EXPERIMENTAL EVALUATION OF CALCIUM CHLORIDE POWDER EFFECT ON THE REDUCTION OF THE PAVEMENT SURFACE LAYER PERFORMANCE

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ABSTRACT

Some roads have a gravel layer and most asphaltic roads have gravel shoulder and part of that sand is fine grained soil. Road dust increases in heavy traffic and affects safety, economy, quality and environment. Different stabilizers are used to control the dust in gravel topping roads. One of them is calcium chloride. One of its common uses is the dust control in gravel topping roads. In this research, in order to achieve the optimal mixture procedure after grading the gravel material of pavement surface layer, the effect of calcium chloride salt on the physical properties of the fine grained part was investigated in different percent of calcium chloride samples and different percent of moisture in two dry cases. Results show that increasing the calcium chloride percent in the dry case, the moisture absorption amount of the fine grained part of the gravel topping materials is increased, by contrast, uniaxial tensile and compressive strengths decrease with the increase of calcium chloride more than certain percent. The amount of calcium chloride has a reverse effect on liquid limit, plasticity limit and plastic index, conversely, uniaxial tensile and compressive strengths such that increasing the calcium chloride salt by 6% will increase the plastic limit by 6% and the liquid limit by 12% and plastic index by 25% and also the uniaxial tensile strength is increased by 11% and the uniaxial compressive strength is decreased by 36%.

KEYWORDS

Road pavement; Axial strength; Calcium chloride; Moisture absorption; Gravel surface layer

INTRODUCTION

Land transport systems, especially roads, play an important role in economic and social development. The lowest traffic and rural roads are important roads for some industries and factories, farmers and stockbreeders they can be used for transporting raw materials and products and are made of gravel surface layer. These roads are mostly considered as the lowest level of facilities and most governments provide a cover for these roads in order to provide better services for the villagers. One of these methods is the use of calcium chloride and magnesium chloride solution in roads and passages to reduce dust. Due to the availability of these minerals in the desert, there is the ability to use these materials to avoid the costs imposed on the transportation system, as well as to protect the environment and sustainable development of roads.

The project of roads change has been performed in 27 states of USA. Most of the roads are changed into unpaved ones in these 27 states are subjected to a mean daily traffic volume in a range of 21 to 100 vehicles [1]. Disregarding the problems of the unpaved roads may lead to public dissatisfaction and reduction of exploiting amount and also high costs and cause some problems for creatures from safety aspect [1]. Dust is increased by the increase of traffic that affects the vehicles driving conditions and endangers them [2]. In order to control the dust, stabilizers are used and calcium chloride is one of them. Calcium chloride is the salt of calcium and chlorine that behaves as the halide ion sample and it is in solid state at room temperature. Since this substance is sensitive to moisture, it is kept in containers [3]. Usually calcium chloride is used for snow and ice melting at passageways and mountainous roads in winter; soil roads dust control, soil stabilization of desert zones, gas and oil industries and accelerating concrete in winter season [4]. Calcium chloride and magnesium chloride are both capable to absorb the air moisture.

Calcium chloride can absorb moisture up to 17 times more than its weight at a relative humidity of 95%. Among the environmental advantages of the use of calcium chloride and magnesium chloride solution, we can mention its capability to control the dust, reduce the respiratory disease, increase visibility and accidents reduction, reduce the road and vehicles maintenance cost (in such a way that has avoided the creation of bump and damage to the roads infrastructure), solve the problems of the road side inhabitants, improve the quality of agricultural products. Thus it is quite natural and the constituents of this solution are not harmful for the environment [4]. Shukla et.al funded that, the mixing of potassium chloride growths the unconfined compressive strength and shrinkage limit of soil. Best quantity of potassium chloride is found to be almost 8-9% of dry soil mass [5]. In previous study, Saberian and Khabiri examined the effect of ordinary Portland cement on the strengths and plasticity of soil contaminated with diesel [6]. The Oil Palm Fronds (OPF), which is a waste material, was used to stabilize the lateritic soil by Nnochiri, and Aderinlewo [6].

Khabiri et al. have investigated in their research the effect of calcium chloride salt on the fine grained physical properties in different percent of calcium chloride and different percent of moisture in two dry cases in order to reach the optimum admixture procedure. Results showed that by increasing the percent of calcium chloride in dry condition, the moisture absorption capability of the fine grained part of the gravel surface layer is increased. This moisture increase can be up to 80%. Furthermore, the amount of calcium chloride has a negative effect on the liquid limit l, plastic limit and plastic index such that increasing the calcium chloride salt by 6%, the plastic limit, liquid limit and plastic index have increased respectively by 6, 12 and 25 percent [8]. Latsford et al. have investigated the road gravel surface layer in the USA in their research. Their study shows that almost 40% of USA roads have gravel surface layers. They used a type of clay stabilizer based on the traffic volume in order to control the dust on the surface of these roads [9].

Echt et al. have investigated the amount of produced dust due to drilling and respiratory problems faced by workers in a research. They have found by measuring the amount of dust in a case study in drilling that the maximum volume of the produced dust is due to quartz. After adding silica additive they have concluded that this additive significantly reduces the ambient dust [10,11]. Wood et al. in their research to control the wastes resulted from hot asphalt recovery and substituting these wastes by sand concluded that calcium chloride reduces the dust that is resulted from the extra addition of sand to asphalt on the roads surface [11,12].

Prasad et al. investigated different types of stabilizers of soils in their study. These stabilizers can be of solid wastes that can improve stability, durability and moisture absorption of soils. They concluded that the grit and calcium chloride waste additive can lead to soil stability [13]. Silac et al. have investigated the effects of plants ash and calcium chloride on the soil stability in a research. They concluded that calcium chloride is very efficient in controlling the dust. Also in researches that were performed in Texas transportation institute, it was shown that the mixture of calcium chloride and plant ash change the physical and chemical nature of this mixture and improves roads performance [14].

One of the problems of gravel surface layer roads, dust stabilizers is that they are rain-washed. In the studies that were performed on stabilizers, the results showed that calcium chloride removes a part of clay. Thus, it avoids its saturation under moisture [15]. More than 50% of USA roads are sand surface layer roads and they know them as a vital section of the transportation system. One of the biggest disadvantages of gravel roads is dust that is imposed to them on the vehicle transportation time. Inhabitants that live near gravel roads surface problems such as dust that is settled on their houses and cars and this decrease their life quality. Dust can also have undesirable effects on the air and environment quality and reduce safety (visibility disturbance) for the drivers. In order to control dust in gravel roads, local organizations use dust stabilizers on their roads that are usually calcium chloride and magnesium chloride but there are some other substances [16].

There are many ways for soil stabilization that one of their most important ones is the use of electrolytes for the dust control. Venkara performed some tests on electrolytes such as calcium chloride and potassium chloride [17]. Bahari et al. investigated clay nanocomposite material with 1% weight ratio with the considered area soil in their research. By performing uniaxial compressive strength and consolidation tests on the soil, it was observed that by adding Nano clay to the soil, the amount of shear strength, adherence and compressibility of soil are increased [18]. In researches that have been performed under the name of "effectiveness and environmental effects of road protective material" in Colorado State of the USA, the following results are derived:

- The type of stabilizers is effective on the amount of runoff or the road surface affect after raining.
- By increasing the vehicle speed, the produced dust in the road is increased.
- It seems that using Lignum stabilizers in some cases is more effective than calcium chloride and magnesium chloride stabilizers [16,17].

In any cases few researcher have focused on the issue of calcium chloride powder effect on the reduction of dust emissions of the pavement surface layer.

The purpose of this study is to investigate the effect of calcium chloride amount on the soil engineering properties and also this salt effect on the compressive and tensile strength of soil in gravel surface layer roads. Regarding the research process, physical and mechanical tests were carried out on soils containing calcium chloride. These tests include identification of soil plasticity properties and the effect of calcium chloride on these soil characteristics, and since the top granular layer is under the loading of the vehicle's wheel, its resistance to damage were also investigated by laboratory tests.

MATERIALS AND METHODS

Calcium chloride whose natural type is salt is available in sea water and can be extracted from salt bed in nature. Oromiyeh Lake is one of the biggest lakes in the world. The salt of Oromieh Lake is composed of minerals such as potassium, calcium, magnesium and many other minerals [8]. The chemical component and formula of calcium chloride is found in nature in the forms presented in table 1[14].

Tab. 1 - Calcium chloride compounds available in nature and their molar mass [14]

Name	Chemical components	Molar mass(gr/mole)
Calcium dichloride	$Cacl_2$	110.99
Calcium chloride dihydrate.	$Cacl_2.2H_2O$	147.02
Calcium chloride tetrahydrate	$Cacl_2.4H_2O$	183.04
Calcium chloride hexahydrate	$Cacl_2.6H_2O$	219.08

Determination of the soil properties

In order to determine the properties of the soil, two tests were performed on the samples:

a) Plastic limit test is the moisture percent in which sample is at the beginning of plasticity, in other words it is the intermediate point between plastic and semi-solid states (ASTM D4318 - 17 Standard Test Method).

b) Liquid limit test, is the boundary between plastic and liquid states and is the moisture percent in which soil has a little shear strength. In other words, the sample moisture content at the beginning of liquid limit (ASTM D4318 - 17 Standard Test Method).

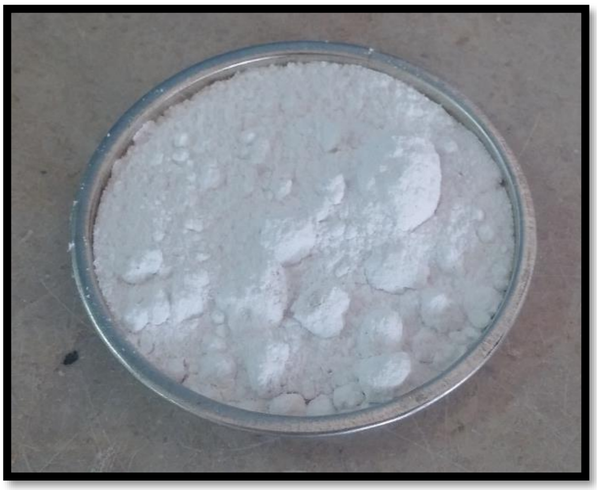

Fig. 1 - Used calcium chloride salt in the experimental tests

Studies show that calcium chloride salt helps in water absorption by the soil [8]. During the Atterberg limit test, the residual of the soil that was mixed with different percent of calcium chloride salt was wetted after some time that shows the ambient moisture absorption by soil. Also the test showed that calcium chloride salt reduces the tensile and compressive uniaxial strength (ASTM D2166 / D2166M - 16) and also by increasing the percent of calcium chloride salt in the soil, the adherence between the soil particles become less and the unoccupied volume will be more. In order to achieve these results, soil samples with different percent of 0, 2, 4, 6 of calcium chloride was compressed in this study and then was subjected to tensile and compressive uniaxial test.

Fig. 2 - Samples compression and Soil Sampler *test*

Fig. 3 - Compressed Soil Sample for UCS

Atterberg limit and soil moisture absorption

The Atterberg limits are a simple measure of the critical water fillings of a fine-grained soil, its shrinkage limit (SL), plastic limit (PL), and liquid limit (LL). In Figure 4, the results of the liquid limit and plasticity limits with different percent of calcium chloride salt are presented. Figure 4 shows that there is a reverse proportion between the salt percent and the soil liquid limit and by adding calcium chloride to soil; the liquid limit and plasticity of soil are reduced.

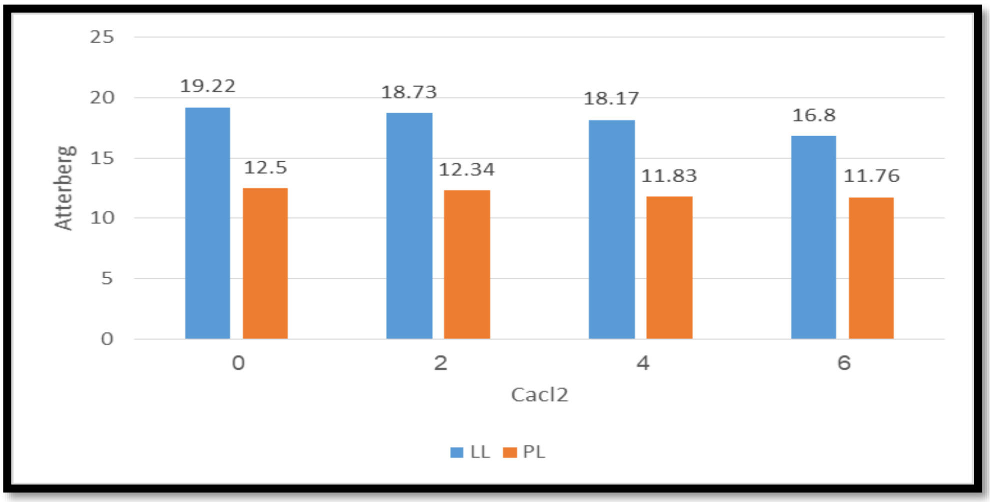

Fig.4 - Comparison of soil liquid limit and plasticity effect for different percent of calcium chloride salt

A definite amount of fine grained soil of road gravel surface layer that has been passed through sieve and combined with different amounts of calcium chloride including 0, 2, 4, 6 weight percent and put for 3 hours in the furnace. After 3 hours, the samples have been taken out of the furnace and the weight of each was measured and the specimens were subjected to ambient moisture for 48 and 72 hours in the laboratory.

The results show that the increase of calcium chloride amount will increase the amount of moisture absorption and also the time increase from 48 to 72 hours lead to a 35% increase in the moisture absorption.

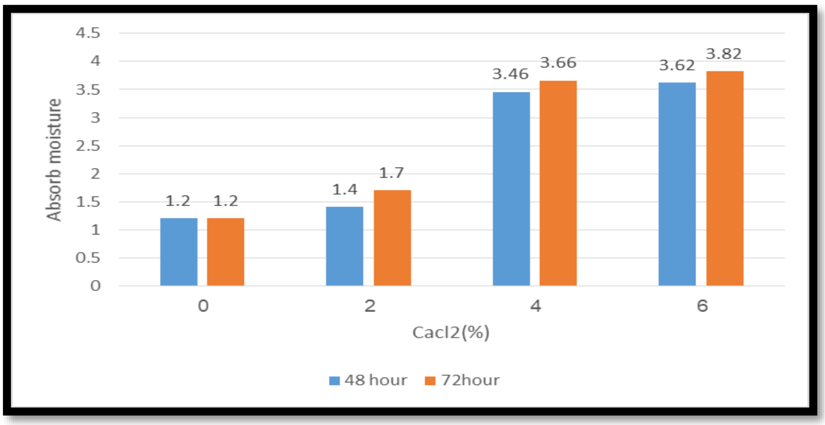

Fig.5 - Results of the soil moisture absorption for different percent of 48 and 72 hours' calcium chloride

Figure 6 shows that there is a direct relation between the moisture absorption and salt increase. By increasing the salt amount, the moisture absorption is increased and this moisture absorption is observable up to 90 percent compared to the typical soil.

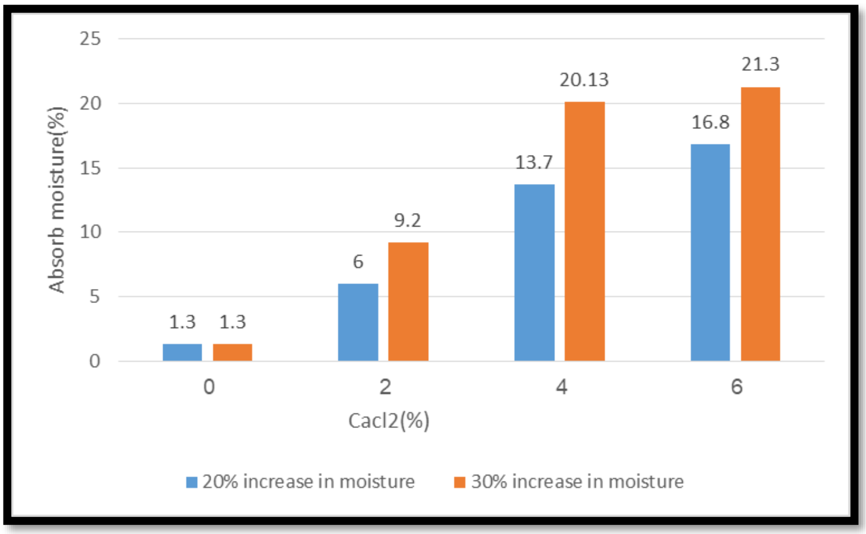

Fig.6 - Results of soil moisture absorption for different percent of calcium chloride

Unconfined compression and indirect tension tests

By increasing the calcium chloride salt percent, the required strength for the vertical and horizontal deformations of specimens is reduced. Thus it can conclude that the increase of calcium chloride salt percent leads to a reduction in the soil strength and accelerates the soil rupture.

Tab. 2 - Comparison of the required strength amount for the soil deformation at different percent of salt

Displacement (0.1 millimeter)	Strength (Kn) Unconfined Compression			
	$Cacl_2$(0%)	$Cacl_2$(2%)	$Cacl_2$(4%)	$Cacl_2$(6%)
5	0.1188	0.066	0.066	0.0396
10	0.2376	0.1188	0.1188	0.066
15	0.3036	0.1518	0.1254	0.0924
20	0.33	0.1716	0.132	0.1188
Strength (Kn) - Indirect Tensile Test				
5	0.0924	0.0396	0.0264	0.0132
10	1716	0.1056	0.066	0.0198
15	0.2112	0.1254	0.0792	0.0264
20	0.2376	0.132	0.0792	0.0264

Figure 7 shows that the increase in the calcium chloride salt will reduce the horizontal and vertical uniaxial strengths for the specimen rupture. This decrease in strength can be due to the reduction of adherence amount between the soil particles and the increase of free space (void) in the soil. Such that by an 4% increase of the calcium chloride salt, the vertical strength of the specimen for 0.5mm and 2mm displacements reduced respectively by 40% and 31% and the specimen horizontal strength in 0.5mm and 2mm displacements reduced respectively by 66% and 80%.

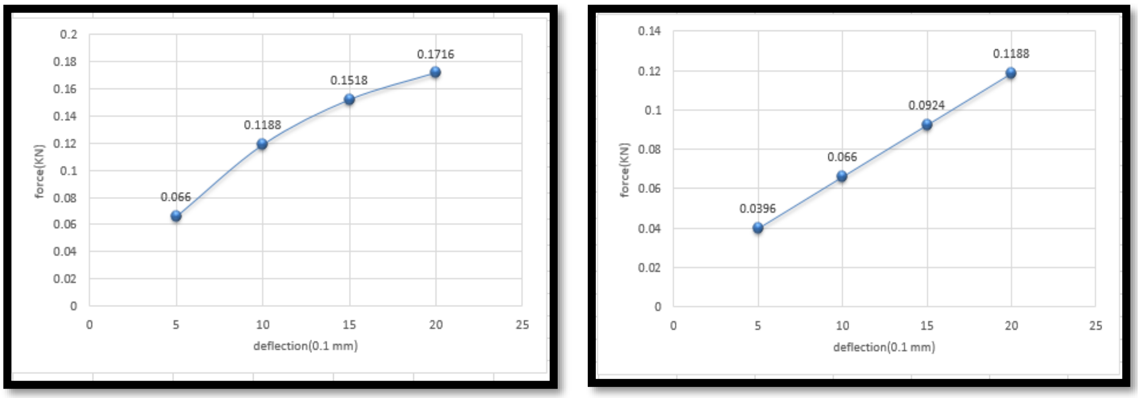

Fig.7 - Uniaxial test of 6% calcium chloride (right) uniaxial test of 2% calcium chloride (left)

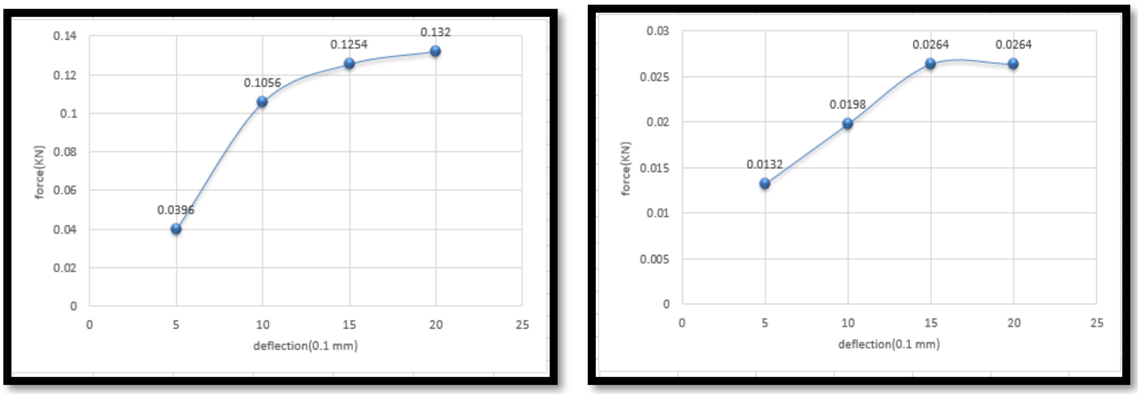

Fig.8: Indirect tension test of 6% calcium chloride (right) Indirect tension test of 2% calcium chloride (left)

Figures 9 and 10 show the results of the vertical and horizontal strength tests at different percent of calcium chloride and different displacements.

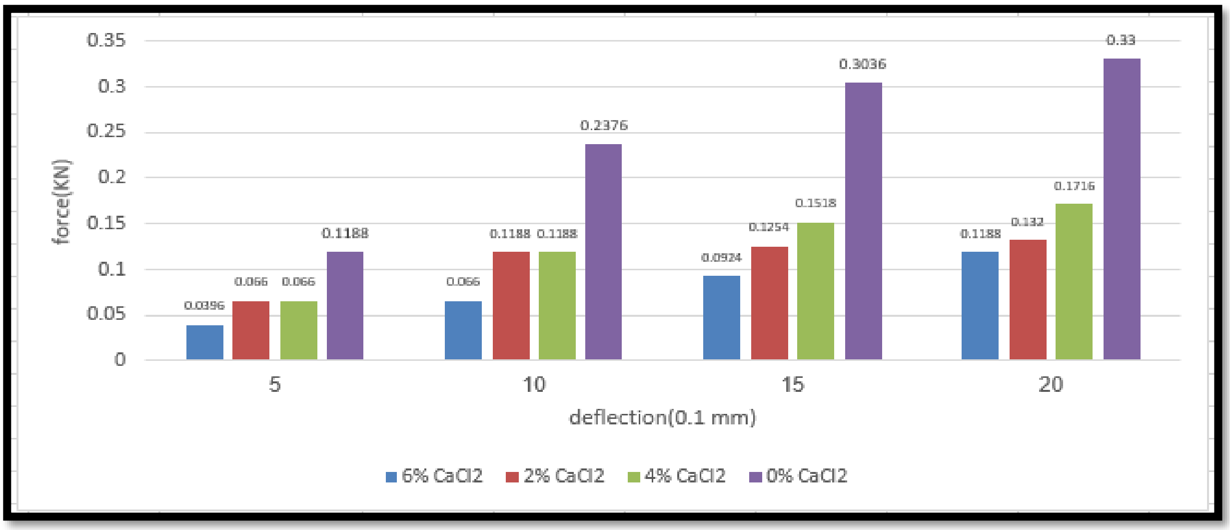

Fig.9 - Comparison of unconfined compression test results

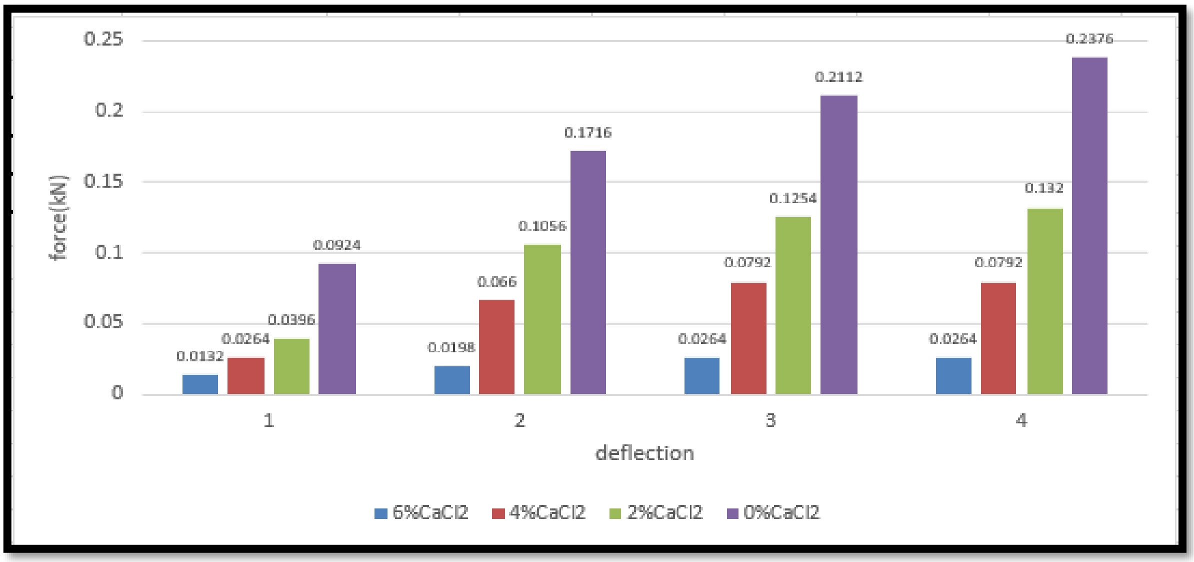

Fig.10 - Comparison of indirect tension test results

Fracture energy in unconfined compression and indirect tension tests

Figures 11 and 12 show that by increasing the percent of calcium chloride in the soil, the area surrounded under the diagram is reduced. Thus the fracture energy has been reduced in the case in which the specimen is subjected under indirect tensile loading and unconfined compression loading. Hence the soil strength is decreased and ruptures at a shorter time and by a small strength.

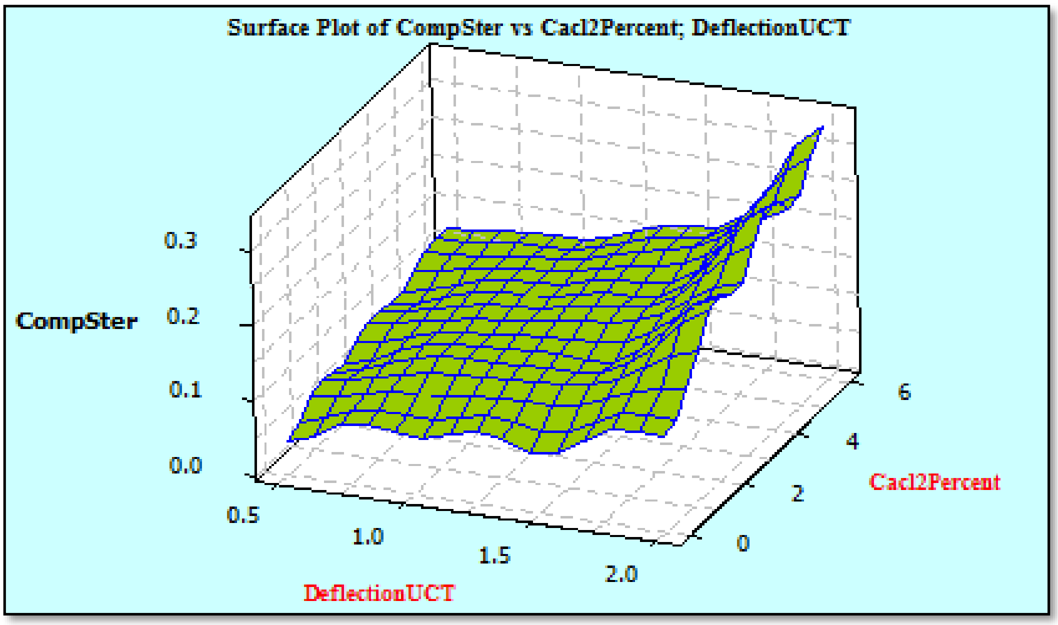

Fig.11 - The area surrounded under diagram for the unconfined Compression test with various percent of calcium chloride

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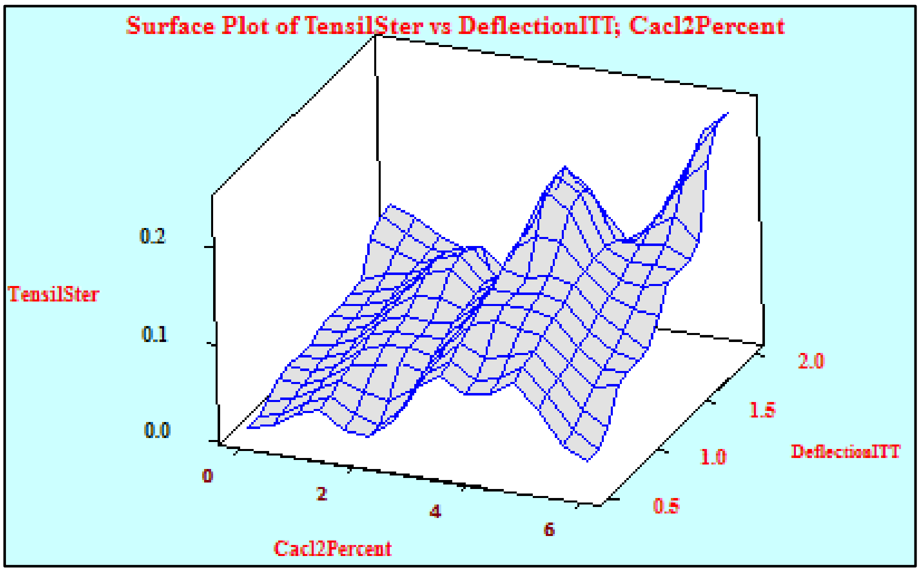

Fig.12 - The area surrounded under diagram for the indirect tension test with various percent of calcium chloride

DISCUSSION OF RESULTS

Large-scale images can display the interior properties of the soil with calcium chloride additive. According to Figure13, by increasing the amount of calcium chloride, as is observable, the amount of adherence between the soil particles is decreased and the void is increased, as calcium chloride leads to greater moisture absorption and adherence between the particles has become unbalanced.

Figure 14 shows propagation of cracks in the soil sample in two different loading conditions. Table 3 shows the comparison between the area below the stress-strain diagrams, as the calcium chloride increases, this area decreases, in other words, the fracture energy decreases. Consequently, it is suggested that this salt be added to the soil with additional mixture such as plant ash.

Tab. 3 - Comparison of the area under the strength-displacement at different percent of calcium chloride

Different percents of $Cacl_2$	Integral Of Indirect Tensile Test	Integral Of Unconfined Compression Test
0	2.97	4.17
2	1.68	2.11
4	1.05	1.88
6	0.36	1.28

Fig.13 - Investigation of the free space amount at different percent of calcium chloride

Fig.14 - The style of specimens fracture under indirect tension and unconfined compression test

CONCLUSION

The purpose of this study is to investigate the effect of calcium chloride amount on gravel roads, based on the soil tests, and this previously discussed research. There is a reverse proportion between the salt percent and the plastic limit and liquid and plastic index of soil and adding calcium chloride salt to soil reduces the plastic limit and liquid limit. Such that increasing the salt percent up to 6% the plasticity limit, liquid limit and plastic index are respectively reduced by 6-12-25 percent. The addition of calcium chloride to soil increases the absorption of soil moisture and soil will be wet but test conditions are of high importance in the effect of calcium chloride salt on soil such that if the test is not performed under suitable conditions, there would be a difference of about 80% between the results. Due to the addition of calcium chloride salt in the soil, it decreases soil strength and causes it to rupture under a smaller strength than the regular case. Thus, it is recommended that this salt be added to the soil with another mixture such as plant ash. Also, the addition of calcium chloride salt in the soil causes reduce the area under the strength - displacement curve, in other words, the soil sample has a more restrictive effect.

Civil engineering researchers need to continue conducting full-scale tests to determine the factors that contribute to adding calcium chloride salt performance in unpaved road.

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