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Evaluation of Incorporating CKD and RAP on the Performance of Cohesive Soil

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ABSTRACT.

The aim of this study is to investigate the effect of adding recycled materials such as CKD and RAP to weak cohesive soils, in addition to evaluate the change in the strength of these soils. This study was conducted on soil type MH, and only RAP particles finer than 10 mm were used in preparing the mixtures. 7, 14, and 28 days were selected as curing periods for soil-CKD and soil- CKD- RAP mixtures to obtain the effect of curing periods on soil improvement. The results showed that adding 20% of CKD to the natural soil increased the unconfined compression strength UCS from 0.43 MPa to 2.6 MPa at a 28-day curing period. Also, the results showed that adding 25% of RAP to the soil- 20% CKD mixture increased the UCS value to 5.3 MPa after 28 days of the curing period. The final results showed that the optimum contents of CKD and RAP added to the cohesive soil were 20% and 25%, respectively, while the optimum curing period was 28 days

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1. Introduction

Cohesive soil is fine-grained soil consisting mainly of clay and silt, and it may have multiple problems when its cohesion stress is low and also when it contains a high percentage of water. These problems include low shear strength, high compressibility, and high water retention, which make it unsuitable for building various structures on it due to its instability. Accordingly, it is necessary to stabilize cohesive soils before starting any project. Use of cement and lime in chemical stabilization of the soil is the most common method. (Davidovits, 2015) referred that the manufacture of one ton of cement release 0.85 - 1 ton of carbon dioxide CO_2 into the air. Hence, it is necessary to think of alternative materials that are environmentally friendly, and highlight good and acceptable results in improving cohesive soils.

Since fine soil stabilization depends mainly on calcium in the form of lime, the use of CKD compounds (especially those containing a high percentage of free lime) may be an alternative to lime. Use of CKD may give cementing properties similar to cement Portland which has a significant influence on soil stabilization (Rahman,

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Rehman, & Al-Amoudi, 2011). In fact, the chemical stabilization is the change in physical and chemical properties of the soil which can be accomplished by adding different materials such as; lime, cement and some recycled materials, including CKD. CKD reduce soil shrinkage and swelling, as well as improving shear strength and decreases soil plasticity, which all leads to increase the strength of bearing foundations (Elbaz, Aboulfotoh, Dohdoh, & Wahba, 2019). A field study was conducted to compare soil stabilization by using lime and CKD, which was collected from different cement factories. The results showed that the use of CKD was better than using lime in soil improvement (Miller & Zaman, 2000). (Rimal, Poudel, & Gautam, 2019) reported that soil stabilization is done by means of cement or chemical additives, and they are either basic materials such as cement or waste materials such as CKD. The author used CKD proportions (2.5, 5, 7.5 and 10) % to stabilize the soil and proven it's effective in improving the soil, taking into account the possibility of higher contents which were used in subsequent years by other researchers. (Shukla & Tiwari, 2019) indicated that the physical properties of clayey soils are significantly improved when using 5%,10%,15%,20% and 25% of CKD.

RAP may be used in the soil to improve its mechanical properties because it contains crushed aggregate, which results in an increase the maximum dry density MDD for clay soils due to the large specific gravity of RAP materials compared to that of clay soils. In general, adding aggregates to the soil improves its properties (Magar, Xiao, Singh, & Showkat, 2021). Use of RAP in many lateritic soils, improves their properties and makes them suitable for the construction of many projects because lateritic soils have poor engineering properties which does not conform to the applicable engineering specifications. Inclusion of RAP materials in lateritic soils sorts out high water retention, low strength, high plasticity, high permeability and poor workability problems of such soils (Akinwumi, 2014; Maignien, 1964). (Saride, Avirneni, Javvadi, Puppala, & Hoyos, 2015) used RAP with the Fly ash to stabilize the base and subbase layers. In recent study (Kwad, Abdulkareem, & Ahmed, 2020) highlighted that the addition of 10 to 50% RAP to the subgrade soils type sandy silt improved the physical and mechanical properties of this type of soil.

MDD of soil increases with increasing the CKD content, as is the case with the optimum moisture content OMC also increases for the two types of soils, CL and ML (Rimal et al., 2019). (Jala & Sharma, 2019) reported that MMD decreases with increasing CKD content up to 15%, while the OMC increases with increasing CKD content up to 15% for the plastic clay soil, CH, which is considered high compressive soil. This modifications in MDD and OMC with adding of CKD due to the flocculation of soil particles. (Mustapha, Jibrin, Etsuworo, & Alhassan, 2014) reported that the addition of RAP to clay soil changes the value of MDD. The value of MDD increased from 1.895×10^{-6} g/cm^3 for natural soil to 2.170×10^{-6} g/cm^3 associated with including 60% of RAP. However, further increase in RAP content led to decrease MDD until it reached 2.017×10^{-6} g/cm^3 at 100% RAP. (Ogunrinde, Adejumo, & Amadi, 2020) studied the effect of adding RAP to clay soil which was classified as A-6 according to AASHTO and showed that MDD increased with inclusion of RAP materials. Moreover, OMC decreased when adding RAP materials to the soil. This means that the addition of RAP improves the soil, especially that use in work of embankments and filling.

The UCS value increase significantly when adding CKD as a stabilizer. The results showed that the UCS increases from 210 to 1100 kPa in case of incorporating 16% CKD after 28 days of curing (Miller & Zaman, 2000). A significant increase in UCS was observed with the addition of CKD as highlighted by (Miller & Azad, 2000). The authors showed that a sufficient CKD proportion must add to soil in order to complete the reactions that occur between minerals in the clay with chemicals in CKD. In fact, this reaction leading to form cement compounds which are responsible for increasing soil strength. (Rimal et al., 2019) studied the change occurs in UCS of two types of soils CL and ML as results of adding CKD. The authors were reported that the UCS increased with increasing CKD contents for both soils. It should also be noted that CKD increased the UCS of ML soil more than that of CL soil.

UCS of soil-cement mixture decreases with the addition of RAP due to the presence of bitumen in the RAP which prevents friction between soil particles. However, with increasing the curing period of soil up to 28 days, the UCS returns to increase again due to cement that presence in the soil (Ghanizadeh, Rahrovan, & Bafghi, 2018).

The value of UCS increased with addition of RAP to the mixture of soil type CL with sugarcane bagasse ash SCBA, due to the formation of strong bonds in the soil- SCBA- RAP mixture which resulted from the pozzolanic reactions of SCBA (Ochepo, 2014). (Adhikari, Khattak, & Adhikari, 2020) investigated the effect of adding RAP in two types of soft soils namely MH and CL and indicated that RAP had a great effect on UCS. Increasing the content of adding RAP increased the UCS value of the soil- RAP mixture. (Akinwumi, 2014) indicated the effect of adding RAP on the reduction of UCS value with increasing in the RAP content in the soil- RAP mixture. When adding RAP beyond 12% content, the author noticed a significant drop in the value of the UCS by 88.4%.

The utilize of industrial waste in the soil stabilization field is quite popular. Generally industrial waste causes many environmental problems, so the use of industrial waste in soil stabilization is the best method to dispose it off. Utilizing waste in soil stabilization is beneficial in several ways such as; saving biodiversities, disposal of waste, improving soil properties like increase strength, reduce compressibility in addition to maintaining the natural soil and construct economical structures. Therefore, CKD and RAP were used in this study as recycled materials to increase soil shear strength and reduce compressibility. It should also be noted that no research has adopted both CKD and RAP together to improve the mechanical properties of cohesive soil which distinguish the current study.

2. Materials and Methods

2.1 Materials

2.1.1 Soil

Soil was collected from a quarry near city of Ramadi, Iraq. The soil was mechanically pulverized before using it at the laboratory. It was classified as highly plastic silty soil (MH) according to the Unified Soil Classification System (USCS). Content of gypsum and total shattered salts, TSS were 12.05% and 2.81%, respectively. Particles size distribution of soil is shown in Fig. 1. As observed from hydrometer analysis, this soil consists of 65% silt and 35% clay. Other properties of the soil are shown in Table 1. Soil chemical compositions are listed in Table 2, which were measured using XRF test. It is clear that there is a high content of silica SiO_2 in the soil.

2.1.2 Cement Kiln Dust (CKD)

CKD used as a soil stabilizer in this study which was brought from the Kubaisa cement factory which is located west of Ramadi city. Several tests were conducted on this material to determine its properties. Specific gravity of CKD is 2.05. Particle size distribution is shown in Fig. 1 while CKD chemical properties measured using XRF test are presented in Table 2. It is clear that there is a high content of calcium oxide CaO in the CKD.

2.1.3 Reclaimed Asphalt Pavement (RAP)

The RAP is materials that are removed from old roads in order to be rehabilitated them, so they are treated as a waste which must be recycled or disposed. RAP was collected from one of the roads in Karbala, Iraq after scraping the upper layer by a milling machine with a thickness of 100 mm in order to rehabilitate the road. The age of the scraped RAP reached 10 years. The RAP was sieved on 10 mm sieve size in order to exclude large particles so that the RAP can be used in accordance with UCS specification ASTM D2166 (ASTM, 2013). The percentage of bitumen in the RAP is 4.7%, while the particles size distribution of RAP is shown in Fig. 1.

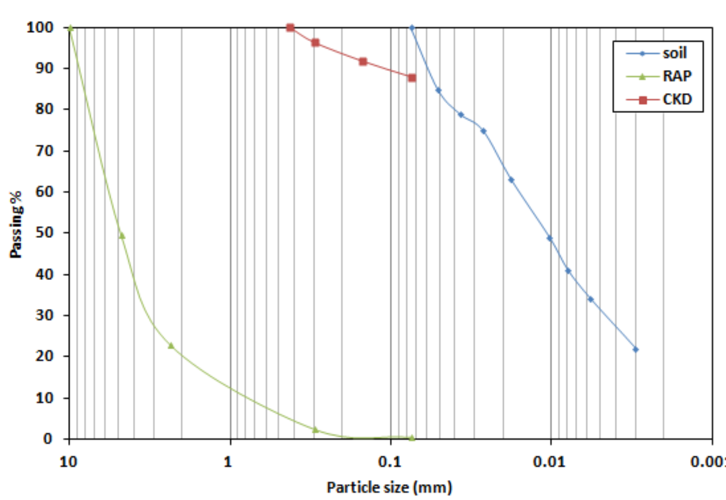

Fig.1 Particles size distribution of materials

Table 1- Properties of soil

Property	Value	Standard
Unified Soil Classification System (USCS)	MH	ASTM D2487 (ASTM, 2017)
Liquid Limit (LL)	74%	ASTM D4318 (ASTM, 2017)
Plastic Limit (PL)	59%	ASTM D4318 (ASTM, 2017)
Plastic Index (PI)	15%	ASTM D4318 (ASTM, 2017)
Specific Gravity (Gs)	2.67	ASTM D854 (ASTM, 2014)
Maximum Dry density (γ_{dmax})	18.6 kN/m^3	ASTM D1557 (ASTM, 2012)
Optimum Moisture Content (OMC)	16.4%	ASTM D1557 (ASTM, 2012)

Table 2 - Chemical properties 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 Methods

2.2.1 Modified Compaction Proctor test

Compaction is the process of decreasing the soil voids in order to increase its density. This process aims to find the maximum dry density (MDD) and the optimum moisture content (OMC) of the soil.

Soils that have a high MDD and low OMC are good for using in most engineering projects. In this study, modified compaction test was performed according to ASTM D1557 (ASTM, 2012) for samples of natural soils and samples of soils stabilized with 5, 10, 15 and 20% of CKD to observe MDD and OMC of the stabilized soil as well as the natural soil. After determining the optimum CKD content that added to the soil, compaction tests were conducted on the soil - CKD mixtures incorporated by 15, 25 and 35% of the RAP to measure MDD and OMC for these mixtures. MDD and OMC are observed from modified compaction tests were used to prepare UCS samples for natural soil, soil stabilized by CKD and soil stabilized by CKD and RAP.

2.2.2 Unconfined compressive strength (UCS) test

Many researchers have used UCS test to assess the effectiveness of stabilized materials. In this study, the effects of CKD and RAP contents, and curing period on the UCS of the cohesive soil was considered. Two types of molds were used in preparing of UCS specimens. The first type, with dimensions of 63mm in diameter and 126mm in height, was used in preparing specimens of natural soil and soil stabilized by CKD. The optimum percentage of CKD was determined by UCS test on this type of specimens. The axial strain used in testing first type of specimens was 0.9 mm/min. The second type of molds used in this study was 100 mm in diameter and 200 mm in height, which was used in preparing soil stabilized by CKD-RAP samples. The optimum content of RAP was determined by UCS test on this type of specimens. The axial strain used to test these specimens was 1.4 mm/min. The second type of mold was used for soil- CKD mixtures stabilized by RAP to satisfy the ASTM D2166 (ASTM, 2013). The reason behind that is to specify the diameter of the mold used in preparing the UCS specimens which should not less than 10 times of the diameters of the soil particles on which the test is to be conduct. It should be noted that the aforementioned axial strain rates and molds dimensions were used in this test to conform to the ASTM D2166 (ASTM, 2013). 7, 14 and 28 days were selected as curing periods for all mixtures in this test. The curing was carried out by wrapping the specimens with multiple layers of thin nylon and keeping it in plastic bags to maintain moisture and completely isolate them from the air, then placed in dry oven at maintain temperature of 25ºC. Then the optimum period for curing soil stabilized by CKD and CKD-RAP was chosen.

3. Results and discussion

3.1 Compaction properties

Compaction tests results of natural soil and the soil stabilized by different CKD content are presented in Fig.

2 (a), Fig. 2 (b) and Fig. 2 (c) which shows the relationship between MDD and OMC, respectively with different CKD content included into the soil. It is clear that MDD decreases with the increasing of the CKD content, as the addition of 20% of the CKD decreased the MDD by 9.1%. OMC increases with increasing of the CKD content, as the addition of 20% of CKD increased the OMC by 12.8%. Many pervious researchers such as (Abdulkareem, Eyada, & Mahmood, 2021) showed that the MDD decreased and the OMC increased as the content of the CKD increased. However, the change in density and moisture content depends on several factors, including the type of soil and the properties of the CKD. The decrease in MDD may be due to the flocculation of soil particles as a result of the addition of CKD. While the increase of moisture content with addition CKD is due to demanding water from the CKD which causes the cationic reaction. After determining 20% as the optimum CKD content, compaction tests were performed on soil- 20% CKD mixture with different RAP content. The results which are presented in Fig. 3 (a) show that MDD increases with increasing RAP content in the soil- CKD mixture. The addition of 35% RAP to soil-CKD mixture has led to an increase in MDD by 1.6 kN/m^3, while OMC decrease gradually. In fact, the addition of 35% of the RAP has led to decrease in OMC by 4.7%, as shown in Fig. 3 (b) and Fig. 3 (c), respectively. The reason of this increase in the value of MDD when RAP materials are included to the soil is due to the increase in the coarse aggregate which leads to a higher density of the mixture. Moreover, the reason of decreasing OMC of the mixture is the lack of demanding water absorbed by RAP because it consists mainly of aggregate and bitumen, and these two materials are characterized by adsorbing little water.

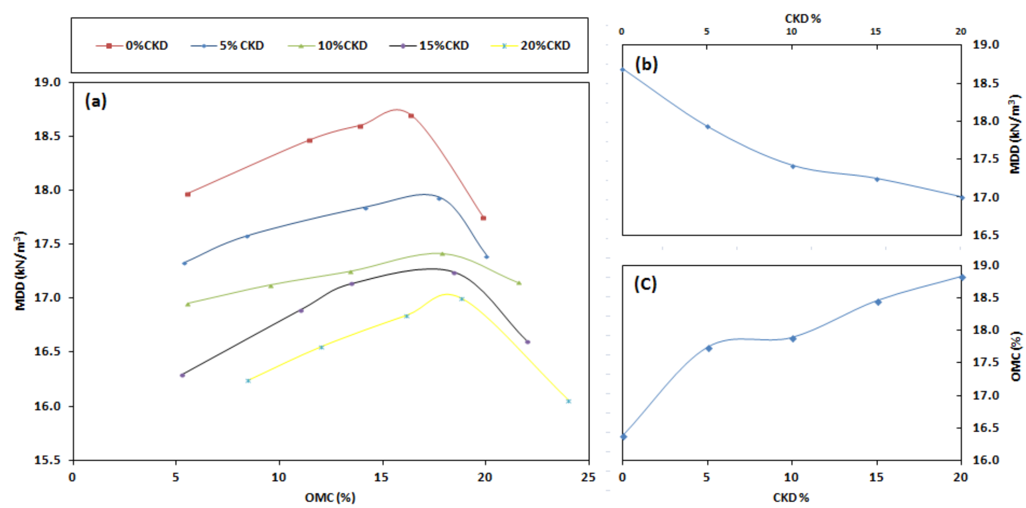

Fig. 2 Effect of CKD content on the compaction behavior of soil (a) compaction curves, (b) variation of MDD with CKD, (c) variation of OMC with CKD

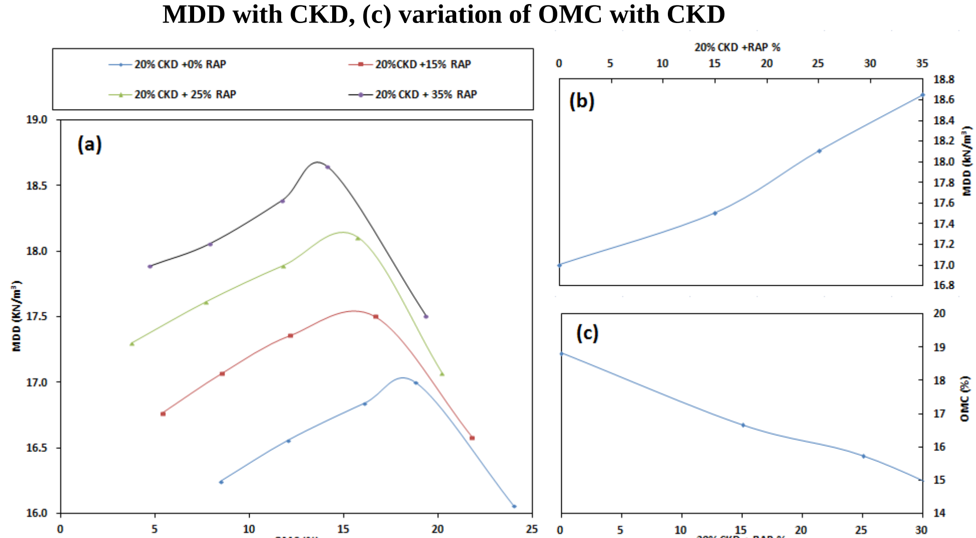

Fig. 3 Effect of CKD-RAP content on the compaction behavior of soil (a) compaction curves, (b) variation of MDD with CKD-RAP, (c) variation of OMC with CKD-RAP

3.2 Unconfined compression strength (UCS)

Unconfined compressive strength UCS test was performed to assess the effectiveness of CKD and RAP in improving of cohesive soils as recycled materials. This test is important to assess the soil to bearing excessive loads resulting from various engineering projects. Fig. 4 and Fig. 5 represents the results of the UCS of the natural soil and soil mixture with different CKD contents and cured at different periods. It is clear from the results that the value of UCS increases with increasing CKD content in the soil. The value of UCS increases to 2.68 MPa with addition of 20% of CKD after 28 days of curing.

The modification of the engineering characteristics of soil due to utilize of chemical stabilizers can be attributed to two main reactions; short term reactions as a results of cation exchange which results flocculation of soil particles and pozzolanic activity which represents long term reactions. Through the primary stage of reactions between clay soils and the chemical additives, exceeded calcium ions in CKD content or in lime changes the charge density of electronics around the particles of clay by replacing other monovalent cations in the clay particles. This causes an increase in the attraction interparticle which cause aggregation and flocculation and finally, decrease the soil plasticity. Also, the pozzolanic reactions are dependent on temperature and time-bound. During this reaction, the high pH results in alumina and silica to be dissolved and combine with the calcium, which occurred in the lime or the CKD to produce cementitious compounds; calcium aluminate hydrates, CAH, calcium silicate hydrates, CSH, and calcium aluminosilicate hydrates, CASH (Nalbantoglu & Gucbilmez, 2001). It should be noted that the soil used in this study contains a high content of silica and CKD contains a high content of calcium oxide as shown in Table 2. This confirms the effectiveness of CKD in improving these types of soils, according to what was mentioned in the previous studies.

With time, the soil gains strength due to continue in the interactions. The strength gained with time explains the major role for curing in the UCS value, which increases with increasing curing period. Increasing the curing period means giving enough time to increase the reactions that occur as a result of adding CKD to the soil, which eventually leads to increasing the strong bonds among particles resulted from compounds that have cement properties. According to the results of the UCS, as illustrated in Fig. 4, it can be considered that the 20% of CKD is the optimal content, while the 28 days of curing can be considered as the optimal curing period.

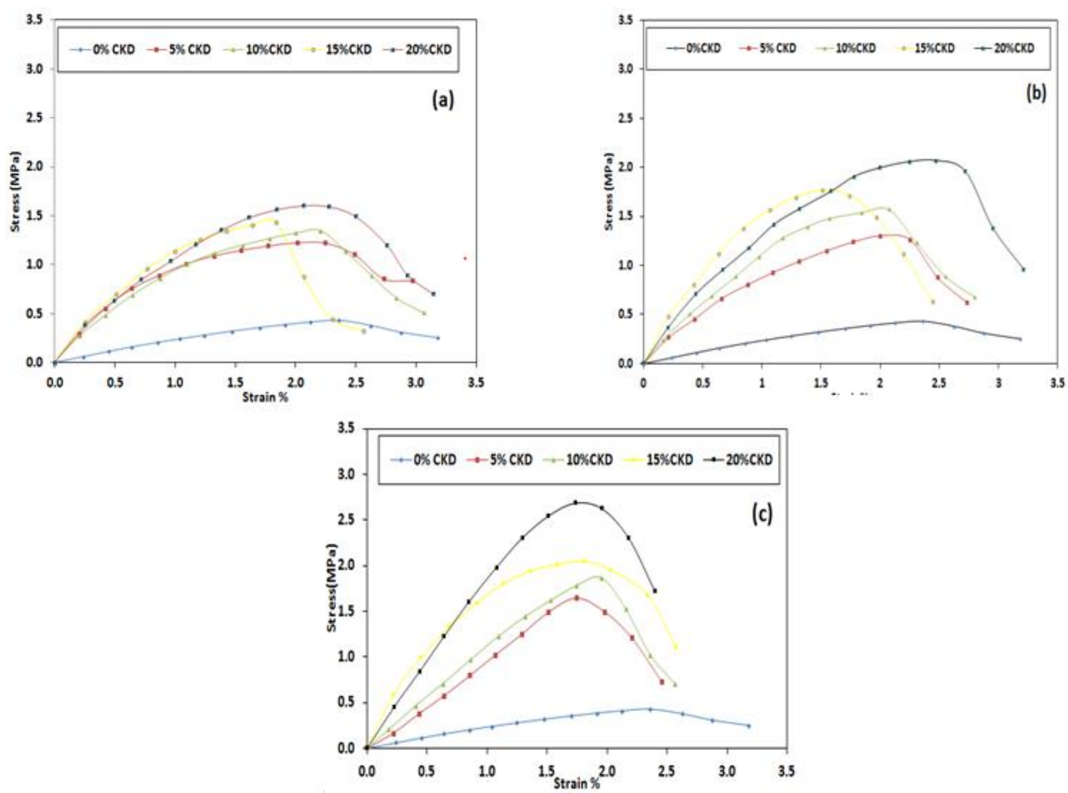

Fig. 4 Stress-strain of CKD treated soil for varying curing periods: (a)7days (b)14days (c)28 days

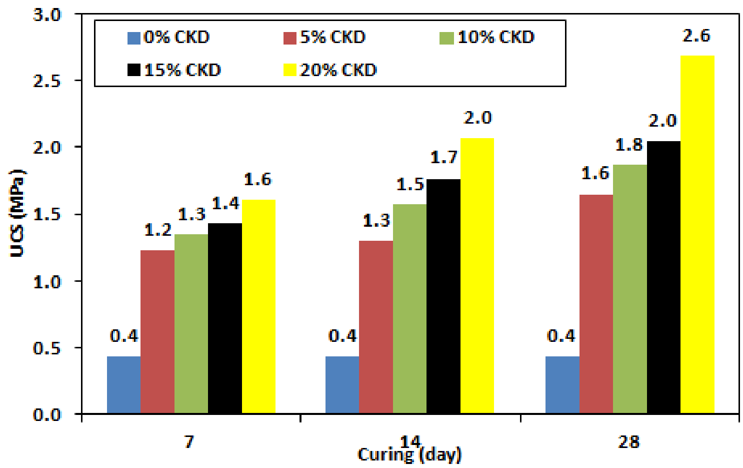

Fig. 5 UCS results for different CKD contents and cured at different periods

Fig. 6 and Fig. 7 represents the results of UCS of the natural soil and soil mixtures prepared with 20% of CKD and different contents of RAP cured at three different periods. The results show that the value of UCS increases with the increasing RAP content up to 25% RAP in the soil. The value of UCS was 5.33 MPa at 25% RAP content as a maximum obtained value. Then, the UCS decreases gradually until its value reaches 3.64 MPa at the 35% of RAP content. These changes in the UCS value were at 28 days of curing period, which can be considered the optimal period. Comparably similar results occurred for the other curing periods, but the best improvement was at 28 days' period due to the presence of CKD in the mixture. When RAP is added to the soil, two factors work in opposite directions: density and friction. RAP causes an increase in soil density and thus increasing the strength of the soil. While the bitumen covering the RAP granules decreases the friction between the soil particles, which leads to decrease its strength. At the early stages of adding RAP, the effect of density is higher than the effect of lack of friction due to bitumen, which leads to increasing the strength of the soil. However, as the content of RAP continues to increase, the effect of bitumen begins to increase until its effect becomes higher than the effect of the density. This increasing in the effect of bitumen leads to a gradual decline in strength. This is the reason for increasing the value of the UCS with increasing the addition of RAP. However, beyond 25% of RAP content, UCS. According to the results of the UCS for soil stabilized by CKD- RAP, it can be considered that the 25% is the optimal content for including RAP materials, while the 28 days can be considered as the optimal curing period.

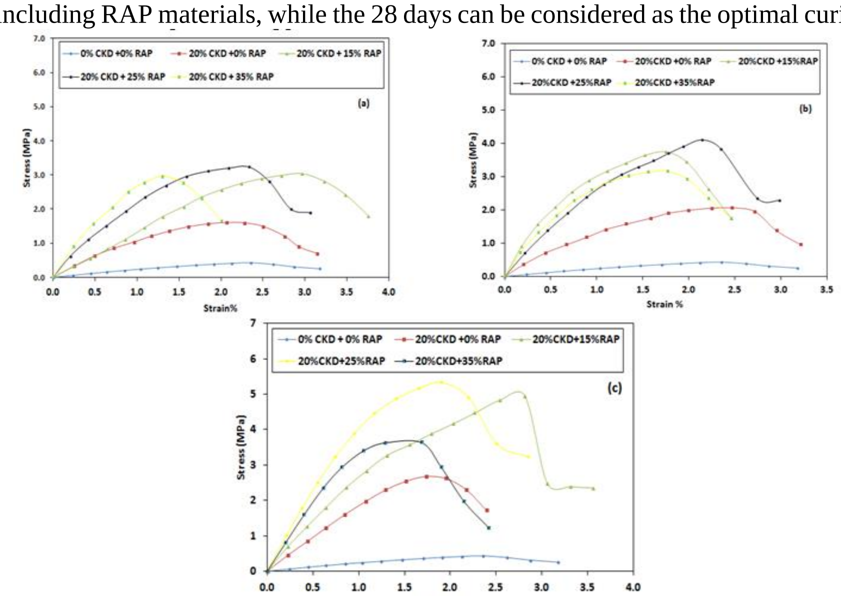

Fig. 6 Stress-strain of CKD-RAP mixture treated soil for varying curing periods: (a)7days (b)14days (c)28 days

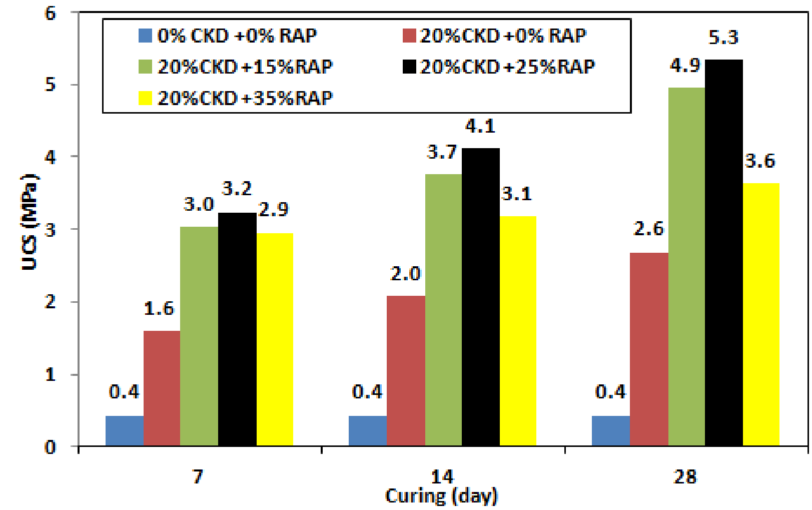

Fig. 7 UCS results for mixtures of 20% CKD with different RAP contents cured at different periods

4. Conclusions

The main points of conclusion are as follows:

1. The MDD decreases and OMC increases, with increasing CKD content in the cohesive soils. However, the 20% of CKD decreased the MDD by 9.1% and increased the OMC by 12.8%. On the other hand, as the RAP content increases, the MDD of soil-20%CKD increases and OMC decreases. However, the MDD increased by 8.8% and OMC decreased by 25%.
2. The addition of CKD led to increase the value of UCS. The UCS of soil treated with 5% CKD after 28 days curing was 1.6 MPa whereas the UCS of 20% CKD treated soil was found to be 2.6 MPa at 28 days. Therefore, the addition of CKD is the main reason for increasing the UCS by almost 6 times associated with up to 20% of CKD.
3. The addition of RAP led to increase the value of UCS. The UCS of soil- CKD mixture treated with 15% of RAP after 28 days curing was 4.9 MPa whereas the UCS of 25% RAP treated soil- CKD mixture was found to be 5.3 MPa on the 28 days curing. It can be therefore concluded that the addition of RAP increased the UCS by almost twice.

In general, it can be to conclude that CKD and RAP can be effective additives as it improves strength of the soil significantly. The results of current study are limited to 5, 10, 15 and 20% of CKD and 15, 25 and 35% addition of RAP. Further investigating of increasing the percentages of CKD and RAP is recommended to gain more understanding about the behavior of improving the performance cohesive soils.

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