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# The Effect of CKD and RAP on the Mechanical Properties of Subgrade Soils

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**ABSTRACT**

The construction of pavement layers on subgrade soil with good characteristics decreases the thickness of these layers, which in turn lowers the cost of building and maintaining roadways. However, it is impossible to avoid constructing pavements on unsuitable subgrade due to a number of limitations. Using conventional additives like lime and cement to improve subgrade properties results in additional costs. As a result, utilizing by-products (cement kiln dust and reclaimed asphalt pavement) in this field has benefits for the environment, economy, and technology. Large amounts of cement kiln dust (CKD), a by-product material, are produced in Portland cement factories. On the other hand, large amounts of reclaimed asphalt pavement (RAP) are accumulated as a result of the rehabilitation of old roads. This paper discusses using CKD and RAP to improve the characteristics of poor subgrade layers by conducting a series of Unconfined Compressive Strength (UCS) and California Bearing Ratio (CBR) tests on samples of natural soil and soil stabilized with different percentages of CKD and RAP with different curing times to investigate their impacts on soil properties. The curing was carried out by wrapping the stabilized samples with several layers of nylon and then placing them in plastic bags at room temperature. The compaction results illustrated that the addition of CKD increases OMC and decreases MDD, in contrast to RAP, which decreases OMC and increases MDD. The addition of CKD and RAP led to a significant and unexpected increase in the CBR values. The results show that the soaked and unsoaked CBR values improve from 3.4% and 12.1% for natural soil to 220.1% and 211%, respectively, after adding 20% CKD and curing the samples for 28 days. Also, the addition of 25% RAP to soil-20% CKD blend increased the soaked and unsoaked CBR values to 251% and 215%, respectively. All the additions resulted in a significant reduction in swelling.



## 1. Introduction

The subgrade layer, which is called the level of formation, is the foundation of the pavement. Its importance lies in preventing excessive rutting, providing great support for all layers above it, limiting pavement rebound deformations to allowable limits and preventing the development of excessive permanent deformation in the pavement structure during the service life [1]. Subgrade that contains a high percentage of fine-grained soil has multiple problems, such as high compressibility, low shear strength and water retention, that make it inappropriate for constructing pavement structures on it because of its instability. As a result, subgrade soils must be stabilized before any work can begin. The most popular technique for chemically stabilizing soil is using cement and lime. Reference [2] reported that the production of each ton of cement releases 0.85 to 1 ton of $CO_2$ into the

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atmosphere. Hence, it is important to think of recycled materials that are safe and provide good and acceptable performance in improving subgrade soils.

Since the stabilization of fine-grained soil depends essentially on Ca in the lime form, the use of CKD might be the most suitable option. Utilizing CKD may result in cementing characteristics similar to cement, which may have a significant impact on soil stabilization [3]. Chemical stabilization has been the modification of the soil physical and chemical characteristics, which can be achieved by adding various materials like lime, cement, as well as some recycled materials, such as CKD. Incorporation of the CKD reduces the shrinkage and swelling of soil, in addition to increasing shear strength and reducing soil plasticity, which leads to improving the strength of supporting foundations [4]. A study was performed to compare soil improvement by utilizing lime and CKD, which was collected from various cement factories. The author demonstrated that using CKD was more effective than using lime for improving soil [5]. Reference [6] stated that cement or chemical additions, which are either main materials like cement or by-product materials like CKD, are used to stabilize soil. The author demonstrated the effectiveness of CKD percentages (2.5, 5, 7.5, and 10%) in stabilizing the soil while taking into consideration the possibility of greater contents that were utilized in later years by other studies. Reference [7] stated that utilizing (5, 10, 15, 20, and 25)% of CKD greatly improves the physical characteristics of clayey soils.

RAP may be incorporated with soil to enhance its mechanical characteristics because it includes crushed aggregate, which increases the maximum dry unit (MDU) for clay soils because of the higher specific gravity ($G_s$) of RAP particles compared to clay soils. Generally, soil characteristics are improved by adding aggregates [8]. The utilization of RAP in several lateritic soils enhances their properties and makes them appropriate for the construction of many projects, as lateritic soil has poor engineering properties and does not meet the applicable engineering requirements. RAP materials are used to solve several problems of lateritic soils, such as low strength, high water retention, high plasticity, high permeability, and poor workability [9, 10]. Reference [11] stabilized the base as well as subbase layers by mixing RAP materials with fly ash. The mechanical and physical characteristics of subgrade soil were improved by adding 10, 20, 30, 40 and 50% RAP to this soil [12].

The MDU and OMC increase as the CKD content increases for the two soil types, ML and CL [6]. Reference [13] observed that dry density decreases with increasing the content of CKD up to 15%, whereas the moisture content increases with increasing the content of CKD up to 15% for the clay soil type CH, which is high compressive soil. The modifications in OMC and MDD with the addition of CKD occur because of the soil particle flocculation. Reference [14] stated that the value of MDD is modified when RAP is added to clay soil. With the inclusion of 60% of RAP, the MDU value increased to 2.170 g/m$^3$ after it was 1.895 g/m$^3$ for natural soil. However, as the RAP percentage increased beyond 60%, the MDU decreased until reaching 2.017 g/m$^3$, associated with adding 100% RAP. Reference [15] investigated the impact of adding RAP materials to clay soil type (A-6) according to the AASHTO classification system, and indicated that MDD increased when RAP particles were added to the soil. Additionally, OMC was reduced when RAP materials were added to the soil. This indicates that the soil is improved by adding RAP, especially when it is used for filling and building embankments.

The UCS increases greatly when adding CKD to the soil. The results demonstrate that the UCS improves from 0.21-1.1 MPa in the case of adding 16% CKD at 28 days as a curing time [5]. Reference [16] studied the impact of the inclusion of RAP in two different types of soils, MH and CL, and found that RAP would have a significant impact on UCS.

Reference [17] indicated that the CBR value increases as the CKD content increases. This increase is caused by the proper amounts of calcium being available in CKD, which is necessary for the production of basic components; calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH). These components are the reason for the high strength of the soil. Reference [18] determined the CBR of soil type A-6, as classified by AASHTO, stabilized for 90 days by rice husk ash (RHA) and CKD. The author noticed that the value of CBR increased over time with the inclusion of RHA and CKD by 20% of soil. The pozzolanic characteristics of CKD are the cause of this increase. CKD stabilized soil is more effective than that of RHA due to CKD cementitious properties. Reference [19] demonstrated that a higher CKD percentage in clay soil, CH, causes the CBR value to increase. The hydration reactions that produce cementitious chemicals may be responsible for this increase.

Reference [20] investigated the impact of adding lime and RAP on the soil CBR value. The author reported that the increase in the RAP percentage to 95% caused an increase in the CBR value from 4.8 to 23 % for the soaking conditions and from 21.9 to 56 % for the unsoaking conditions. This CBR value is the highest calculated for different contents of clay, lime, and RAP. However, the inclusion of RAP materials slightly changed the CBR value of the lime and clay mixture. Reference [14] investigated the CBR of soils stabilized with 60% of RAP particles for a variation of moisture levels. According to the author, the highest CBR value was 48.6% at 6.68% water content. While at the optimum water content (9.8%), the value of CBR was 16%. Reference [15] showed that the CBR increased as the RAP content increased. The authors stated that the inclusion of RAP particles, at a percentage of (1, 7, 28, and 60%), enhanced the CBR value to (13.5, 15.5, 17.2, and 18.9%), respectively. It is known that natural soil has a CBR of 11.1%. This means that the subgrade soils were suitable for the inclusion of RAP particles at any of the aforementioned percentages.

It is quite popular to use industrial waste for soil stabilization. Industrial waste is generally very harmful to the environment, so the best way to dispose of it is to utilize it to stabilize soil. Saving biodiversity, disposing of waste, enhancing soil properties like increasing strength and decreasing compressibility, as well as maintaining the soil, are all advantages of using waste in soil improvement. Another advantage is the ability to build cost-effective structures. Therefore, to improve the shear strength of soil and decrease compressibility, this study used CKD and RAP as recycled materials. It should also be noted that no research has adopted both CKD and RAP together to improve the mechanical properties of subgrade soil which distinguish the current study.

## 2. Materials and Methods

### *2.1. Materials*

#### *2.1.1 Soil*

Soil was obtained from a quarry near Ramadi city. It had mechanical pulverization before being utilized in the lab. In accordance with the Unified Classification System, soil has been classified as a high plasticity clayey silt (MH). The particle size distribution of soil is shown in Fig 1. and was determined using hydrometer analysis in accordance with ASTM D422 [21]. The natural soil, soil-CKD and soil-CKD-RAP mixtures were subjected to the compaction test (modified Proctor method) described in ASTM D1557 [22], in order to determine the maximum dry density (MDD) and optimum water content (OMC). The soil MDD and OMC were 18.4 kN/m$^3$ and 14%, respectively. The soil physical and chemical characteristics are shown in Table 1 and Table 2, respectively. The chemical components for soil and CKD were determined from XRF analysis performed in the capital, Baghdad.

#### *2.1.2 Cement Kiln Dust (CKD)*

CKD is a by-product material from the cement industry, which was obtained from the Kubaisa factory for cement manufacture, west of Ramadi city. These materials harm the environment if they are not properly disposed of. The results of the chemical test XRF on CKD are shown in Table 2. CKD has a specific gravity (Gs) of 2.06. The primary component of cement kiln dust, which is considered to be the fundamental factor that causes the pozzolanic reactions in CKD, is calcium oxide. This causes the material strength to increase. According to the grain size distribution, 88% of CKD passed sieve No. 200 (0.075mm).

#### *2.1.3 Reclaimed Asphalt Pavement (RAP)*

A significant amount of RAP particles are being collected in various locations throughout Iraq as a result of an increase in rehabilitation projects and the maintenance of existing roadways. The used RAP for this study was taken from a road in Karbala after scraping the top layer with a milling machine to a 100 mm thickness in order to repair the road. The scraped RAP age was over ten years. The RAP materials were sieved with a sieve size of 10 mm to ensure that they could be used in accordance with the UCS requirement. According to ASTM D2166 [23], soil particles must not have a diameter greater than 0.1 times the size of the mold being utilized. The asphalt binder represents 4.7% of the RAP content.

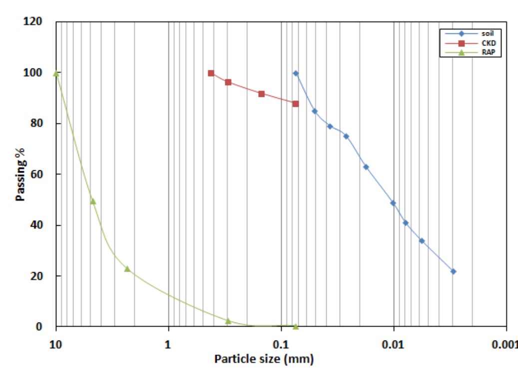


**Figure 1.** Grain size distribution of the study materials

**Table 1**. Soil properties

| Property | Value | Standard |
|---|---|---|
| Unified Soil Classification System (USCS) | MH | ASTM D2487 [24] |
| Liquid Limit (LL) | 74% | ASTM D4318 [25] |
| Plastic Limit (PL) | 59% | ASTM D4318 [25] |
| Plastic Index (PI) | 15% | ASTM D4318 [25] |
| Specific Gravity (Gs) | 2.67 | ASTM D854 [26] |
| Maximum Dry density ($\gamma_{dmax}$) | 18.6 $kN/m^3$ | ASTM D1557 [22] |
| Optimum Moisture Content (OMC) | 16.4% | ASTM D1557 [22] |

**Table 2**. Chemical characteristic of soil and CKD

| | $SiO_2$ | $Al_2O_3$ | CaO | $Fe_2O_3$ | MgO | $Na_2O$ | $K_2O$ | $SO_3$ | MnO |
|---|---|---|---|---|---|---|---|---|---|
| Soil (wt. %) | 50.3 | 15.61 | 9.802 | 5.193 | 10.12 | 4.65 | 1.779 | 1.3423 | 0.0662 |
| CKD (wt. %) | 1.779 | 0.0756 | 50.59 | 2.175 | 0.076 | 0.42 | 0.9630 | 1.564 | 0.0754 |

### *2.2 Method*

#### *2.2.1 Compaction modified proctor test*

Compaction is the technique of decreasing the voids in soil to increase the density. The purpose of this test is to determine the soil maximum dry density, MDD, and optimum water content, OMC. Most engineering projects can benefit from using soils with a low OMC and a high MDD. A modified compaction method was used on samples of untreated soils and soil treated with (5, 10, 15, and 20%) CKD in accordance with ASTM D1557 [22]. Compaction tests were performed on the mixtures of soil-CKD mixed with 15, 25, and 35% of RAP materials to evaluate OMC and MDD for these mixtures after the optimum CKD percentage included in the soil had been determined. The OMC and MDD calculated from compaction tests were utilized to prepare the samples of UCS for untreated soil and soil improved with CKD and RAP.

#### *2.2.2 Unconfined compressive strength (UCS) test*

In this study, the effects of RAP and CKD content, in addition to curing period, on the unconfined strength of natural soil were evaluated. The UCS specimens were prepared using two different mold types; the first had dimensions of 63 mm in diameter and 126 mm in height to determine the optimum percentage of CKD. To determine the optimum percentage of RAP, the second type of mold was used, with dimensions of 100 mm in diameter and 200 mm in height. It should be mentioned that the dimensions of molds were selected in this test to meet ASTM D2166 [23]. The specimens were cured for 7, 14 and 28 days after they were carefully isolated from the air using several layers of nylon, then stored in plastic bags to keep them moist. The optimal time to cure soil improved with CKD and RAP blends was then determined.

#### *2.2.3 California bearing ratio (CBR) test*

The California bearing ratio, CBR, is a test for the assessment of the subgrade strength of pavements and roads. The test was performed according to ASTM D1883 [27] by a cylindrical piston of 50 mm diameter at a slow rate of penetration. The specimens of CBR were prepared using a modified compaction test in accordance with ASTM D1557 [22]. The soaking CBR specimens were immersed in water until 96 hours before the test. This test was carried out on the natural soil, the mixture of soil with the optimum percentage of CKD, which was determined from the UCS, and the mixture of soil-CKD with different percentages of RAP. All stabilized soil samples were cured for 28 days at room temperature.

### *2.3 Sample details*

Compaction tests were conducted on blended soils as well as natural soil according to Modified Proctor tests method. A mechanical machine was used to compact the soil and blends. Distilled water was used to prepare samples for all the tests in this study. Water is added to the dry homogeneous mixture of the soil with the recycled materials gradually with continuous mixing so that the water is distributed evenly over all the particles of the mixture. The samples are prepared for a period not exceeding 30 minutes from the addition of water to avoid conglomerating the CKD particles or any reactions with the components of the soil or water. Water is added to the dry homogeneous mixture of the soil with the recycled materials gradually with continuous mixing so that the water is distributed evenly over all the particles of the mixture. The samples are prepared for a period not exceeding 30 minutes from the addition of water to avoid conglomerating the CKD particles or any reactions with the components of the soil or water. Five moisture contents were used to obtain MDD and OMC for soil, three in the dry condition and one in the wet condition, as well as the optimum moisture content. The first moisture content started with a value less than the OMC value, then water was added with an increment of 4 percentages between one moisture content and another according to the ASTM D1557 [22]. Compaction was performed in a standard mold with diameter of 101.6 mm and a height 116.4 mm with an extension attached at the top in five layers with hammering with 25 blows per layer using a hammer weighing 4.5 kg and a fall height of 457 mm.

The UCS test was conducted on seven different mixtures of soil. Three samples for each mixture and each curing period were investigated. Manual compaction was used in preparing the samples of the first type using a hammer with a weight of 24.47 N and a fall height of 308.8 mm. Five layers with 29 blows for each layer were applied to obtain the energy required for the modified effort (2,700kN-m/m$^3$). For samples which were prepared in the second type of molds, mechanical compaction was used with 42 blows for each layer in order to obtain the energy required for the compaction method with the modified effort.

The samples of CBR were compacted using modified proctor test according to the ASTM D1557 [22]. This specification involves compacting five layers of soil into a mold with 152.4mm in diameter and 127.8mm in height with 56 blows for each layer

## 3. Results and Discussion

### *3.1 Compaction Properties*

Figs 2 (a), (b), and (c), which illustrate the relationship between OMC and MDD with various CKD content included in the soil, demonstrate the results of compaction tests performed on natural soil and soil improved by different CKD percentages. It is obvious that MDD reduces as CKD content increases. The inclusion of 20% of CKD reduced the dry density by 1.6 KN/m$^3$. This was may be due to the low specific gravity of CKD in comparison with the specific gravity of natural soil. Furthermore, OMC increases as CKD content increases, where the inclusion of 20% CKD resulted in a 2.5% increase in OMC. The soil particle flocculation caused by the inclusion of CKD may be the reason for the reduction in MDD. However, the demand for water from the CKD that results in the cationic reactions is what causes the increase in moisture content when CKD is added.

Compaction tests were also carried out on the mixtures of soil with 20% CKD and various RAP contents after 20% CKD was determined to be the optimum CKD percentage. The results are shown in Fig 3 (a), which show that MDD increases as the percentage of RAP in the soil-CKD blend increases. A 35% RAP addition to the soil-CKD mixture increased dry density by 1.6 kN/m$^3$, whereas OMC gradually decreased. The OMC decreased by 4.7% as a result of the inclusion of 35% of RAP materials, as illustrated in Fig 3 (b) and (c). The reason for the increase in the MDD value when RAP is included in the soil is the higher specific gravity of the RAP materials compared to the soil- CKD mixture. Due to the fact that RAP consists of bitumen and aggregate, two materials that are known for adsorbing little water, the OMC of the blend decreases for this reason.

It can be used the compaction results in regression analysis to determine the relationship between MDD and CKD content. Equation (1) with an R-squared of 0.916 can be used to estimate the MDD of the remaining mixes in the experiment matrix.

$$MDD=18.468-0.0814CKD \quad (1)$$

Where,

MDD; maximum dry density (kN/m$^3$)

CKD; cement kiln dust (%)

Also, another regression model was developed for the prediction of the OMC of blends, with the projected OMC providing a means for determining the appropriate proportions of CKD and soil to be used for the preparation of specimens. The OMC model in Equation (2) has an R-squared of 0.90.

$$OMC=16.736+0.1124CKD \quad (2)$$

Where,

OMC; optimum moisture content (%)

CKD; cement kiln dust (%)

Also, the results were utilized in regression analysis to determine the associations between MDD and RAP content in the soil-20% CKD mixture. With a high R-squared of 0.982, the MDD of the remaining mixtures in the experiment matrix can be calculated using Equation (3).

$$MDD=16.924-0.0475RAP \quad (3)$$

Where,

MDD; maximum dry density (kN/m$^3$)

RAP; reclaimed asphalt pavement (%)

In addition, a regression model was formulated to estimate the OMC of blends, with the projected OMC to determine the appropriate quantities of RAP, CKD and soil to be utilized for specimen preparation. The R-squared of the OMC model in Equation (4) is 0.993, as a very high value.

$$OMC=18.796+0.1307RAP \quad (4)$$

Where,
OMC; optimum moisture content (%)
RAP; reclaimed asphalt pavement (%)

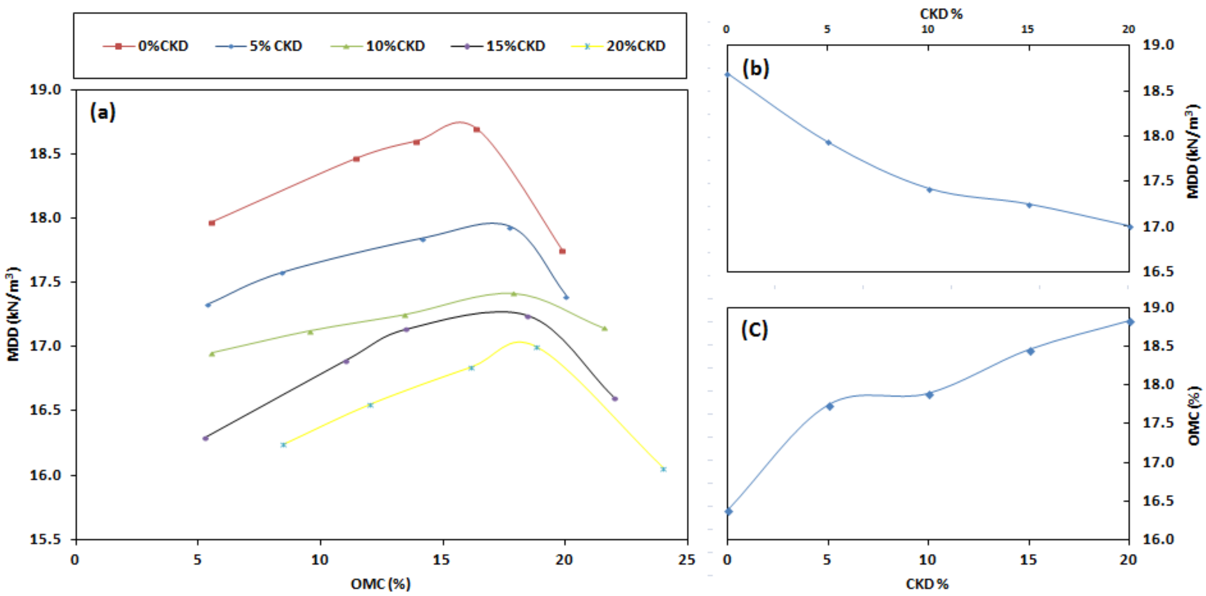


**Figure 2.** Effect of CKD percentage on the compaction properties of soil (a) compaction curves, (b) change of dry density with CKD, (c) change of moisture content with CKD

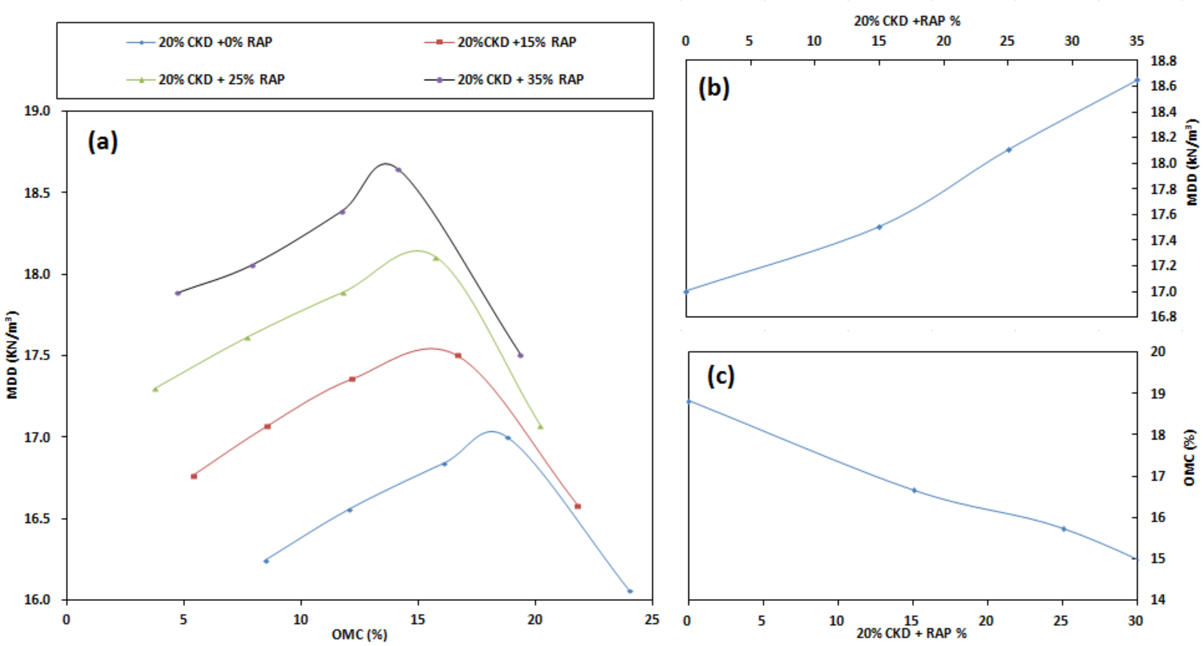


**Figure 3.** Effect of CKD-RAP percentage on the compaction properties of soil (a) compaction curves, (b) change of dry density with CKD-RAP, (c) change of moisture content with CKD-RAP

### *3.2 Unconfined compression strength (UCS)*

The efficiency of RAP and CKD in improving the subgrade soils as waste materials was evaluated using the unconfined compressive strength (UCS) test. The UCS results of untreated soil and a mixture of soil with various CKD percentages and cured at different times are shown in Fig 4. The results demonstrated that the UCS value improves as the CKD percentage in the soil increases. After curing the samples for 28 days, the UCS value improved to 2.69 MPa with the addition of 20% CKD. The interaction of calcium ions presents in CKD with mineral ions present in the clay causes the clay particles to agglomerate, which results in an increase in the UCS. This interaction occurs on the surface of clay particles as a result of ion exchange, as reported by [28].

Fig 5. shows the UCS results for untreated soil and mixtures of soil and 20% CKD with various amounts of RAP materials cured at three time periods. The results indicate that as the RAP level in the soil increases up to 25%, the UCS also increases. The maximum value obtained for UCS is 5.3 MPa by adding 25% of RAP particles. The UCS then gradually decreases in value until it reaches 3.6 MPa by adding 35% RAP. These modifications in the UCS occurred after curing for 28 days, which is considered the optimum time. The added RAP materials may have increased the density, which would explain why the UCS increased. The reduction in the UCS with the increase in RAP content beyond 25 % may be due to the bitumen that covers the RAP materials, which prevents the friction between particles, as indicated by [29].

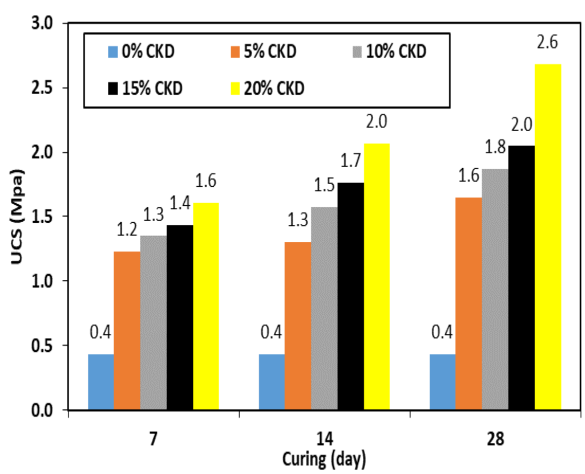


**Figure 4.** UCS results for various CKD percentages and cured at Different times

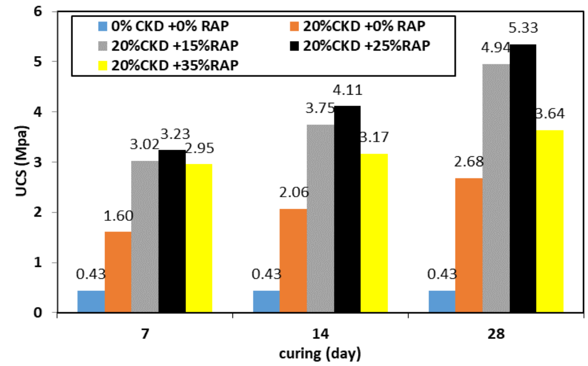


**Figure 4.** UCS results for blends of 20% CKD with various RAP percentages cured at different times

### *3.3 California bearing ratio (CBR)*

#### *3.3.1 CBR value*

Figs 6 and 7. show the results of unsoaked and soaked CBR, respectively, for the natural soil, soil stabilized by 20% CKD, and soil-20% CKD mixture stabilized by different RAP content. It can be concluded that adding the optimal content of CKD (20%) to the natural soil leads to an unexpectedly large increase in the value of unsoaked and soaked CBR. The unsoaked CBR value of the soil-CKD mixture increased to 211% after it was 12% for the natural soil, and soaked CBR increased to 220% after it was 3% for the natural soil. This CBR value in immersion conditions in comparison to its value in non-immersion conditions may be due to pozzolanic rections resulting from the continuous cation exchange and hydration process that leads to the formation of calcium aluminate hydrates in addition to calcium silicate hydrates, as reported by [30]. The hydration reaction that results in the production of cementitious components may be the cause of the increase in the unsoaked CBR value, as illustrated by [19].

Furthermore, it was found that adding RAP-20% CKD blends to natural soil and leaving them to cure for 28 days significantly increased the CBR values for the various RAP levels, with 25% RAP achieving the higher value. The unsoaked CBR of soil-20% CKD-25% RAP blend was 215%, while the soaked value for the same blend was 251%, as the maximum value. The aggregation of the heterogeneous RAP particles due to the presence of CKD may be the reason for this modification in the CBR, As shown by [31]. Also, the improvement in the CBR with the addition of RAP materials may be due to the new particle distribution of the blend. The fine soil particles work to provide the adhesion between the RAP particles by filling the large voids between the RAP particles, as indicated by [32].

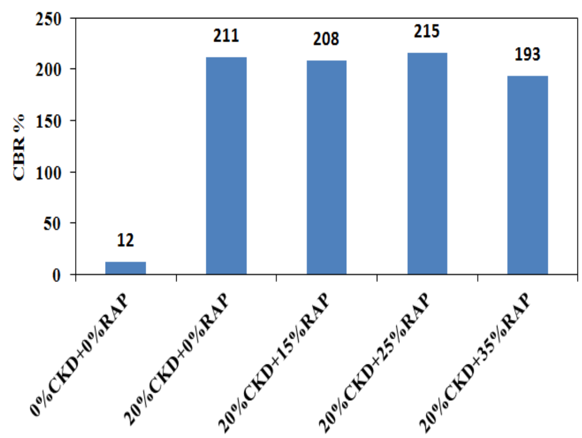


**Figure 6.** The results of unsoaked CBR value with the addition of CKD and RAP

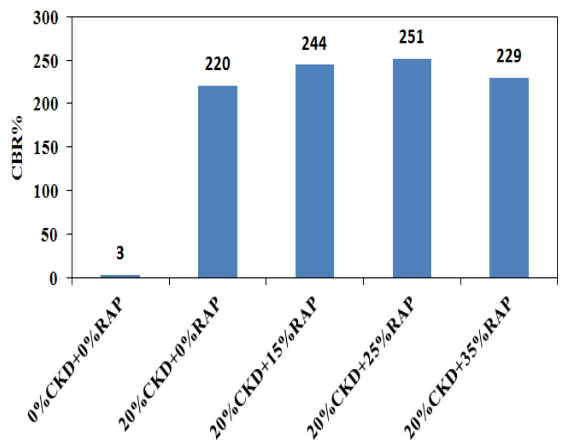


**Figure 7.** The results of soaked CBR value with the addition of CKD and RAP

*3.3.2 Swelling*

Swelling is one of the main factors in assessing the efficiency of soil stabilization and its long-term performance, and it was estimated by immersing CBR samples in water for 96 hours, according to ASTM D1883 [27]. In general, fine soils are poor in resistance to swelling conditions and may fail with high moisture content. Therefore, a swelling value was calculated from the CBR test for the soil under study, as it consists of clay and silt. The swelling results determined from soaking CBR specimens are illustrated in Fig 8. The specimens were immersed in the water and the swelling was observed after soaking for 96 hours of specimens of untreated soil and soil improved by CKD and RAP. For the untreated soil, the swelling was 3.97 %, which is considered a high value. When the CKD was included, the swelling reduced greatly to 0.19% after curing for 28 days. The inclusion of (15, 25 and 35%) of RAP particles to the blend of soil-20% CKD significantly decreased the swelling percentage, which decreased with the increase of RAP materials in the mixtures. Furthermore, 35% of RAP particles achieved the lower value of swelling, where it was reduced by 99.19 % at this percentage of RAP. The reason for this reduction of swelling value in soil improved by CKD may be that the CKD decreases voids in clay due to the production of cementitious compounds as a result of the exposure of the CKD to water, as reported by [4]. Moreover, decreasing the swelling with the addition of the RAP particles may be attributed to the fact that the RAP materials are characterized by a lack of water adsorption, which causes a reduction in swelling percentage for the blend.

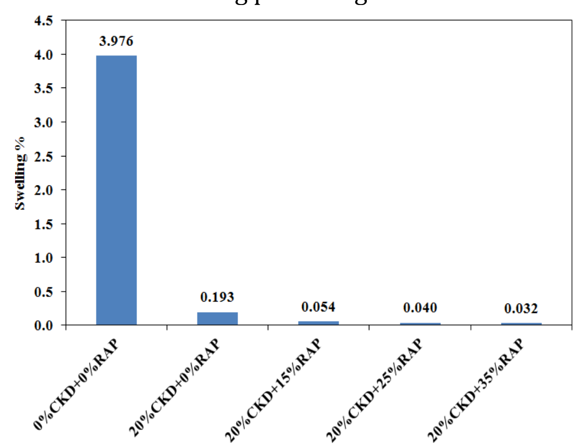


**Figure 8.** Results of swelling value with adding CKD and RAP

## 4. Conclusion

The effectiveness of enhancing subgrade soil with waste materials, CKD and RAP, of various contents was investigated in this study. The following are the important points of conclusion:

1. As the CKD content in soil increases, OMC increases and MDD decreases. However, the MDD was reduced by 9.1% and the OMC was increased by 12.8% due to the high proportion of CKD (20%).
2. The OMC for the blend of soil-20% CKD decreases and OMC increases when the RAP percentage in the soil increases. The OMC was reduced by 25%, while the MDD improved by 8.8%.
3. The inclusion of CKD improved the UCS value. The UCS of soil treated with 20% CKD was increased by 521% after 28 days of curing.

4. The UCS increased as a result of the incorporation of RAP. After 28 days of curing, the UCS of the 25% RAP-treated soil-CKD blend was improved by 1142%.
5. The inclusion of 20% CKD increased the CBR of the soil. the Soil-CKD mixture with 20% CKD improved the unsoaked CBR by 1658% and the soaked value by 6370%.
6. The unsoaked and soaked CBR for the blends of soil-20% CKD was found to enhance with increasing the RAP percentage in the mixture. the unsoaked and soaked CBR of soil stabilized by 20% CKD and 25% RAP increase by 1691% and 7282%, respectively.
7. The addition of CKD and RAP significantly reduced the swelling. The swelling value of soil stabilized by 20% CKD and soil stablized by 20% CKD-35 % RAP was decreased by 95% and 99%, respectively.

The study demonstrated the effectiveness of the CKD and RAP in soil stabilization as a subgrade layer.

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