University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 4 Volume 28 April 2022

Civil and Architectural Engineering

Experimental Study on Using Cement Kiln Dust and Plastic Bottle Waste to Improve the Geotechnical Characteristics of Expansive Soils in Sulaimani City, Northern Iraq

Nihad Bahaaldeen Salih	**Kamal Ahmed Rashed**	**Karmand Abdulwahab**
Department of Water Resources, College of Engineering, University of Sulaimani, Northern Iraq nihad.salih@univsul.edu.iq Corresponding Author	Department of Civil Engineering, College of Engineering, University of Sulaimani, Northern Iraq kamal.rashed@univsul.edu.iq	Former Master Student, Department of Civil Engineering, College of Engineering, University of Sulaimani, Northern Iraq, engkarmand2012@gmail.com

ABSTRACT

In this study, stabilization of expansive soils using waste materials namely; Cement Kiln Dust (CKD), and waste plastic bottles (WPB) was experimentally investigated. Using CKD and WPB are exponentially increasing day by day, due to their capability to solve both environmental and geotechnical problems successfully. Expansive soils were collected from locations with a wide range of plasticity index (PI) (15 - 27) and liquid limit (LL) (35% - 64%). Stabilizer percentages were varied from 0% to 20%, and curing durations for CKD cases were 7 and 28 days. Results showed the best percentages of CKD and WPB are 12% of each one respectively. LL, plastic limit (PL), and swelling percent (SP) loss were observed, which are 46%, 55%, and 96% respectively, and a CBR increase that is 98% with the addition of a mixture of both CKD and WPB was obtained. The best percentage of the utilized stabilization materials are the mixture of 12% CKD and 12% WPB after 28 days curing.

Keywords: Expansive Soil, Geotechnical Properties, Soil Stabilization, CKD, WPB.

دراسة تجريبية لاستخدام غبار افران الأسمنت ومخلفات القاروارات البلاستيكية لتحسين الخصائص الجيوتقنية للتربة الانتفاخية في مدينة السليمانية، شمال العراق

نهاد بهاءالدين صالح	**كمال احمد رشيد**	**كارمند عبدالوهاب**
استاذ مساعد كلية الهندسة، جامعة السليمانية	استاذ مساعد كلية الهندسة، جامعة السليمانية	طالب ماجستير سابق كلية الهندسة، جامعة السليمانية

الخلاصة

في هذه الدراسة، تم فحص التربة الانتفاخية المثبتة باستخدام النفايات وهي غبار افران صناعة الأسمنت (CKD) و نفايات قارورات بلاستيكية (WPB) تجريبياً. و يتزايد استخدام CKD و WPB بشكل كبير يومًا بعد يوم، نظرًا لقدرتهما على حل المشكلات البيئية والجيوتقنية بنجاح. حيث تم جمع التربة الانتفاخية من مواقع ذات مدى واسع من مؤشر اللدونة (PI) (15 -

*Corresponding author

Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2022.04.02

Article received: 16/12/2021
Article accepted: 13/2/2022
Article published: 1/4/ 2022

27) وحد السيولة (LL) (64٪ - 35٪). تباينت النسب المئوية للمثبت من 0٪ إلى 20٪، واستغرقت فترات المعالجة لحالات استخدام CKD 7 و 28 يومًا. أظهرت النتائج أن أفضل نسب CKD و WPB هي 12٪ لكل منها على التوالي. و لوحظ الفقدان في قيم LL، وفي حد البلاستيك (PL)، وفي نسبة التورم (SP)، حيث كانت 46٪، 55٪، و 96٪ على التوالي، والزيادة في قيمة CBR بلغت 98٪ مع إضافة خليط من CKD و WPB. حيث اثبتت ان أفضل نسبة من مواد التثبيت المستخدمة هي خليط من 12٪ CKD و 12٪ WPB بعد 28 يومًا من المعالجة.

1. INTRODUCTION

Soil stabilization can be done by mechanical methods or addition of manufactured modifiers (cement, lime, bitumen ... etc.) or waste materials (WPP, GP, CKD …etc) or a combination of both to improve soil's strength. Stabilization improves workability and durability of soils. Expansive soils are those soils which possibly swell and shrink within moisture condition changes. The volume changes resulting from swelling/shrinkage may cause damages to structures founded on them. Those soils are a global problem facing construction world. The estimated damage, for instance, to buildings, roads, and other structures built on expansive soils exceeds 15 billion dollars in the US annually (**Al-Rawas and Goosen, 2006**).
Approximately 14.2 million tons of CKD are produced annually in the USA (**EPA, 1993**). CKD can be categorized as belonging to one of four classifications, depending on the kiln process employed and the degree of separation in the dust collection system (**Collins and Emery, 1983**). Many researchers globally worked on expansive soils stabilization by using CKD such as **Moses and Saminu (2012)**, which evaluated the CKD effect on some engineering properties of expansive soil, the optimum percentage of CKD was up to 16%. Then, CKD was also found to have a negative role; it decreased the values of USC and CBR of stabilized soil for sub-base and base materials in the pavement. CKD also was utilized for the evaluation as a stabilizer of contaminated expansive soil by heavy metals. CKD was found to impact some geotechnical parameters such as Atterberg limits decrease, compaction parameters increase, and improve UCS values of expansive soil. The best CKD percent was found to be 10%; however, the 8% also showed a notable role for improvement purposes (**Gupta et al., 2015**).
Plastic wastes have become one of the major problems for the world. Due to their thicknesses, all the plastics are not recyclable. A common problem with recycling plastics is that they are often made up of more than one kind of polymer (heterogeneous character) or some sort of fibers added to the plastics (a composite) to give added strength. Plastic waste is used as a soil stabilizer, which takes a very long time for natural decomposition. Therefore, it is mixed with expansive soil which helps in mitigating volume changes. Polypropylene production was about 55 million tons in 2013. Based on production, synthetic plastic is the world's second most widely produced plastic. Polypropylene is similar to polyethylene in many aspects (**Gowthami and Sumathi, 2017**).
Reusing plastic waste from water bottles has become one of the challenges worldwide. Bottled water is the fastest-growing beverage industry in the world. The annual consumption of plastic bottles in the world is approximately 10 million tons and it grows about 15% every year (**Patil et al., 2016**).
Various available waists and natural materials have been utilized for the purpose of soil stabilization, especially fine-gained soils, such as steel slag and crushed Limestone (**Abdalqadir and Salih, 2020; Abdalqadir et al., 2020; Abdalqadir et al., 2021**). Recron-3S and CKD were utilized for expansive soils treatment. Using Fiber reinforcement results improvements of some soil properties such as stress-strain patterns and progressive failure in place of quick post-peak failure of plain samples. Then, UCS was increased by 7 times with admixture stabilization and 9 times with admixture with fiber modification compare to the plain samples. Shear strength parameters and CBR value were significantly increased due to both admixture stabilization and

admixture with fiber treatment. Moreover, LL, PL, and PI were decreased by 23 %, 41%, and 57% respectively due to utilizing CKD (**Rao et al., 2012**).
Cut waste plastic and crushed waste glass as stabilizers were studied by **Fauzi et al. (2016)**. The additive use as 4%, 8%, 12% added on dry mass of soil sample. Optimum moisture content (OMC) and maximum dry density (MDD) values were decreased and increased respectively, and CBR values increased when HDPE waste content and Glass were increased. Glass (GP) and plastic waste powder (PWP) in geotechnical applications was used by **Gowtham et al. (2018)** which evaluated clay soil stabilization by 2%, 4%, 6%, 8% of GP and PWP. CBR values were increased, 2.45 to 9.40 and 2.64 to 8.5 for 2.5mm and 5 mm penetration respectively, by utilizing 6% GP and PWP. Also, OMC and MDD were goes on increase and decrease respectively with an increase in the percentage of PWP.
Hence accordingly, expansive soils that can be stabilized by various natural or waste materials, the aim of this study was decided on. Expansive soil was chosen to be treated with CKD and waste plastic bottles (WPB) separately and as a mixture in order to improve the undesired geotechnical properties and save environmental sustainability by utilizing massively available wastes in a cheap way. The novelty of this study is in the consideration of both CKD and WPB together, which is not clearly consider in the related researches so far, the following results section will present the achieved contribution.

2. MATERIALS AND METHODS

2.1 Materials

Materials used in this experimental study were: expansive soils, cement kiln dust, and waste plastic bottles. Details of each utilize material were explained in the following sections (2.1.1 – 2.1.3).

2.1.1 Expansive Soils Site Selection

Soil locations were selected to cover a wide range of swell–shrink potential, which is based on a previously conducted study by **Khursheed (2003)** and mentioned in Table 1. The selected areas are in the boroughs of Sulaimani city, Northern Iraq, which commonly known that they are rich with expansive soils. Also, the selection of the in-situ soil samples depended on the samples plasticity index values (range from 23 to 27), and visual observation of cracks in the visited areas during the carried out field trips (see Tables 1 and 2, and Fig. 2 and 3, Part A). Two sites were selected among the visited areas to obtain in-situ soil samples with various plasticity indices, which were then mentioned as soil Q, and soil B. The samples visual description is dark brown clay with very little stones. The samples were taken from a depth of 1.0 meters from the natural ground surface. Shelby tubes were used to prevent any natural samples disturbance before testing.

2.1.2 Cement Kiln Dust (CKD)

With regard to utilizing CKD has been used as a chemical stabilizer for the expansive soil samples treatment. CKD was collected from one of the available cement factories in Sulaimani Governorate, Northern Iraq. In order to remove the undesired sizes of CKD, it has been sieved on sieve no. 200 (0.075 mm). The chemical composition of the used CKD is presented in Table 3.

2.1.3 Polypropylene Plastic (Waste Plastic Bottles, WPB)

Regarding the utilized WPB, It is a mixture of plastic fiber collected from used chairs and bottles (see Figure 3, Part B). In focus on used bottles of water, fiber strips were selected. The utilized WPB particles were obtained by manually cutting the used bottles into small pieces, which were then sieved on a 2.36 mm sieve and the passed particles from the sieve were collected and used for the experiments of this study. The mechanical properties of the WPB sample are presented in Table 4.

2.2 Methods

Stabilization materials for soils possibly utilized after sieving on sieves such as No. 40 or No. 200, which passed particles then can be used for treatment purpose due to their uniform distribution of particle sizes (**Abdalqadir and Salih, 2020; Abdalqadir et al., 2020; Abdalqadir et al., 2021**), which considered in the preparation of experiments samples of this study. Also, the practical soil stabilization method was conducted following the mentioned methods in the studies of **Al-Omari et al. (2016)**, **Masood et al. (2021), Irshayyid and Fattah (2019), and Fattah et al. (2011)**. CKD and WPB were added by the percentages of 2%, 4%, 6%, 8%, 10%, 12%, 14%, and 16% for CKD, and 4%, 8%, 12%, 16%, and 20% for WPB of the dry mass of in-situ expansive soil samples. Similar procedure was performed for all prepared experiments soil samples. For samples mixed with CKD, they were cured at 3, 7, 14, 21, and 28 days. For soil Q, in order to know the effect of curing time, the test result of 28 days curing was the most effective duration, while for soil B, the samples were cured and tested at 7 and 28 days were effective. Calculation of MDD and OMC was done by using the modified proctor compaction test method for both soil Q and B.

For one-dimensional consolidation test, soil samples were compacted in the consolidometer ring at OMC and MDD obtained from the performed modified proctor compaction test. For swelling tests, prepared samples were tested under the same initial surcharge pressure, 6.9 kN/m^2. For some reasons, for soil Q, the samples were prepared at another dry density and moisture content, 15.72 kN/m^3 and 12.2% (95 % of dry side of compaction curve), which was made because of the high OMC and unclear SP for soil Q specifically. On the basis of SP test, the best treatment percent for the expansive soils treated either by CKD or WPB was 12%. Thus, the mix proportion was utilized for soil B was 12% CKD and 12% WPB.

A locally-designed and manufactured mold (see Fig. 1) was designed to compact soil samples in the conventional oedometer ring, which has the dimension of 19 mm in height and 5 cm in diameter. For CBR test, soil sample was prepared at MDD and OMC. After compaction, CBR samples were immersed in water for 7 days, daily SP was recorded. After 7 days, the samples were tested and their penetrations were recorded. Significant numbers of the prepared soil samples were carried out as shown in Table 5.

Table 1. Locations of the selected sites for natural soil samples collection and their Atterberg. limits.

Location	Latitude	Longitude	LL (%)	PL (%)	PI
Bakrajo (B)	35° 33' 37''N	45° 20' 44''E	55.72	32.21	23.51
Wllwbe	35° 31' 44''N	45° 25' 27''E	51.6	22.21	29.4
Qularaesy	35° 36' 16''N	45° 20' 23''E	38.95	26	12.95
Qerga (Q)	35° 31' 18''N	45° 28' 26''E	63.58	36.21	27.37

Table 2. Some of the geotechnical properties of the utilized natural expansive soil samples.

Property	Standard	Soil Q	Soil B

Liquid Limit, LL (%) Plastic Limit, PL (%) Plasticity Index, PI	ASTM D 4318-14 ASTM D 4318-14 ASTM D 4318-14	63.58 36.26 27.37	55.72 32.21 23.51
Linear Shrinkage Limit, LSL (%)	ASTM C 356 – 10	15.71	12.86
Specific Gravity (G_s)	ASTM D 854-14	2.56	2.65
Maximum Dry Density, MDD (kN/m^3) Optimum Moisture Content, OMC (%)	ASTM D1557-12 ASTM D1557-12	16.55 22	17.91 17.2
Swelling Percent, SP (%)	ASTM D4546-14	8.95	7.95
California Bearing Ration, CBR (%)	ASTM D1883-16	2.2	3.81

Table 3. Chemical composition of the utilized CKD (conducted in the College of Science, University of Koya, Northern Iraq).

Chemical Compound	**Composition (%)**
CaO	69
SiO_2	17.8
Fe_2O_3	4.05
Al_2O_3	3.21
MgO	1.33
TiO_2	0.222
K_2O	0.868
SO_3	3.23
MNO	0.096

Table 4. Mechanical properties of the utilized WPB.

Property	**Value**
Density	(0.91 – 1) gm/cm^3
Average Size	2.36 mm
Tensile Strength	(350 – 375) MPa
Modulus of Elasticity	1800 N/mm^2
Resistance to Acidic and Alkali Actions	Very good

Table 5. Number of the carried out laboratory experiments for all utilized soil samples.

No. of Experiments	**Type of Conducted Experiment**	**Utilized Soil Samples**

54	Liquid Limit (LL)	Soil B + Soil Q
54	Plastic Limit (PL)	Soil B + Soil Q
54	Plasticity Index (PI)	Soil B + Soil Q
42	Linear Shrinkage Limit (LL)	Soil B + Soil Q
56	Swelling Percent (SP)	Soil B + Soil Q
8	Swelling Pressure (for Soaked CBR)	Soil B + Soil Q
46	Swelling Pressure (SPr)	Soil B + Soil Q
8	Standard Proctor Compaction	Soil B + Soil Q
8	California Bearing Ratio (CBR)	Soil B + Soil Q

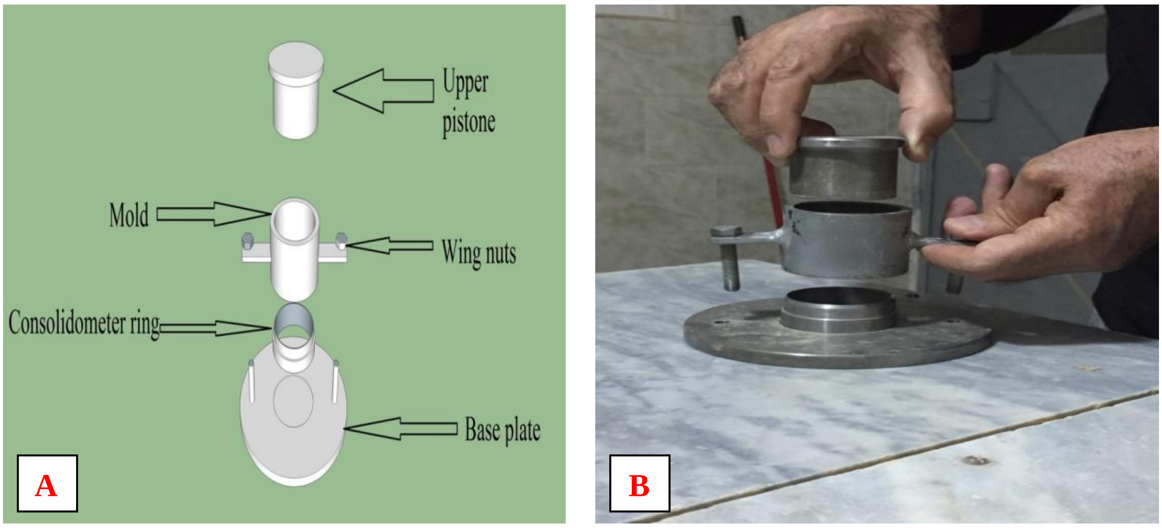

Figure 1. Sketch (Part A) and a real photo (Par B) of the locally-designed and manufactured mold for soil samples preparation inside the conventional oedometer ring.

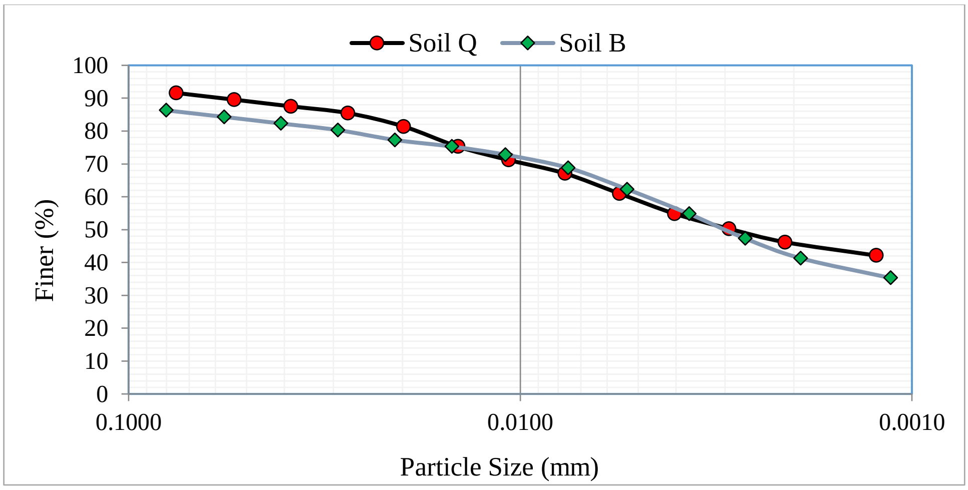

Figure 2. Grain-size distribution for both used expansive soils Q and B.

Figure 3. Part A: the field inspection for the selected sites for expansive soils collection (shrinkage crack), Part B: the crushed waste WPB before sieving to the required size.

3 RESULTS AND DISCUSSIONS

The main aim of this study that listed in the introduction and repeated here for clarity, is the stabilization of expansive soils by CKD and WPB that are experimentally investigated. Notable improvements were achieved in the examined geotechnical properties of the expansive soil samples, which are consistency, swelling, compaction, and CBR parameters due to the utilization of CKD and WPB. These four key points are supported by a powerful set of evidence which demonstrates that expansive soils can be notably improved by using CKD and WPB. The discussion is based on the four key points and major findings listed above. In order to focus the discussion, this section is divided into five secondary sections, 3.1 – 3.5 which deal with an explanation and understanding of the results.

Some notable differences in the improvement level for each mentioned geotechnical properties between utilized soil samples B and Q. these differences were achieved due to the obtained differences among the examined properties such as LL, PL, PI, ..etc for the in-situ soil samples. Soil composition has a significant role to achieve the level of improvement in term of stabilization acceptance.

3.1 Effect of CKD and WPB on consistency parameters (LL, PL, and PI)

The experimental data in Fig. 4 - 9 show clearly that the addition of CKD and WPB individually or as a mix of both is causing decreases in LL and PL values. Transferring the understanding gained from this study's experimental work presents that the Optimum content of CKD and WPB were 16% for soil Q and 12% for soil B. These different reductions can be attributed to the capability of CKD more than WPB to control the consistency parameters by reducing the absorbed water by the soil samples. These reductions were due to a decrease in the thickness of both surface layers of clay particles found in the expansive soil samples. Cation exchange reaction, which causes an increase in the attraction force leading to flocculation of the particles, is in charge of LL and PL reductions. So, LL and PL reductions are attributed to the cementitious properties of CKD due to the high content of calcium oxide, which aids the flocculation and aggregation of soil particles. The addition of WPB separately caused a decrease in LL, PL, and PI. As a comparison, CKD is more effective to decrease consistency properties than WPB. This may be because of the weak cementing bonds between WPB and expansive soil particles. In addition, WPB has no water absorption ability compare with the absorption ability of CKD.

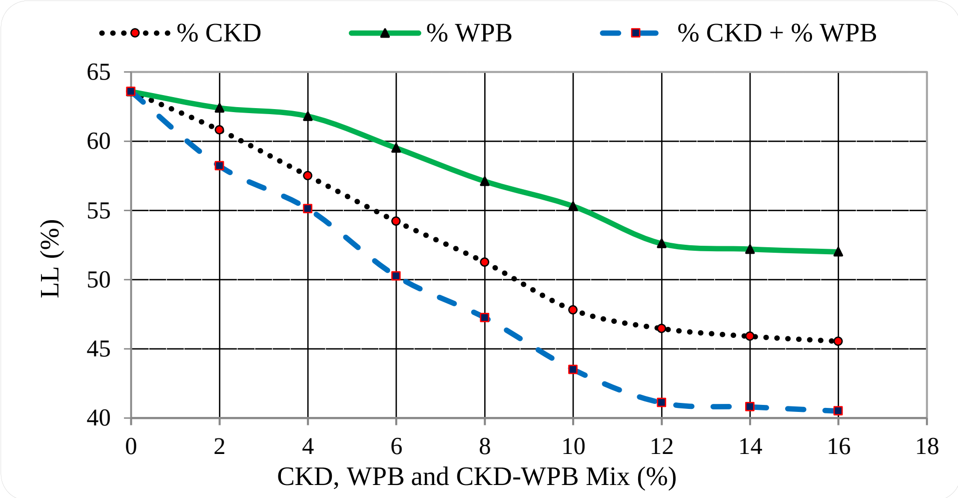

Figure 4. Variation of LL with CKD, WPB, and CKD-WPB mix for soil Q.

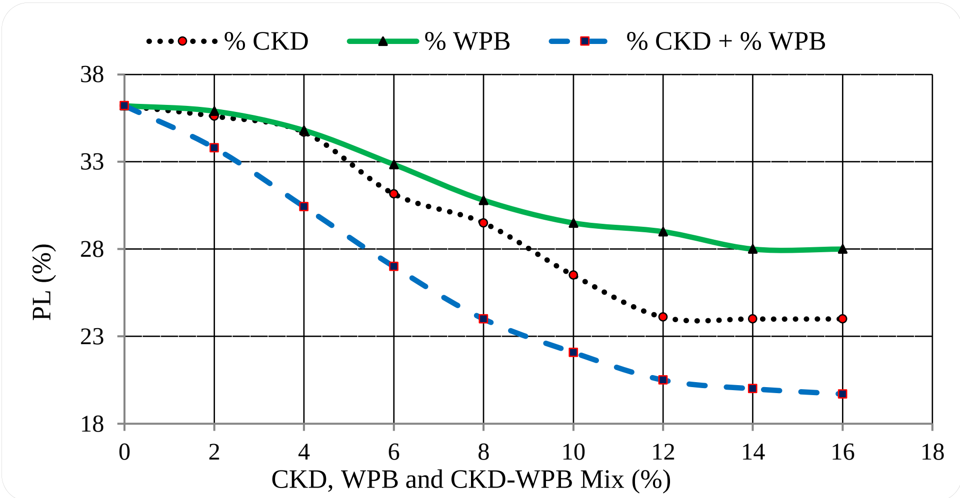

Figure 5. Variation of PL with CKD, WPB, and CKD-WPB mix for soil Q.

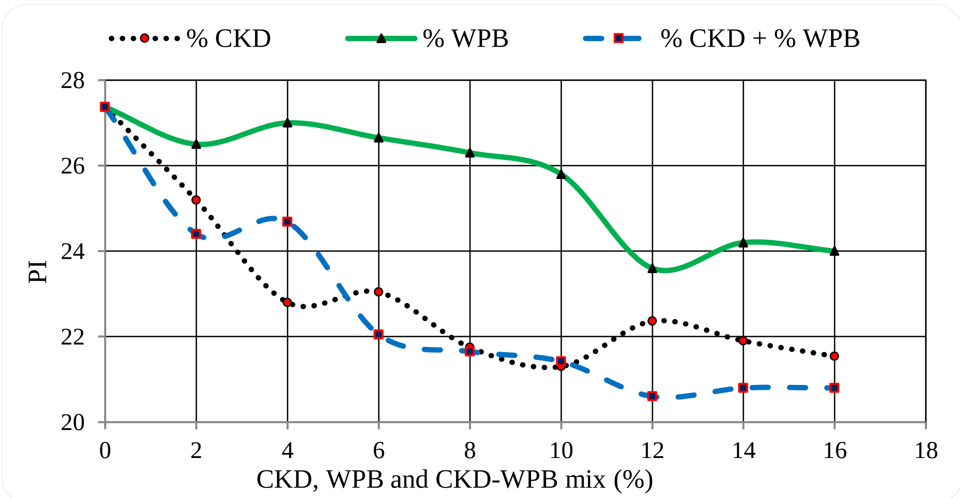

Figure 6. Variation of PI with CKD, WPB, and CKD-WPB mix for soil Q.

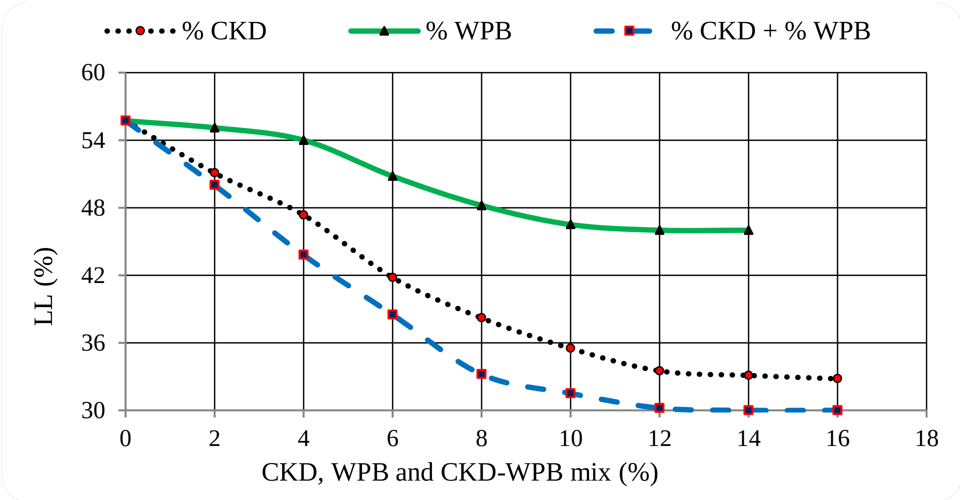

Figure 7. Variation of LL with CKD, WPB, and CKD-WPB mix for soil B.

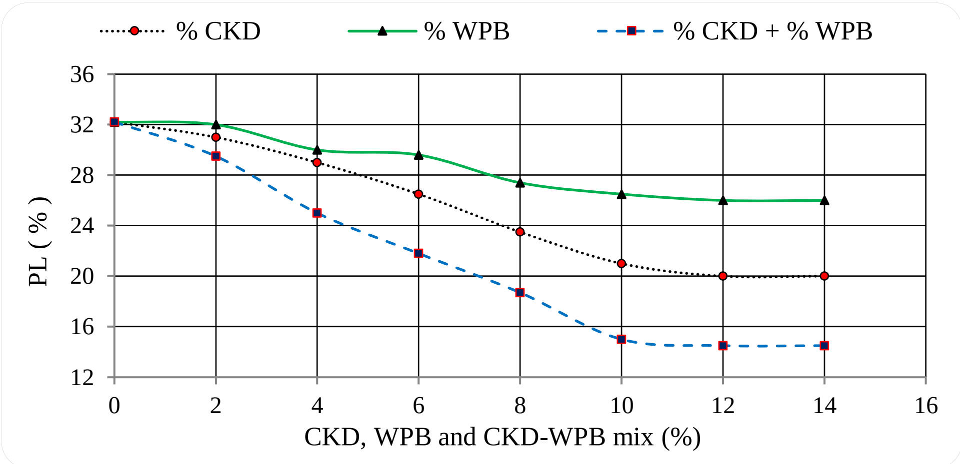

Figure 8. Variation of the PL with CKD, WPB, and CKD-WPB mix for soil B.

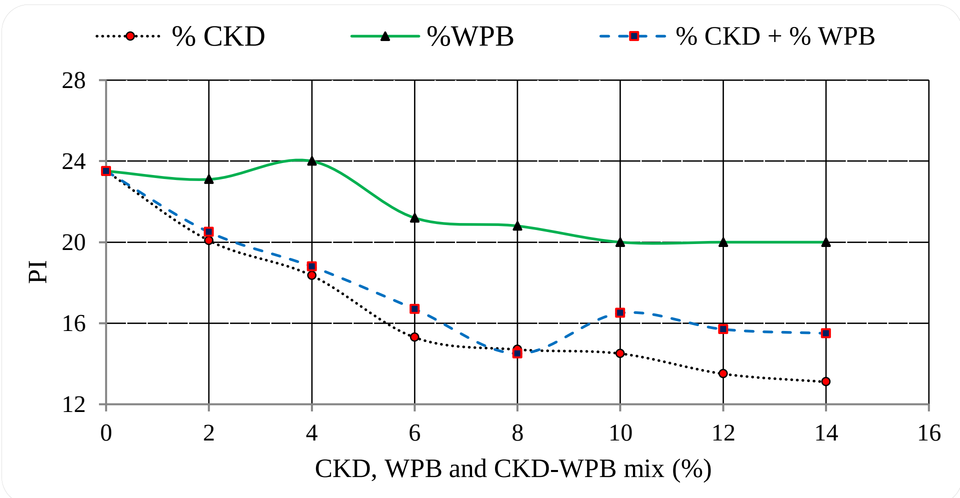

Figure 9. Variation of the PI with CKD, WPB, and CKD-WPB mix for soil B.

3.2 Effect of CKD and WPB on linear shrinkage limit (LSL)

The experimental data are shown in Fig. 10 - 11 presents clearly that the addition of CKD caused a decrease in LSL up to 16%. Similar to the other consistency properties explained in the previous section, this reduction was due to a decrease in the thickness of the double layer of clay particles, which is because of the cation exchange reaction, and hence causes an increase in attraction force leading to flocculation of particles. Reduction in LSL attributed to the cementitious properties of CKD due to the high content of calcium oxide, which aids the occultation and aggregation of the soil particles. The addition of WPB separately caused a decrease of LSL (see Figure 10). CKD is more effective to decrease consistency properties than WPB.

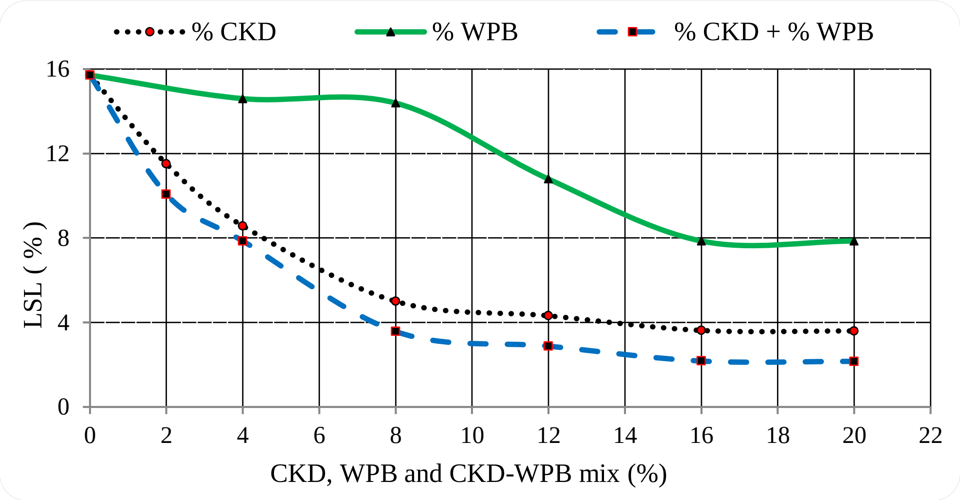

Figure 10. Variation of LSL with CKD, WPB, and CKD-WPB mix for soil Q.

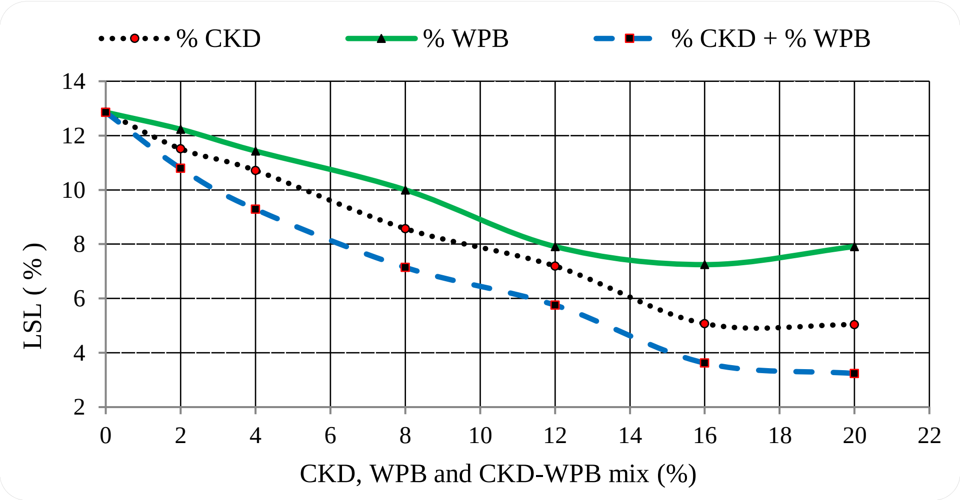

Figure 11. Variation of LSL with CKD, WPB, and CKD-WPB mix for soil B.

3.3 Effect of CKD and WPB on swelling percent (SP)

The addition of CKD clearly decreased the value of SP (see Fig. 12 - 13). However, the amount of reduction was low for 3, 7, and 14 days of curing time. At the same time, 21 and 28 days cured samples were the most effective. Also, the ultimate percent of CKD was 12%; SP was decreased from 14.63% to 4.21% at 12% of CKD and 28 days curing time. The value of SP was decreased significantly with the increase of CKD content. Adding non expansive material to expansive soil can reduce swelling potential. Obviously, with increasing the amount of stabilizer, the proportion of expansive soil decreased. The reduction of a swelling percent was due to the chemical reactions between CKD and expansive soil.
Also, the addition of WPB improved the swelling properties of the expansive soil samples which presented in Fig. 14 – 15. The value of SP decreased with the increase of WPB content up to 16%. This is because the WPB is non-expansive and non-absorption material, therefore, the amount of SP was decreased. So, from the mentioned figure, after 16% of WPB content caused the amount of swelling percent to be increased slightly. This was because the WPB was replaced by the expansive soil, which caused a decrease in the amount of soil and led to less swelling percent. The reduction continues until 16% of the added WPB, the swelling percent after that starts to increase. This may result from the percent of WPB becomes higher which is less capable to resist the water impact. Then, the cell water may work effectively to push the WPB particles in addition to the existing swelling percent from the remaining amount of expansive soil. Therefore, the whole mix of WPB and swelling percent featured more swelling percent.
Regarding the effect of curing time on soil B, 7 and 28 days curing durations were selected (see Fig. 13). The test results of a swelling test of soil Q showed that 28 days curing was the most effective duration.
Moreover, it can be noticed that the decreases of SP with mixture of 12% CKD with 12% WBP after 28 days curing period is more effective (Fig. 14 – 15). Duration of 28 days was sufficient to generate the required cementing bonds between CKD and soil particles from one side, and among soil particles together from the other side. At the end of 28 days, the replaced part of the expansive soil was played its role to stop more volumetric expansion via decreasing the whole quantity of the expansive soil.

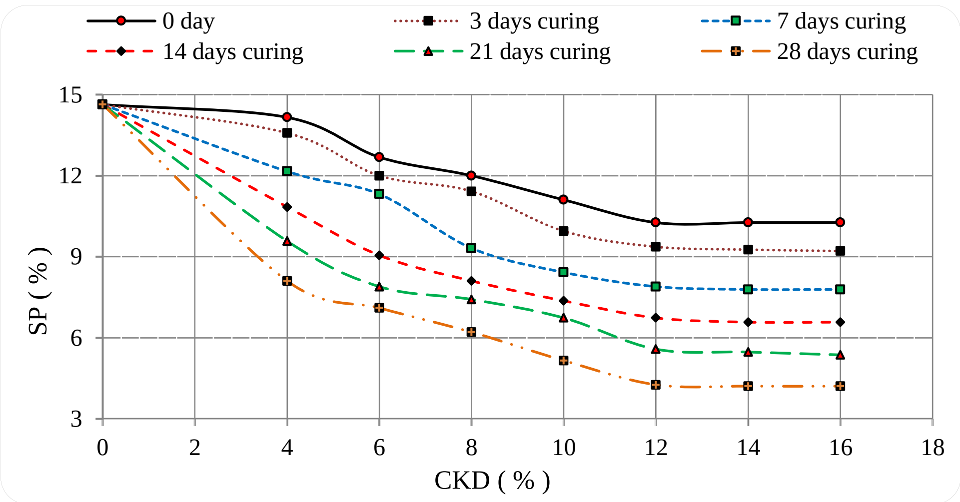

Figure 12. Variation of SP with the mix of CKD and WPB content at 95% dry side and at curing time for soil Q.

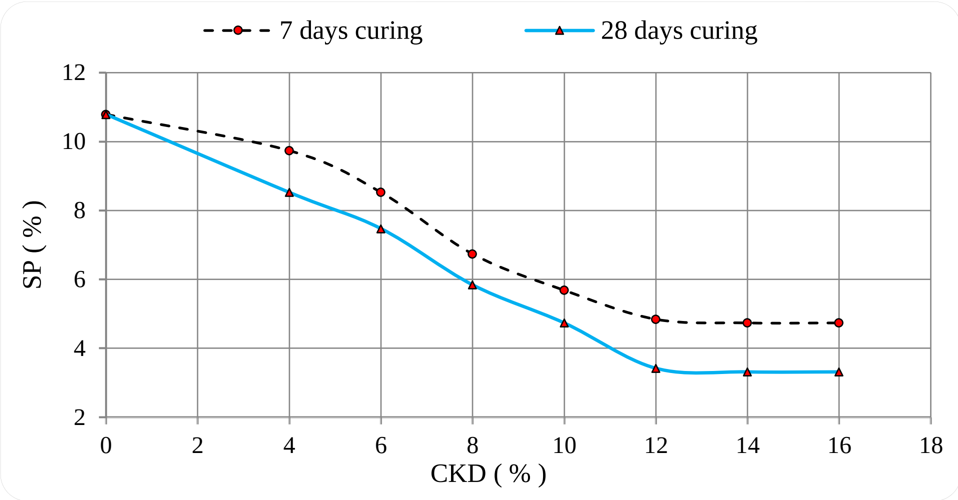

Figure 13. Variation of SP with CKD content for soil B at 95% of the dry side of MDD.

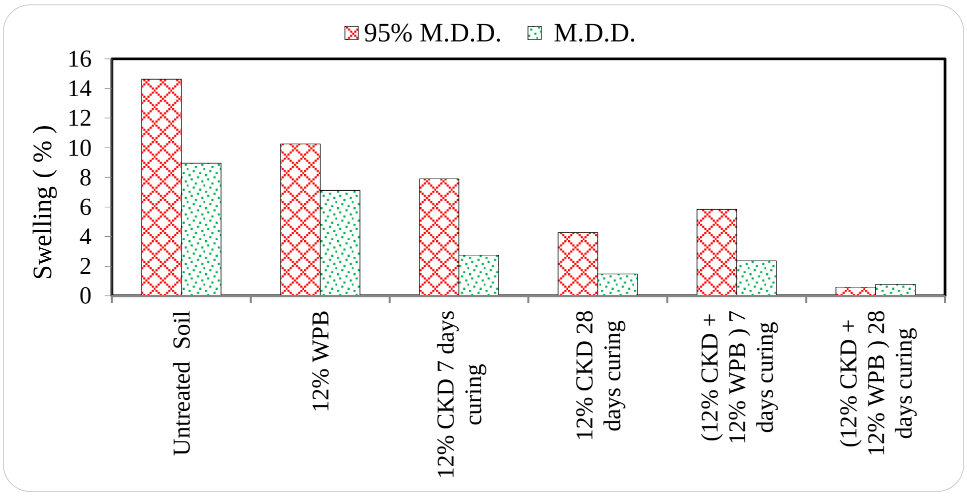

Figure 14. Variation of the SP for soil Q prepared at MDD and 95% MDD.

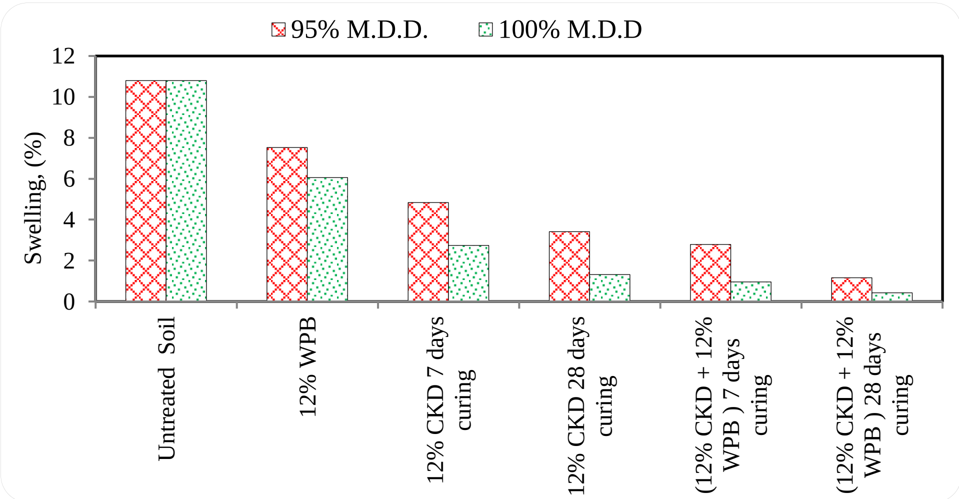

Figure 15. Variation of the SP for soil B prepared at 95% of M.D.D and at M.D.D.

4.4 Effect of WPB and CKD on swelling pressure (SPr)

SPr test is carried out for the soil samples by the method of constant volume test. The SPr test results before and after soil samples treatment shown in Fig. 16 - 18. The value of SPr decreased significantly with the increase of CKD content (Fig. 16 – 17). This is due to the chemical reaction between CKD and soil particles, which became stronger and stiffer than the natural expansive soil. Therefore, CKD filling the void among soil particles caused a decrease of SPr. Also, the addition of WPB influenced SPr value and decreased it (Fig. 18). This is due to the added WPB particles tying the soil particles together and making a strong specimen. At the same time, WPB inserted and distributed among soil particles decreases the voids and leads to lower places for water intrusion and less swelling. Figures 18 show the variation of swelling pressure with the addition of WPB content.

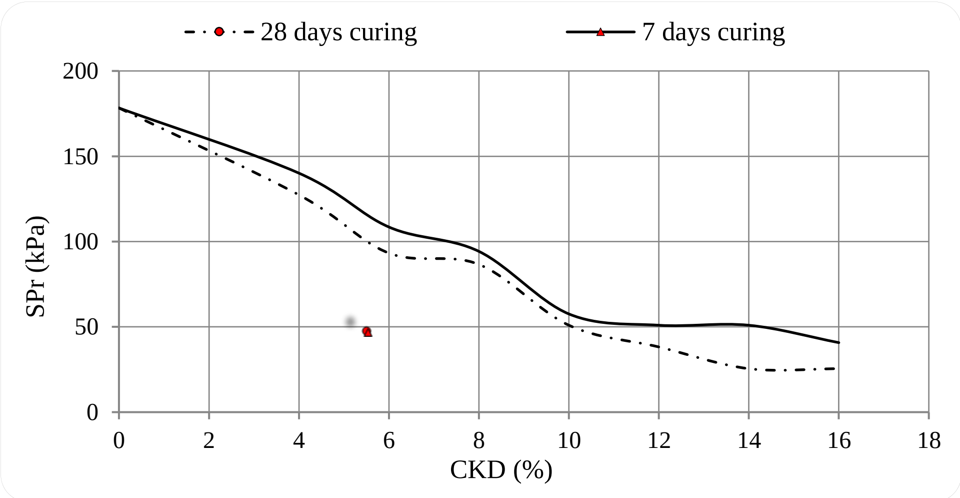

Figure 16. Variation of the SPr of soil Q with CKD content tested after 7 and 28 days.

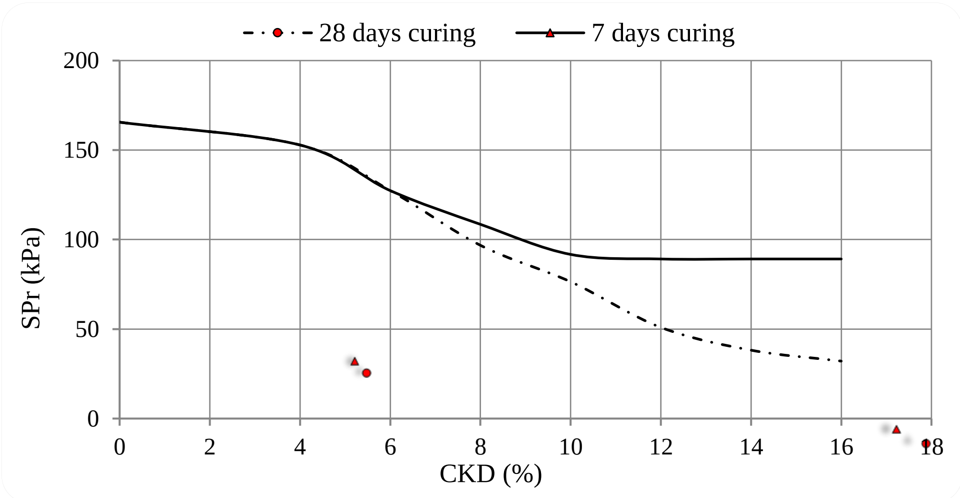

Figure 17.Variation of the SPr of soil B with CKD content tested after 7 and 28 days.

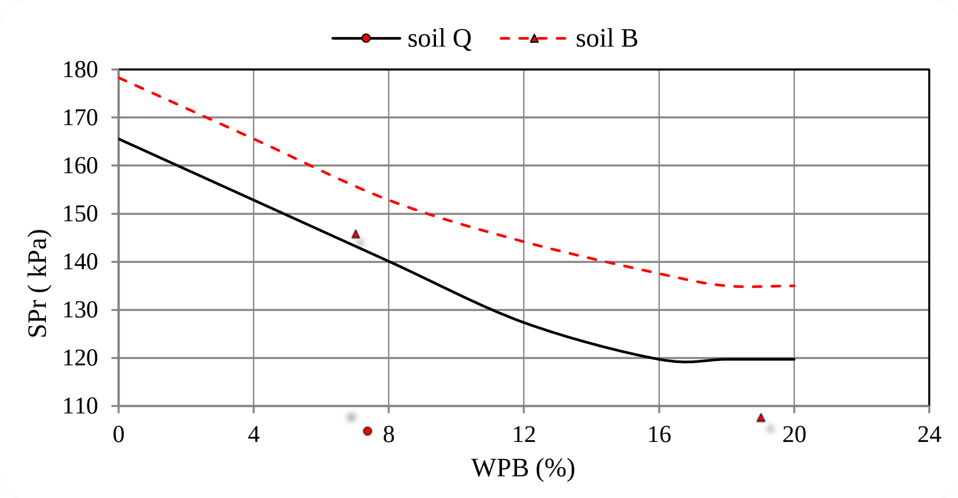

Figure 18. Variation of SPr of soil Q and soil B with WPB content.

4.4 Effect of CKD and WPB on the Compaction Characteristics

The experimental data in Fig. 19 - 20 show clearly that the addition of CKD and WPB individually or as a mix of both is causing changes in compaction parameters.

Considering the result of the previous sections, it was shown that the optimum percent treatment obtained from using CKD and WPB was 12% CKD, 12% WPB and mix of the 12% CKD with 12% WPB. The presented results show that MDD value was increased with the addition of 12% CKD. This is due to expectation of voids filling and making a good bond among the expansive soil particles. In addition, it may also be resulted from the relatively higher specific gravity of the used CKD. Then, OMC was decreased by adding 12% CKD to the soil samples. This is due to the amount of water absorbed by the CKD similar to ordinary Portland cement, which requires a certain water percent for internal chemical hydration process in order to get the desired stiffness. Moreover, by adding 12% WPB to the expansive soils, MDD was decreased. This decrease may be due to the increase in the number of internal voids. So, the decrease in soil cohesion may be due to the relatively low specific gravity of WPB. Then, OMC was decreased, which may be due to the replacement of expansive soil particles by WPB. The added WPB has remained constant in terms of moisture content, which is a non-absorbed material.

The addition of the mixture of CKD and WPB also yielded changes in the compaction characteristics which can be seen in Fig. 19 and 20, which show that the MDD value was increased and OMC value was decreased. This is due to the important role of CKD to generate cementing bonds internally in the mixture among the soil and WPB particles. However, in comparison to the case of 12% CKD separately, the increased magnitude was low. This might be because of the negative role of WPB particles, which is expected to be working as smooth-surface aggregates and may not notably contribute to the chemical process of hydration for cementing bonds generation.

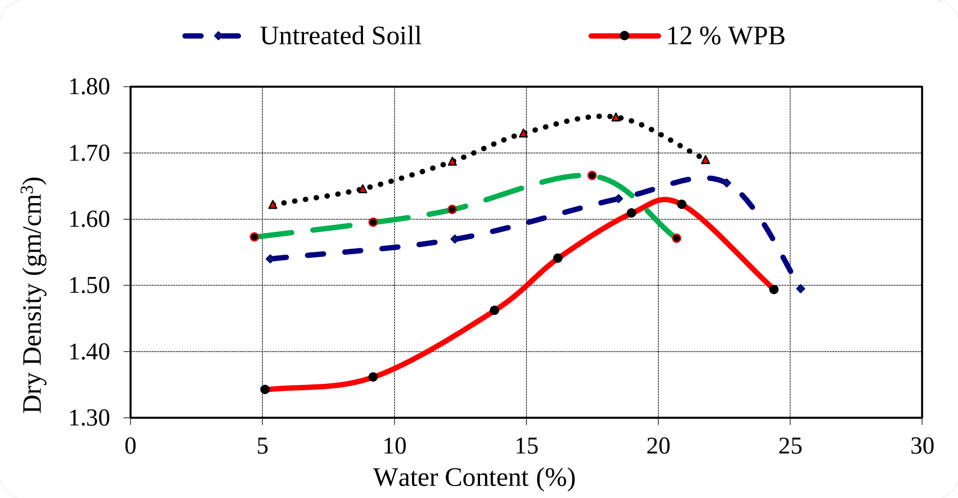

Figure 19. Variation of water content with the dry density of soil Q.

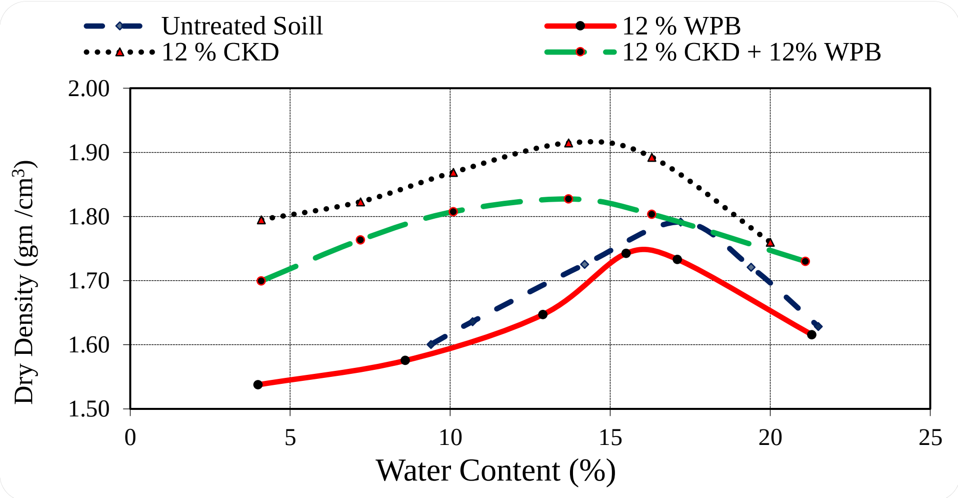

Figure 20. Variation of water content with the dry density of soil B.

4.5 Effect of CKD and WPB on California Bearing Ratio (CBR)

To investigate on CBR value, the samples were prepared at OMC. Similarly, to the previous section 4.4, the used mass of CKD and WPB and mixture of both of them was 12%, added to the expansive soils in order to discover the effect of both materials on the value of the soil's CBR (see Fig. 21 - 23). The amount of SP was measured during the soil samples soaking. SP was decreased by 12% CKD. This may be due to the chemical reaction among soils particles and CKD particles, which might cause good bonds among the soil particles and might decrease the voids among particles. Also, addition of 12% WPB to the soil samples, SP was decreased because of WPB, which is not absorbing water. So, by added mixture of CKD and WPB to the expansive soil, SP was decreased. This may be due to the role of both used materials. CKD worked as cementing bonds among the soil particles and WPB particles. WPB particles are expected to be working as aggregates due to their size, which played a role in decreasing cracks propagation due to swelling. CBR values are illustrated in Figure of 21, which present that CBR values are increased with 12% CKD. Therefore, with CKD alone, CBR value of the mixture is increased nearly 10 to 15 times, in comparison to the addition of WPB only. The effect of WPB on soil mixture is limited because of high plasticity of the used soil samples. This increased CBR value due to 12% CKD, which may be due to the gradual formation of cementing bonds inside the soil by the reaction between CKD and some amount of CaOH present in the soils. Moreover from those figures, by adding 12% WPB to the soil samples, the CBR value was increased. This increase of CBR value due to the effect of WPB can efficiently impede the further development of tension cracks and deformation of the soil. Bond strength and friction at the interface seem to be the dominant mechanisms controlling the reinforcement benefit. In WPB, soil interactions occur at the interface between WPB surface and clay grains, which plays key roles in mechanical behavior.

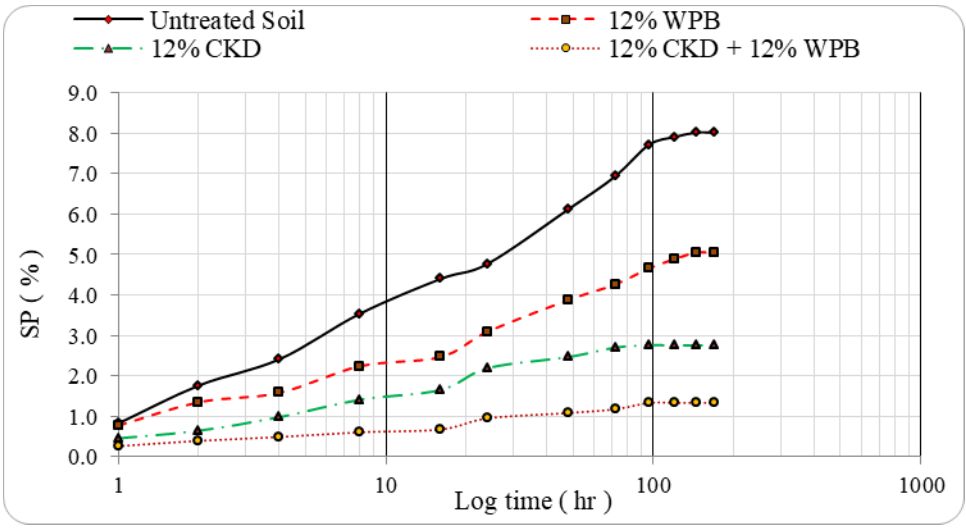

Figure 21. Variation of SP of soaked CBR samples of soil Q.

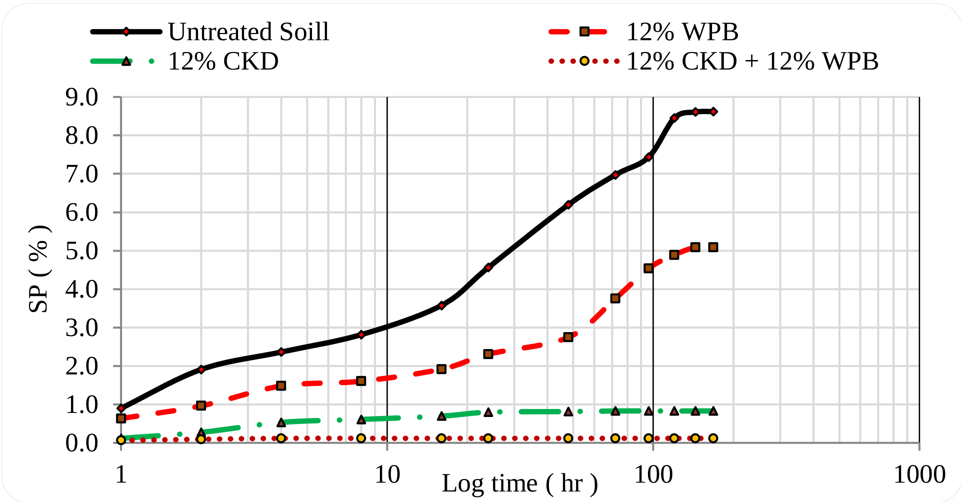

Figure 22. Variation of SP of soaked CBR samples for soil B.

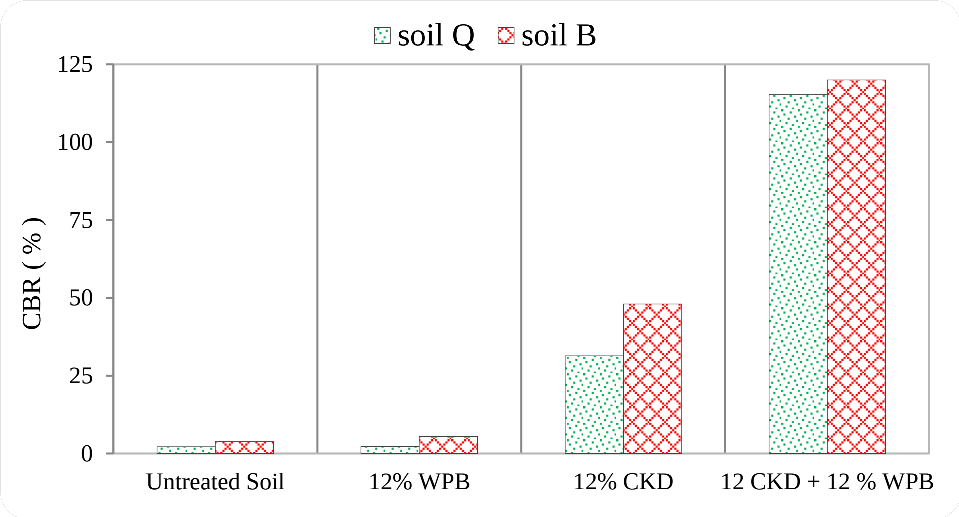

Figure 23. Variation of the CBR values for the untreated soil, WPB, CKD, and the mixture of CKD-WPB added to soil Q and soil B.

4 CONCLUSIONS

The experimental results of the current study are interested since it deals with the properties of problematic soil (expansive soil) treated with notably available kinds of waste materials, which are CKD and WPB. This study can pave a way for further researches in future. Based on the obtained outcomes, the study yielded the following conclusions:

- Atterberg limits are decreased due to the addition of CKD, WPB, and the mixture of both of them to expansive soil up to 16% for soil Q and 12% for soil B. The mix of CKD and WPB was caused higher decease.
- There is a CBR value increase for both soils Q and R due to the addition of CKD, WPB, and the mixture of both of them.
- SP and SPr values of treated expansive soil samples tend to decrease due to the addition of CKD, WPB and the mix of both. The treatment percent up to 12% and at curing durations of 7 and 28 days were showed the best decrease in SP and SPr values.
- There is a better outcomes for the modified compaction parameters, MDD and OMC, the addition of 12% CKD, 12% WPB individually, and the mix of both increased MDD value, and decrease WPB value for Q, B soils.
- The consideration of both CKD and WPB together has a significant role, which has the ability to control increasingly many weak geotechnical properties of expansive soils compare to the utilization of each one individually.

Conflict of Interest: The authors declare that no conflict of interest regarding this study.

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