, 19, and 17 mm) with chemical additives, respectively.

Keywords: Cement, Lime, Ferric Chloride (Fe Cl_3), UCS, Consistency limits, Rutting test.

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1. Introduction

Soil is one of the most fundamental considerations in construction projects. Since the resistance and brief stability of any construction is largely determined by the soil beneath it. In recent years, replacing the weak soil layer with mixed gravel has made it possible to create the foundation layer for roadways. The cost of replacement is expensive, therefore this problem pushed researchers to look for other methods to solve the problem and keep costs down by researching how to improve the properties of the project's weak engineering soil without replacing it with mixed gravel. This is achieved by the use of mechanical methods to compact the soil and improve its properties or through the use of chemical additives that mix with the soil and improve its engineering properties, which is called to soil stabilization process [1], [2].

By binding soil particles together, soil stabilization is widely recognized as an alternative and effective method for improving the properties of engineering soils. Mechanical or chemical methods must be used in this process. Mechanical stabilization, on the other side, is the process of using mechanical compaction energy to increase the density of the soil. Chemical stabilization involves mixing or injecting effective chemical compounds such as cement, lime, fly ash, calcium, and sodium chloride into the soil, and using flexible and viscous materials like bitumen [3]. The use of the appropriate material to install a specific area depends mainly on the type of soil, the type of structure to be built, and the availability of this material to be used [4].

The chemical reaction that occurs when the chemical in question is applied to soil improves the physical and engineering properties of the soil, such as size stability, subsidence acceleration, increased resistance and permanence, and reduced soil compressibility and swelling. Chemical additives also help with flocculation and chemical bonding between molecules. When clay particles are electrically attracted to each other and forced together through sintering, the actual size of the flocculated clay particles increases, and the size of the flocculated clay particles becomes equivalent to fine silt. Furthermore, the chemical bonding forces between individual soil particles evolve with time, as they are dependent on each other. The chemical bonding forces that occur are dependent on the type of chemical stabilizer used [5].

From various contributions, the investigations on the improved properties of clay soil conducted by Meade and Allen (1993) [6], and József et al. (2015) [7] and found an improvement in the bearing strength of the soil and an increase in compressive strength when using lime.

As for cement, it was used by researchers Pandey and Rabbani (2017) [8], and Barbero et al. (2021) [9], and found a significant improvement in compressive strength and other soil properties.

Also, ferric chloride has been used to improve soil properties and increase bearing capacity by Jandial and Gupta (2020) [10], and Kiran et al. (2016) [11].

The main objective of this work is to know the effect of chemicals added on the subgrade layer in the roads of Al-Nasiriya city, determination of the optimum content of chemical materials which will give the best impact on the treated soil, study the effect of the curing period, comparison between the results of improved soils with chemical additives in terms of soil properties (Atterberg limits and rutting test).

2. Materials and methodology

2.1. Materials

2.1.1. Soil

The soil was collected in one of the sites of the city of Al-Nasiriya at a depth of 2 meters from the level of the natural ground. The chemical properties of the soil are shown in Table 1.

Table 1. Chemical properties of soil.

No.	Composition	Value %
1	Al_2O_3	0.34
2	SiO_2	9.42
3	CaO	49.91
4	Fe_2O_3	0.219
5	K_2O	0.133
6	MgO	0.1
7	Cl	0.188
8	Na_2O	0.01
9	SO_3	0.98
10	Loss on Ignition	37.94

2.1.2. Cement

The cement (SEM 42.5 N – SR 3.5) made in Iraq was used to conduct the tests. The chemical properties were checked and shown in Table 2.

Table 2. Chemical properties of cement.

No.	Composition	Value %
1	SiO_2	21.63
2	CaO	56.54
3	Fe_2O_3	6.17
4	Al_2O_3	5.13
5	MgO	3.08
6	Lime saturation factor	0.783
7	Burning loss	3.21
8	SO_3	2.16
9	C_3A	3.22
10	Insoluble substances	1.23

2.1.3. Lime

An Iranian type of lime was used and its chemical properties are in Table 3.

Table 3. Chemical properties of lime.

No.	Composition	Value %
1	$MgCO_3$	1.13
2	$CaCO_3$	89.5
3	MgO	1.38
4	CaO	44.4
5	Al_2O_3	4.2
6	SiO_2	11.89
7	L.O.I	35.6
8	Fe_2O_3	3.3

2.1.4. Ferric Chloride

The ferric chloride used is a dark orange liquid with a concentration of 43±2 %. The chemical properties were obtained from the importing company as shown in Table 4.

Table 4. Chemical properties of ferric chloride.

No.	Test	Result	Specification
1	Appearance	Complies	Clear Dark Brown Liquid
2	Specific Gravity	1.436	1.43 - 1.47 min
3	Assay as ($FeCl_3$)	42.29 %	43 ± 2 %
4	Free Acid as (HCL)	0.078 %	0.03 % max
5	Insoluble Matter	0.026 %	0.06 % max
6	Ferrous Salts as ($FeCl_3$)	Within Limits	0.11 % max
7	Free Chlorine as (CL)	0.0052 %	0.02 % max
8	Nitrates as (NO_3)	0.0084 %	0.06 % max
9	Sulphates as (SO_4)	0.224 %	0.31 % max
10	Zinc as (Zn)	0.0063 %	0.02 % max
11	Copper as (Cu)	0.0021 %	0.16 % max
12	Alkalies and Alkaline earths	0.143 %	0.21 % max
13	Arsenic as (As_2O_3)	0.00013 %	0.0003 % max

2.2. Methodology

In this study, the soil sample was passed through Sieve No. 4 after it was crushed with a hand hammer, the engineering properties of natural soils such as Initial Water Content, Compaction, and Specific Gravity were tested. After that, Consistency Limits, Unconfined Compression Strength (UCS), Rutting Tests and were used for unimproved and chemically treated soils.

2.2.1. Unconfined compressive strength of soil (UCS)

This test was conducted on unimproved soil and soil improved with chemical additives by molded with a diameter of 30.5 mm and a height of 71 mm. For cement, percentages of (1, 3, 5, 7, 9, and 11%) of the weight of dry soil were added. For lime, (4, 7, 10, and 12 %) of the dry soil weight as well, in addition to ferric chloride (0.5, 1, 1.5, 2, and 2.5 %) was used.

The UCS tests were conducted at treatment period of 1 and 7 days to determine the effect of the treatment period on increasing the durability of the improved soil, Fig. 1 shows samples that were tested using a plastic bag to keep samples from drying out.

Fig. 1 Preparation and testing of UCS samples with additives.

2.2.2. Atterberg limits

After obtaining the optimum percentages of chemical additives from the UCS test. These optimum percentage were used to test the consistency limits of soil at a treatment period of 0, 1, and 7 days, Fig. 2 shows the preparation of samples for testing.

Fig. 2 Soil samples improved with chemical additives.

2.2.3. Rutting test

The device manufactured by the researcher was used as shown in Fig. 3 for the purpose of testing the rutting at 10,000 passes, and with a weight of 9 kg, a sample was prepared in a tank with dimensions of (100 width, 60 length and 80 cm height), The compaction were on 4 layers, each layer 30 blows, using a hammer with a weight of 10 kg and a contact area of (10 × 10) cm.

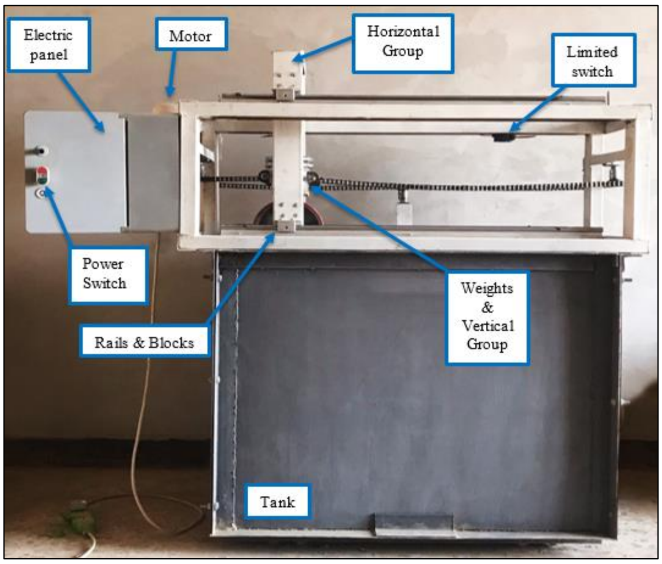

Fig. 3 Device parts overview.

Fig. 4 Sample preparation for normal soil and treated soil.

For the testing of the natural soil, the tank was divided into four layers and each layer was 25 cm, also the amount of water is 16.3 % of the weight of the layer, as for the chemical additives the optimal percentage for each additive were added to the last layer only, which is 25 cm high, and at curing period of one week for all samples.

3. Results and discussion

3.1. Experimental investigation on soil sample

Results for the natural untreated soil are summarized in Table 5 which includes: Initial water content, liquid limit, plastic limit, grain size by hydrometer, classification of the soil according to USCS and IS, specific gravity, Compaction parameters, UCS of the soil, and rutting test.

Table 5. Engineering properties of weak subgrade.

Properties	Result	Specification
Specific Gravity of Soil	2.61	ASTM D 854-14 [12]
Initial Water Content	10 %	ASTM D 4643-00 [13]
Liquid Limit	36.5 %	ASTM D 4318-00 [14]
Plastic Limit	20.22 %	
Plasticity Index	16.28	
Maximum Dry Density	1.804 gm/cm^3	ASTM D 1557-12 [15]
Optimum Moisture Content	16.3 %	
Unconfined Compressive Strength (UCS)	344 kN/m^2	ASTM D2166-00 [16]
Rutting value at 10000 passes	32 mm	
Hydrometer Test	See Fig. 5	ASTM D 422-63 [17]
IS Classification of Soil	A6	
UCSC Classification of Soil	CL	

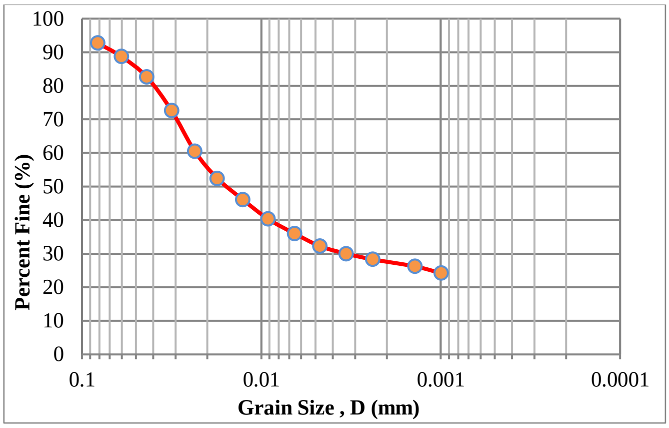

Fig. 5 Hydrometer test for soil.

3.2. Determination of the optimal percentage by UCS test

Soil cement laboratory handbook [18], and an introduction to soil stabilization with Portland cement [21] select the value of cement was 9 % weight percentage of dry soil. And UCS value must be at 7 days generally between 300 psi (2068.4 kPa) and 800 psi (5515.8 kPa) and also soil stabilization with Portland cement [19], this book referred to minimum UCS for cement stabilized soils was from 200 psi (1378.9 kPa) to 400 psi (2757.9 kPa). And soil stabilization for pavement [20] reported the range for UCS at 7 days as 250 psi (1723.68 kPa).

In this study, the percentage of cement will be adopted as 9 % of the dry weight of the soil as the optimal percentage for other soil tests. Fig. 6 indicates the results of the UCS test at 1 day and the Fig. 7 shows the results at 7 days.

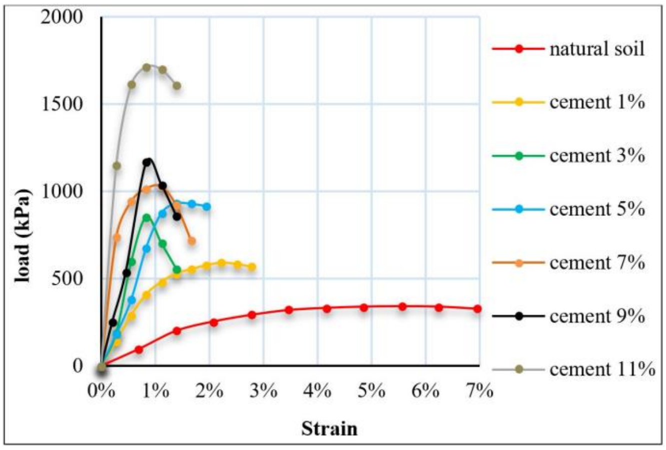

Fig. 6 UCS for (soil + cement) at 1 day.

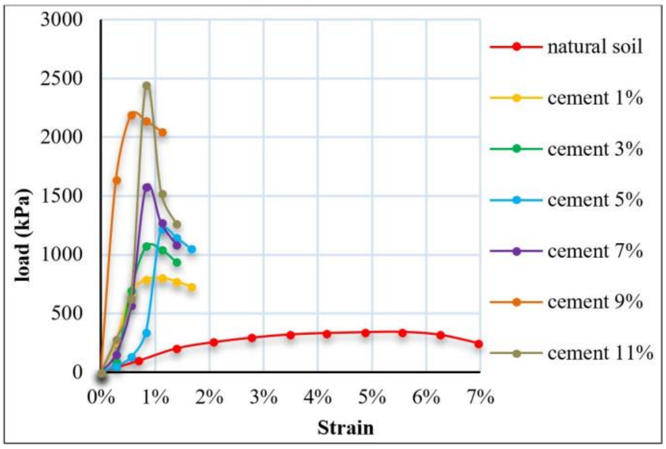

Fig. 7 UCS for (soil + cement) at 7 day.

For Lime, According to UCS determined by Iraqi General Specifications for Roads and Bridges [22], the value of UCS test at 7 days curing must not be less than 1.0 N/mm² (1000 kpa). The UCS test results obtained in this work, the percentage of adding 10 % of lime to soil gave a higher UCS value and thus the Iraqi standard was met. Figs. 8 and 9 refer to the UCS test at 1 and 7 days, respectively.

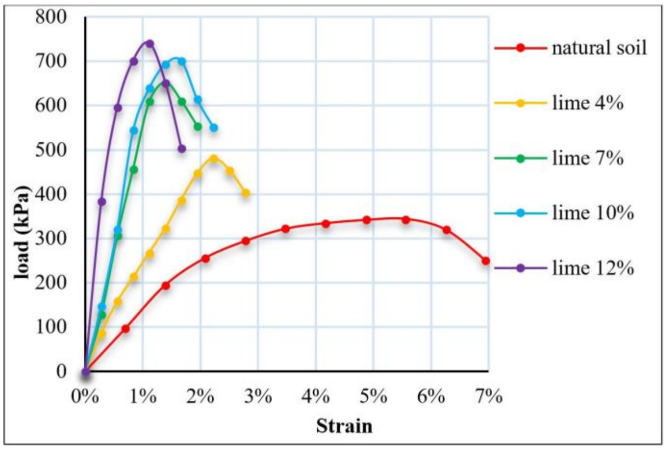

Fig. 8 UCS for (soil + lime) at 1 day.

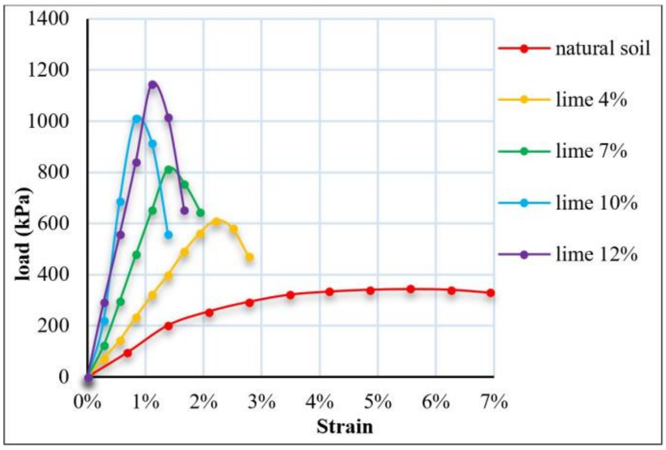

Fig. 9 UCS for (soil + lime) at 7 day.

Many researcher works have been done to improve soils with Ferric chloride [10], [11], [23]-[27]. During their review found that the UCS test is appropriate to determine the optimum percentage, and after that, the UCS value will decrease.

Figure 10 indicates the UCS test at 1 day. Also, from the Fig. 11 the optimum percentage of UCS was reached at 2 % of the $FeCl_3$ adding, and then this value decreased. Accordingly, 2 % of the dry soil weight was named as the optimum percentage.

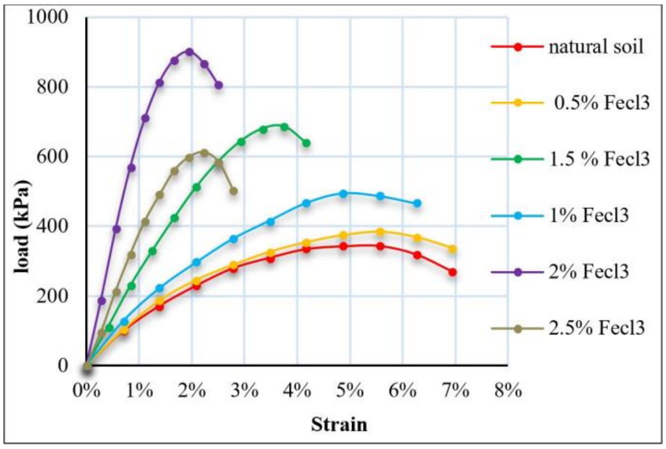

Fig. 10 UCS for (soil + $FeCl_3$) at 1 day.

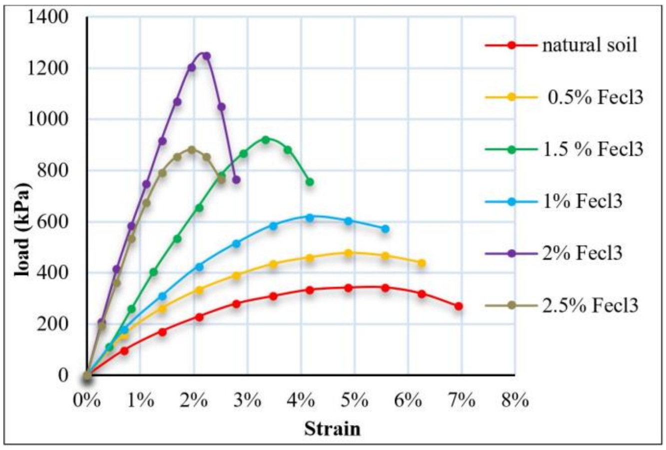

Fig. 11 UCS for (soil + $FeCl_3$) at 7 day.

Figure 12 and Table 6 show a comparison between chemical additives to soil and the effect of curing period (1 and 7 days) on UCS values.

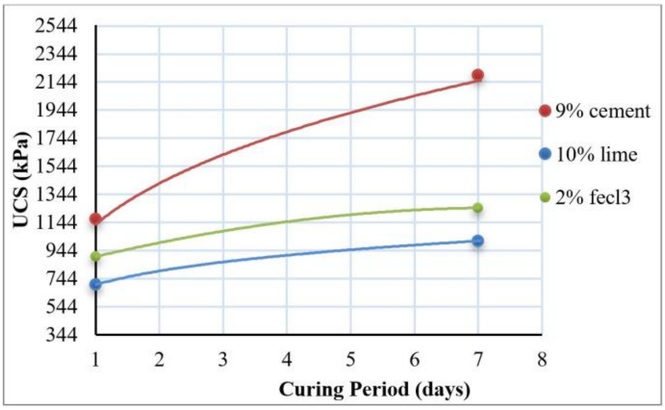

Fig. 12 Treatment influence on the UCS for optimum additives.

Table 6. Comparison the UCS results and curing period.

Improvers materials	Percentage %	UCS (kN/m^2)	
		Cuing 1 day	Cuing 7 day
Cement	0	344	344
	1	668	803
	3	856	1070
	5	932	1219
	7	1031	1579
	9	1172	2195
	11	1716	2444
Lime	0	344	344
	4	483	573
	7	654	710
	10	702	1014
	12	742	1148
$FeCl_3$	0	344	344
	0.5	386	479
	1	496	621
	1.5	688	924
	2	902	1250
	2.5	613	882

3.3. Atterberg limits

The effect of the chemical additives on the consistency limits and influence of curing is presented in Table 7. Also Figs. 13, 14, and 15 show the effect of the curing period on the liquid limit, the plastic limit, and the plasticity index, respectively.

Table 7. Comparison between results and the curing influence on the soil.

Type of soil	Atterberg Limits	Curing Period		
		Immediately	After 1 day	After 7 days
Untreated soil	LL	36.5	-	-
	PL	20.22	-	-
	PI	16.28	-	-
9 % Cement-Treated soil	LL	35.2	31.4	30.1
	PL	20.9	21.8	22.6
	PI	14.3	9.6	7.5
10 % Lime-Treated soil	LL	34.8	30.6	30.4
	PL	20.6	21.3	21.7
	PI	14.2	9.3	8.7
2 % $FeCl_3$-Treated soil	LL	35.9	32.5	31
	PL	20.7	20.8	21.4
	PI	15.2	11.7	9.6

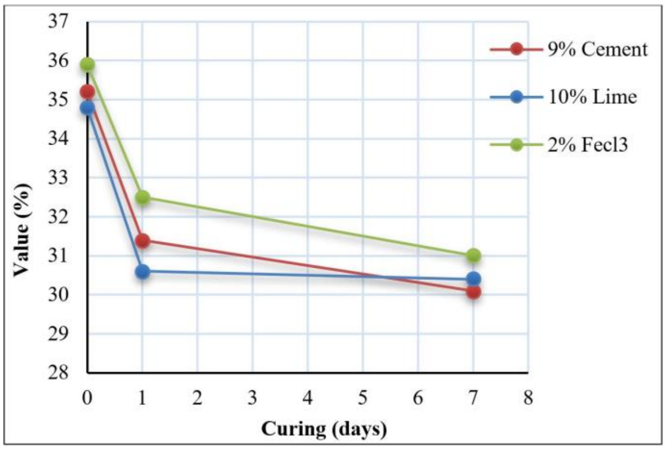

Fig. 13 Effect of additives and curing period on the liquid limit.

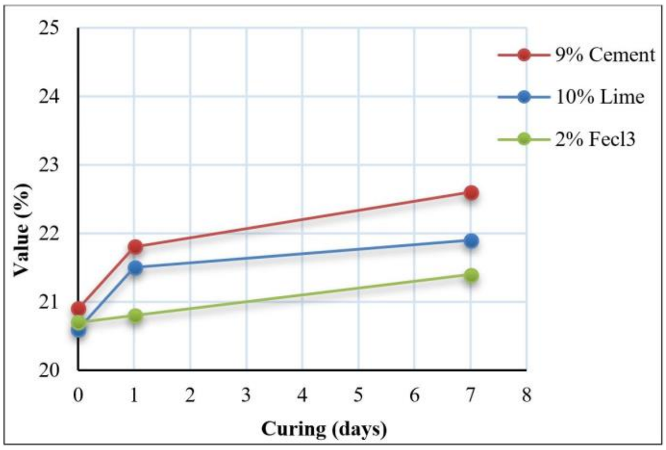

Fig. 14 Effect of additives and curing period on the plastic limit.

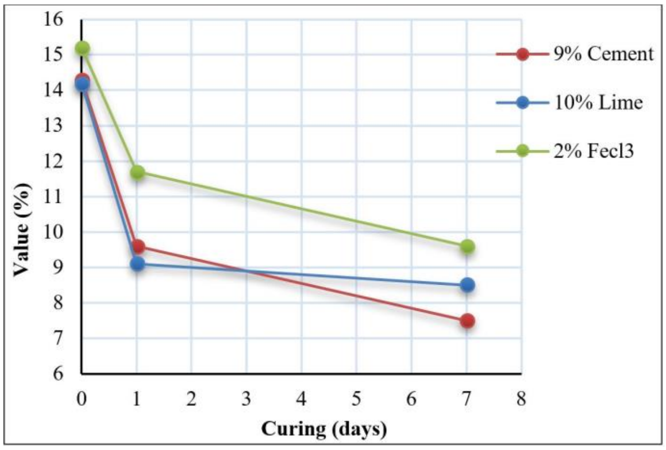

Fig. 15 Effect of additives and curing period on the plasticity index.

The effect of adding 9 % cement by the dry weight of the soil has almost the same effect as ferric chloride on the liquid limit as shown in Fig. 13. This similarity can also be seen in the plasticity index values as shown in Fig. 15, it can be indicated that the similarity of the released cations with the exchange complex can act the same way.

Further, the plastic limit value increased for soil treated with 10 % lime at 1, and then at 7 days the increase was less in contrast to the action of ferric chloride and as shown in Fig. 14. In addition, the plasticity index value of cement decreased more than that of lime on the 7 days of treatment as illustrated in Fig. 14.

3.4. While truck test

Figure 16 and Table 8 show the comparison between the results of the materials with each other as well as with natural soil. And found that cement had the most effect on reducing the rut depth, followed by ferric chloride, and finally lime. The rutting depth can be calculated as shown in Fig. 17.

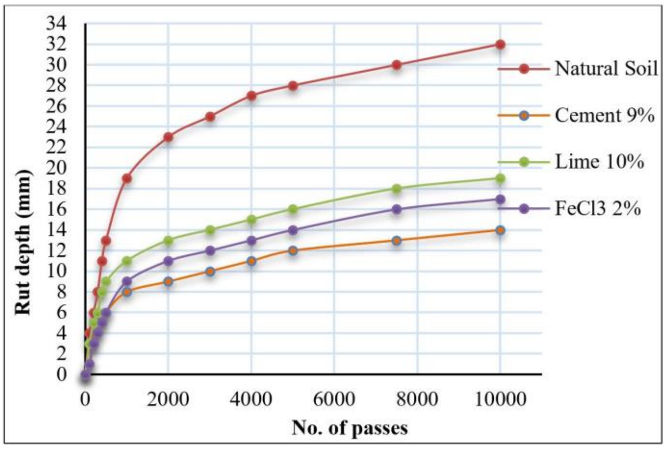

Fig. 16 Comparison of rutting between soil and additives.

Table 8. The rutting depth for natural soil and optimum additives.

No. of passes	Rut depth (mm)			
	Natural Soil	Cement 9 %	Lime 10 %	$FeCl_3$ 2 %
0	0	0	0	0
100	4	1	3	1
200	6	3	5	3
300	8	4	6	4
400	11	5	8	5
500	13	6	9	6
1000	19	8	11	9
2000	23	9	13	11
3000	25	10	14	12
4000	27	11	15	13
5000	28	12	16	14
7500	30	13	18	16
10000	32	14	19	17

Fig. 17 The rutting occurred of the test samples.

4. Conclusions

From the present study, we can conclude the following:

1. By observing the results of the UCS test by adding cement, lime and ferric chloride, it was found that the percentage of improvement was (340 %, 638 % and 731 %) respectively and at a curing period of 1 day, as well as those values increased after one week's treatment period as follows (204 %, 294 % and 350 %) respectively.
2. All chemical additives led to an increase in the plastic limit, as well as a decrease in the liquid limit and plastic index, and this behavior continued with the treatment period to 1 week.
3. By comparing the results of the additives to the natural soil and by testing the rutting of the soil, it was found that the highest percentage of improvement was 56.25 % when adding cement, followed by ferric chloride, which gave an improvement rate of 46.88 %, and finally lime material gave a good improvement and was 40.63 %.
4. Although cement showed the highest positive effects, however, ferric chloride can also be recommended because it showed the second-best effect as an additive as well as it has the lowest percentage (2 %) in contrast to other additives. Also, since it is a liquid material, it is very easy and suitable to be used by mixing it easily with the used water in the field.

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