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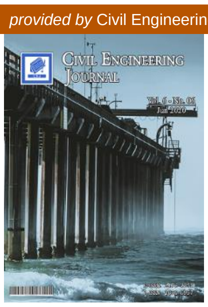

Incorporating of Two Waste Materials for the Use in Fine-Grained Soil Stabilization

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Abstract

The present experimental work briefly aimed to utilize two different waste materials; calcium carbide residue (CCR) and the locally available rice husk ash (RHA) to produce an eco-friendly binder for the use in fine-grained soil stabilization. The effect of different binary mixtures, produced by mixing CCR and RHA with different proportion, on the geotechnical properties of a fine-grained soil was investigated. For the unconfined compressive strength (UCS) test, the soil specimens were subjected to various curing periods (7, 21, 28 and 90 days). The microstructure of the soil treated with the optimum mixture was carried out by utilizing scanning electron microscopy (SEM) test. Results of UCS test showed an interesting growth after the treatment of binary mixtures relative to those samples treated with only CCR. Plasticity index (PI) was found to decrease noticeably with use of CCR only while further reductions in PI were achieved after the RHA incorporation. Clear variations in the microstructure of the treated soil were revealed from SEM testing approving the creation of cementitious products. The results of the current study indicated that the wastes utilized in this investigation could be potentially used as alternatives to the conventional binders and final disposition with economic and environmental advantages.

Keywords: Calcium Carbide Residue; Microstructure; Rice Husk Ash; Soil Stabilization; Unconfined Compressive Strength.

1. Introduction

In areas with weak or soft soils, civil engineering projects have traditionally incorporated enhancement for the properties of the soils utilizing different methods. Soft soils are the most problematic soils in civil engineering due to their high compressibility, and tendency to swell with low compressive strength [1]. The accepted usual technique to mitigate such issues is the process of soil stabilization [2]. Soil stabilization technique has been introduced many years ago in order to make soils meet the engineering projects requirements [3, 4].

Stabilization of subgrade soil has traditionally been carried out using either lime and/or cement which react chemically with soil particles to bind them to each other resulting in stronger soil structure. It is proven that the use of lime and ordinary Portland cement (OPC) as soil stabilizers significantly enhance the properties of the soil by increasing the workability, the durability, and the compressive strength, and led to reduction in the compressibility and permeability as indicated in Jauberthie et al. [5], Önal [6], Modarres and Nosoudy [7], Jha and Sivapullaiah [8]. However, the production processes of lime and OPC have many drawbacks such as negative environmental impact, the

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consumption of natural resources, and the high production cost. The quantity of CO_2 being released into the atmosphere has been increased due to the incessant production of cement [9]. Cement manufacturing contributes to around 6-8% of the global carbon dioxide (CO_2) emissions [10, 11]. Moreover, global cement production was recorded to increase from 4 to 4.6 billion tonnes between 2013 and 2015 respectively [12]. Overall, the worldwide cement industry is forecasted to rise by 5% annually.

Based on what stated above, researchers have paid attention to develop new binder materials by utilizing alternatives to replace or reduce OPC usage. Such materials are called wastes or by-products; they exhibit pozzolanic reaction, meaning that they can self-hardened though they react with cement generating cementitious gels [13]. Nevertheless, some of the by-product materials have a free lime (CaO) contents such as calcium carbide residue (CCR), and ground granulated blast-furnace slag (GGBS). Such substances can react with alumina or silica oxides and hydrate with water generating hydration products alike to what gained from traditional cement hydration [14]. Waste or by-product materials have occupied a big part of research projects in terms of modern cement manufacturing due to the wide range of their chemical properties which could make them very promising in cement replacement industry [15-22]. CCR is a by-product produced from acetylene gas industry; this material possesses a very high content of calcium oxide which can show a good task in the process of hydration and soil stabilization [23]. The global generation of acetylene gas was about 500,000 t in 2014, this produce around 1,423,000 t of CCR. This quantity is expected to increase by 3% in 2020 [24]. CCR has been utilized as a replacement to cement in various construction fields including soil improvement [14, 25, 26]. Dependent on the availability of natural pozzolanic substances in the clayey soils, Kampala and Horpibulsuk [23] used CCR for geotechnical properties enhancement of a clayey soil. They pointed out that the water content increased while the dry density decreased after the incorporation of CCR. The use of CCR indicated a valuable improvement of the Atterberg limits by decreasing PI significantly. They found that the best dosage of CCR was around 10% by the dry mass of the treated clay. Vichan et al. [25] used CCR with the combination of biomass ash to stabilize the Bangkok clayey soil. They found that the pozzolanic materials of the biomass ash boosted the pozzolanic reaction successfully. This reaction led to a substantial evolution in the strength of treated clay. Hanjitsuwan et al. [27] developed an alkali-activated binder system where CCR partially replaced fly ash as additional calcium. Their results indicated that the reaction products were improved due to the inclusion of CCR. CCR showed superior moisture resistance and adhesion when it used as filler instead of traditional OPC in dense bituminous macadam mixes due to the predominance of calcium-based minerals [28]. Li and Yi [29] revealed that more hydration products can be generated by the $Ca(OH)_2$ in CCR which accelerated the hydration of GGBS.

Rice husk represents a rice milling by-product, with a global production of around 100 millions of tons of husk per year [13]. Because of the almost negligible digestible protein content as well as the abrasive character of the husk, it is not suitable as animal feed [30]. Also, the large lignin and ash contents make it unsuitable to be used in the manufacturing of paper as a raw material. Thus, for reducing such amount of waste, the rice husk is typically burned either as a fuel in ovens for power generation, rice drying, etc. or in open heaps. In the burning process, the water as well as the organic compounds of rice husk would be reduced and only 20% of the mass stays as RHA. In case of burning all the rice husks, around 20 million tons of RHA would be produced throughout the world annually. The best alternative to the disposition of the residue is its reuse; this method is also associated with environmental advantages. Pozzolanas are the materials consisted mainly of siliceous and/or aluminous that have little or no cementing characteristics by their own, however they react chemically with calcium hydroxide like lime to produce materials having cementitious characteristics [31]. The RHA contains silica in around 90%, this percentage is the highest in all plant residues. Depended on that, RHA has been utilised to enhance soil characteristics when incorporated alone or mixed with a hydraulic activator like the cement and lime. The stabilization of soil by the incorporation of RHA and lime is significantly attractive for road pavements as it reduces the cost of both construction and disposal, minimizes environmental impacts and decreases the pressure on natural resources to keep them for the important uses. It was found by Nuaklong et al. [32] that the performance of recycled aggregate geopolymer was enhanced due to the inclusion of RHA by improving the microstructure and denser matrix.

The current study presents the effect of using CCR combined with RHA on the geotechnical characteristics of a fine grain soil by evaluating the Atterberg limits and unconfined compressive strength behaviors. The soil stabilized in the current study was improved using different binary mixtures produced from various mixes of CCR and RHA. The samples prepared for UCS test were cured at 7, 21, 28 and 90 days before subjecting to the compression test. Samples treated with the optimum binder were cured at 7, and 28 days to be employed in the microstructural investigation using scanning electron microscopy (SEM) technique to examine the substantial alterations occurred in the microstructure of the soil after treatment.

The current study was carried out via four main stages represented as follows:

- The literature review of recent researches deal with soil stabilization and particularly the role of using waste or by-product materials as alternative binders;

- The second stage is represented by the description of the candidate materials used in this study such as the stabilized soil and binder materials with a brief discussion for their main properties. Research methodology and specimens preparation techniques were also discussed in this part;
- The presentation and discussion of the results obtained from the experimental works were included in the third stage of this study;
- Finally, conclusions were drawn according to the noticeable findings of this research study.

2. Materials and Testing Regime

2.1. Treated Soil

The site of the soil treated in this study is called campus of the University of Karbala which is located in Karbala, Iraq. Figure 1 shows the map of the selected site with coordinates. The soil was extracted from a depth ranged between 0.6 and 1.0 m beneath the ground surface. When the soil arrived at the soil laboratory, a soil sample was collected to determine the natural water content based on ASTM D2216-19, and the rest was air dried for few days then oven dried at 110°C to completely remove any moisture. After obtained the dry soil, the soil lumps were pulverized using a rubber hammer to be ready for the experiments utilized in this study. The curve given in Figure 2 presents the distribution of the particle size of the untreated soil obtained from both sieve and hydrometer analysis. These tests were conducted in accordance with the standard ASTM D422 Table 1 shows the geotechnical and index properties of the pure soil. From the values of LL and PI shown in Table 1, the soil stabilized in this investigation can be categorized as an intermediate plasticity soil.

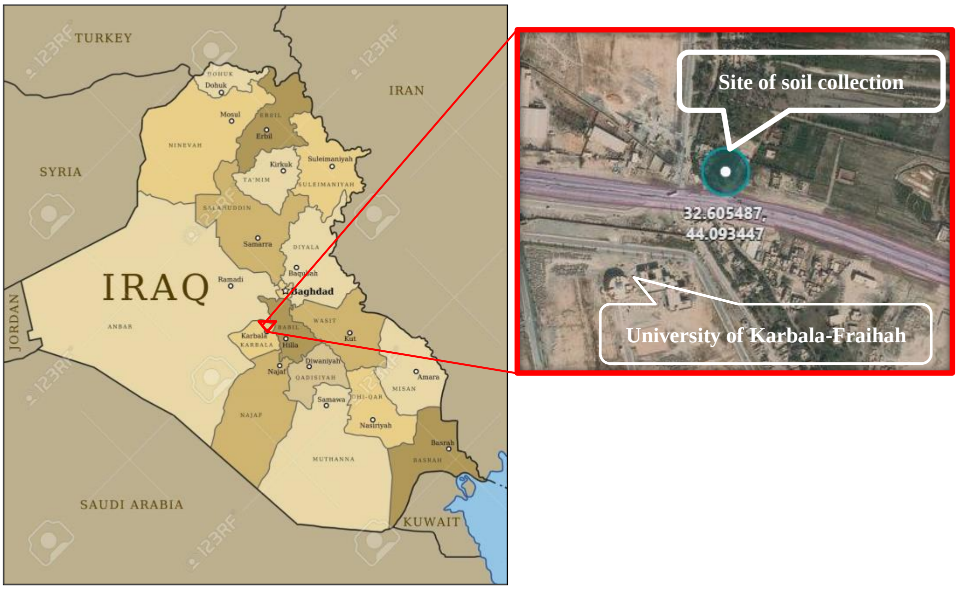

Figure 1. The site of the soil collection in Fraihah-Karbala

Table 1. Main soil properties of this study

Characteristic	Standard	Value and description
Organic content (%)	ASTM D 2974	2.21
Specific gravity	ASTM D 854	2.74
pH	ASTM D4972	3.11
Clay fraction (%)	ASTM D 422	35.21
Silt fraction (%)	ASTM D 422	34.31
Sand fraction (%)	ASTM D 422	30.48
Liquid limit index (%)	BS 1377 part 2 1990	50.10
Plasticity index (%)	BS 1377 part 2 1990	25.34
Linear shrinkage (%)	BS 1377 part 2 1990	8.22
Unified soil classification (USCS)	ASTM D 2488	CH
Optimum water content (%)	ASTM D 698	24.11
Maximum dry unit weight (kN/m^3)	ASTM D 698	15.47
Unconfined Compressive Strength (UCS) (kPa)	ASTM D 2166	64.27

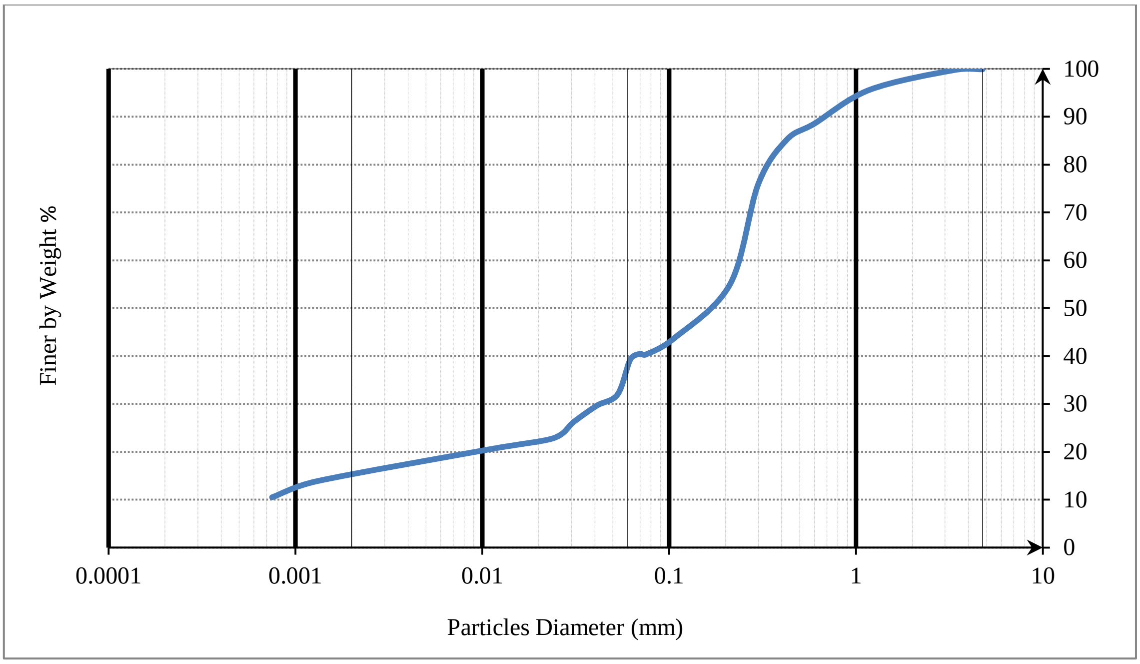

Figure 2. Grain size analysis curve of the used soil

2.2. Binder Materials

Two kinds of waste materials were employed in the research to manufacture the binder material used for soil stabilization. These materials were: CCR; a waste material of acetylene production, and RHA which was provided by the EKA Production Company, Thailand. CCR was received in a thin fragment shape in a semi-wet state, therefore, it was oven dried, crushed and then ground using a grinder type pestle and mortar at 15 minutes to provide a powder material of CCR. RHA was processed before the used by sieving on sieve size 150µm and ground at 30 minutes to increase the fineness as it is preferable to enhance the pozzolanic reactivity. Similar processing procedure was applied by Jafer et al. (2018) [21]. Figure 3 displays the distribution of particle size of CCR and RHA taken from laser particle size analyzer. The achieved fineness of CCR was better than that for RHA which would boost the hydration reactivity of the produced binder. According to literature, a higher compressive strength of concrete was achieved by using finer grades of fly ash [33].

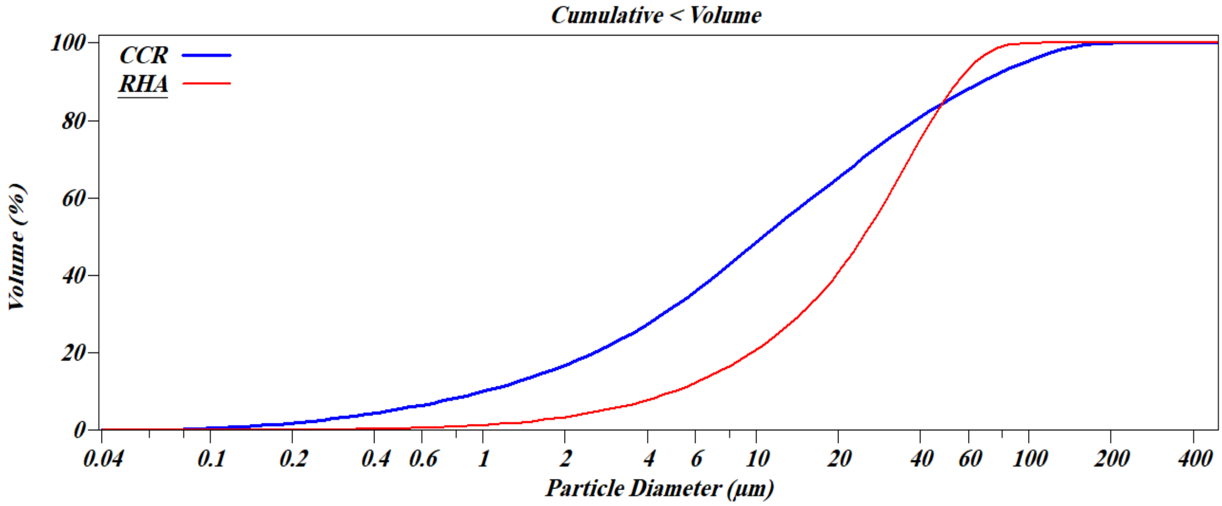

Figure 3. PSD curves of CCR and RHA

Chemical compositions of both CCR and RHA are presented in Table 2. The analysis revealed that CaO comprised most of CCR, while the other oxides were minor which form the rest of the CCR chemical compositions. The chemical tests of RHA indicated an interesting pozzolanic content represented by the silicates and aluminates in addition to the potassium oxide which would help alongside with the high pH value (12.87) to make the hydration reaction maintained for a longer time.

Table 2. Chemical compositions and pH values of the binder materials

Oxide Content (%)	Value and description	
Chemical composition	**CCR**	**RHA**
SiO_2	14.08	84.31
$Al2O_3$	0.9	1.33
$Fe2O_3$	0.00	1.25
MgO	0.77	1.18
CaO	81.84	8.47
TiO_2	0.12	0.41
Na_2O	1.32	0.17
K_2O	0.20	2.04
So_3	0.77	0.16
pH value	13.10	12.87

2.3. Experimental Work

The effect of different binder mixtures produced from the blending of CCR and RHA on the soil consistency limits and compressive strength was investigated. The binder content that was added to the treated soil was fixed at 10% by the dry mass of virgin soil. Mixing proportions that were used are illustrated in Table 3. Atterberg limits test was performed in accordance with BS 1377-2:1990 [34]. A Cone Penetrometer device was utilized to find the LL. UCS test was performed by following ASTM D 2166 using a computerized and motorized tri-axial machine in which the lateral stress was set as zero.

The microstructure investigation was conducted by performing SEM testing. Inca x-act detectors model Quanta 200 and Inspect S were used. Earlier to SEM testing, each fragment sample was coated with gold using a splutter coating machine to increase the resolution. Figure 4 shows the flowchart that represents the research methodology of the study.

Table 3. Mixing proportion adopted in the study.

Mixture Name	CCR % from the total Binder	RHA % from the total Binder
S	--	--
CR	100	0.0
CRH10	90	10
CRH20	80	20
CRH30	70	30
CRH40	60	40
CRH50	50	50

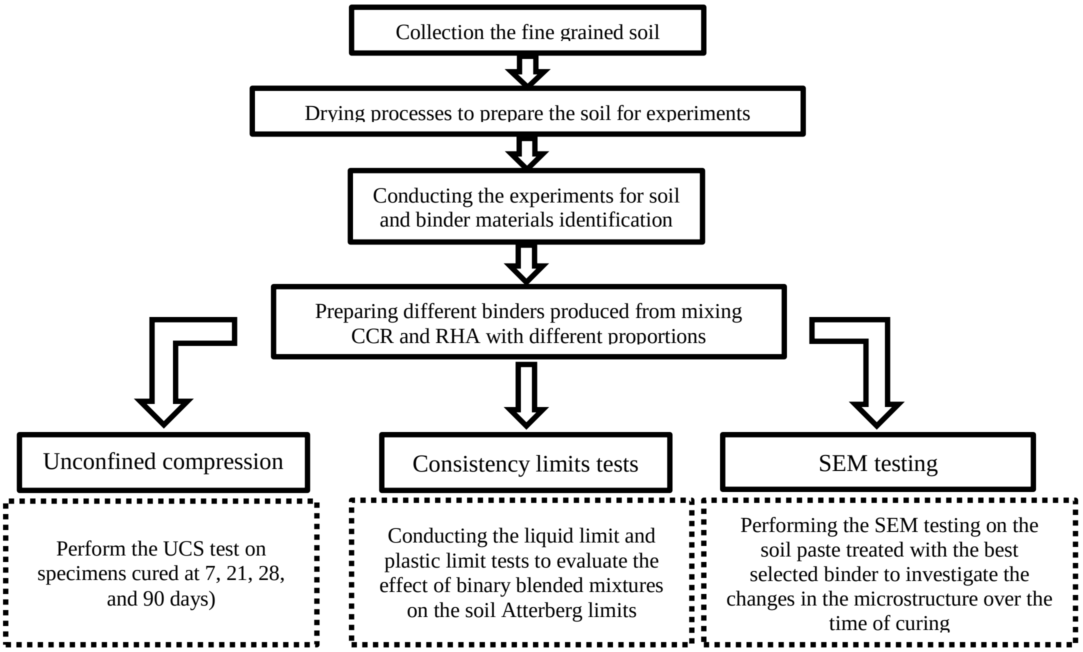

Figure 4. Research methodology adopted in the study

2.4. Sample Preparation and Conditioning

A fixed dosage of the additive at 10% by the dry mass was used. Samples of the pure soil and soil stabilized with various binders prepared according to Table 3 mentioned before was prepared for the UCS test using a constant volume mould to produce samples with dimensions 3.8cm, and 7.6cm of diameter and height respectively. The paste of treated soil samples with each corresponding type of binder was inserted into the mold then subjected to a static load provided by a manual hydraulic jack. Four groups of soil specimens were fabricated for the selected curing times (7, 21, 28, and 90 days), and for each corresponding period of curing, three specimens were prepared for each binder type for more reliable results.

specimens fabricated using the optimum binder were used for the SEM testing after they were subjected to 7, and 28 days curing to monitor the changes in the microstructure of the specimens treated with the optimum binder.

3. Results and Discussion

3.1. Atterberg Limits

Figure 5 presents the influence of the mixing proportions used in this study on the Atterberg limits of stabilized soil. It can be seen that significant increments occurred in LL increased after the incorporation of additives. The use of binder CR (ie. 100% CCR) recorded the highest magnitude of LL. However, slight reductions in LL values after the RHA incorporation were observed. The significant increments may be due to the phenomenon of exchange of cations taken place between the soil clay minerals and the positive ions of calcium produced by CCR [21]. The plastic limit PL also increased with the treatment but the increments of PL were in somehow higher than those for LL. This can be attributed to the agglomeration and flocculation occurred in the particles of the stabilized soil after the inclusion of the high calcium binder CCR [11]. The Atterberg limits test indicated a significant minimization in the plasticity indices of the soil treated with all types of the binders in comparison to that of the original soil. The lowest values of PI were obtained from the soil stabilized with CP50 which was close to the PI obtained from CRH30 and CRH40. Further substitution of CCR with RHA led to a slight reduction in PI values which would not affect the behaviour of the treated soil against the shrinkage and swelling phenomenon. For example, the PI decreased from approximately 11.0 for the soil treated with CRH30 to 10 and 9 for the soil treated with CRH40 and CRH50 respectively. Similar behaviour was reported by Jafer et al. (2018) [21] for a soft soil stabilized with binary blended cementitious binder produced from high calcium fly ash and POFA.

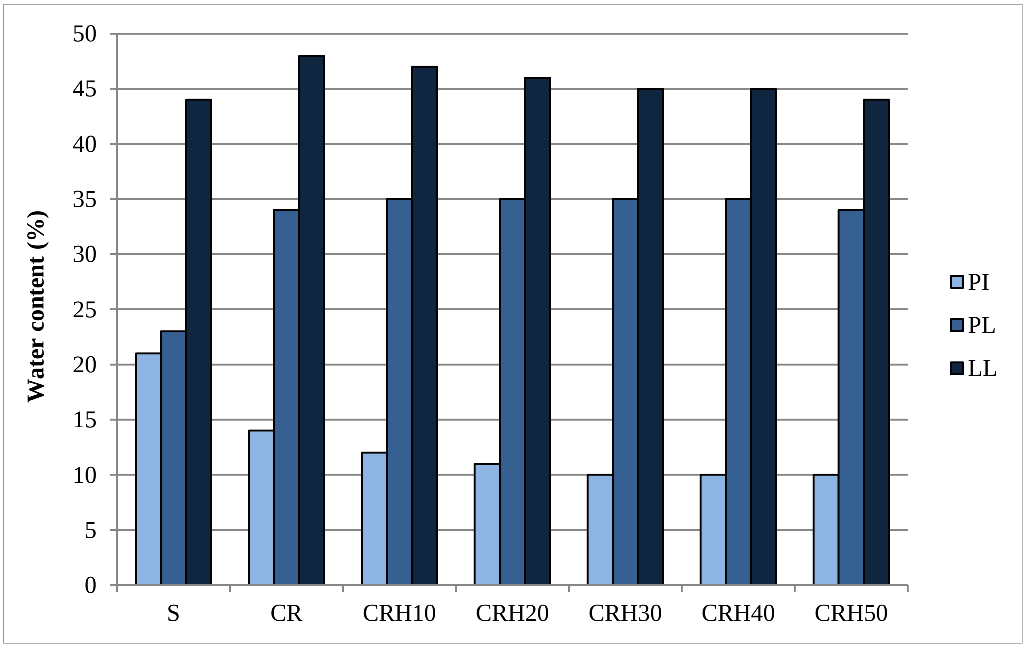

Figure 5. Effect of CCR &RHA on the soil consistency limits

3.2. Soil Strength Results

The results of the UCS test of the soil without additive and soil stabilized by various mixtures cured for different ages are shown in Figure 6. Significant increments were achieved in soil strength after treatment with 100% CCR binder over all curing periods. The UCS increased from 67 kPa for the virgin soil (S) to approximately 0.51 and 0.72 MPa at ages of 28, and 90 days respectively. Moreover, mixtures contained RHA mixed with CCR with different proportion indicated further interesting developments in UCS of the treated soil. The substitution of CCR in the total binder by up to 40% of RHA increased the soil compressive strength significantly for all curing periods. For example, the use of CRH30 binder increased the UCS by 1450% and 145% reference to the untreated and soil treated with 100% CCR binder after 90 days of curing. This behavior is attributed to the pozzolanic reaction took place between the calcium oxide of CCR and RHA silicates after the inclusion of RHA in the mixtures of produced binder [11, 25].

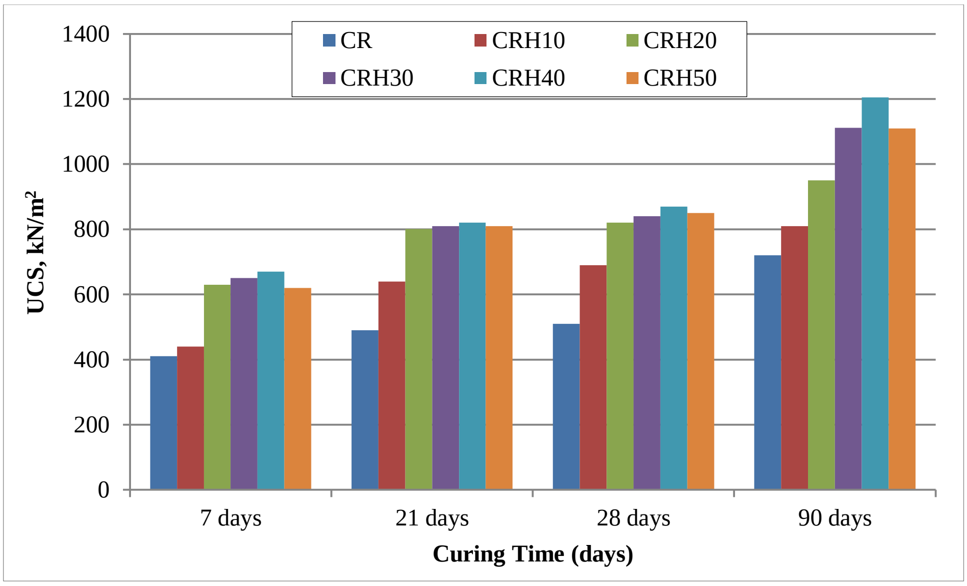

Figure 6. Results of UCS test of the soil treated with different mixtures

From another point of view, Figure 7 presents the enhancement of UCS after the incorporation of RHA in the binders at different curing periods compared with those of the soil treated with 100% CCR. The replacement of CCR with RHA up to 20% indicated a gradual increase in UCS until the age of 28 days. After 90 days, the mixture containing 30% RHA also indicated a growth in UCS. However, Figure 7 shows a slight reduction in UCS for further substitutions (i.e. 40 and 50% RHA). Similar behaviour has been reported by Jafer et al. (2018) [11] when they replaced the cement by 20% RHA to develop the mechanical properties of clay soil. According to the results of the UCS test in this study, the binder CRH40 was considered as the optimum mixture. Therefore, it was utilized to prepare the specimens of the microstructure in this study.

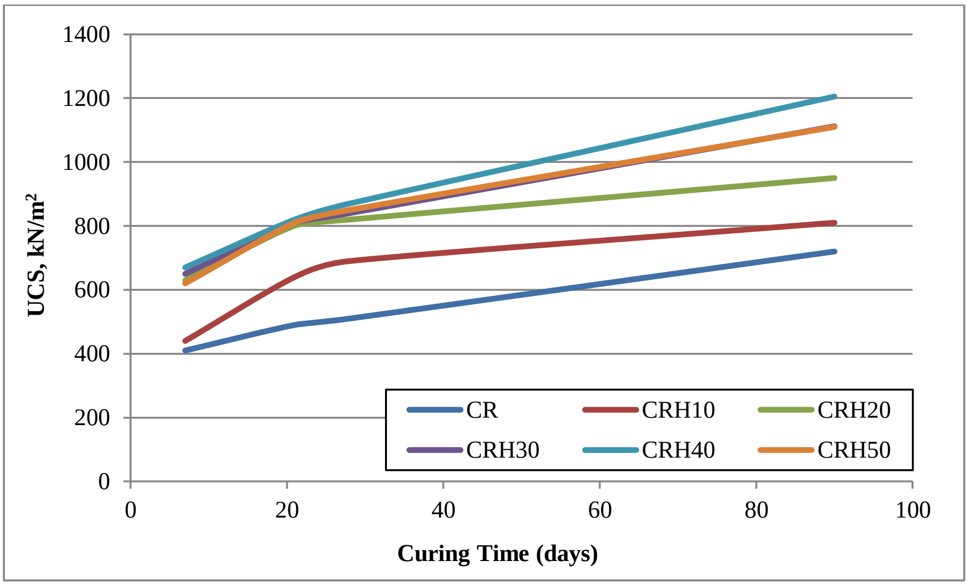

Figure 7. Effect of CCR replacement with RHA on the evolution of UCS

3.3. Scanning Electron Microscopy (SEM) Investigation

Soil specimens treated with the binder CRH40 were prepared for SEM analysis carried out at different ages of hydration (7 and 28 days of curing). Images of the SEM of the treated samples were compared with that of the untreated soil to evaluate the changes occurred in the microstructure of the soil samples after treatment at different hydration periods. This analysis was conducted to understand and elucidate the development in the UCS of the treated soil. Figure 8 displays the microphotograph of the untreated soil. There is no any presence for any hydration product represented by Ettringite, Portlandite (CH), and cementitious gel (C-S-H). Moreover, the voids in the microstructure of the untreated soil can be distinguished. The SEM images of the soil treated with CRH40, illustrated in Figure 9, indicate a clear progression in the formation of hydration products. These products can be easily recognized after 7 days of curing represented by the needle shape particles (Ettringite), platy shape crystals of Portlandite (CH), and the cementitious gel as shown in Figure 9a, and b. With the progression of the curing time, the cementitious gel has become more pronounced and most of the soil particles were covered by the gel represented by C-S-H as shown in Figure 9c, and d for the soil samples cured at 28 days. At this age of curing, the microstructure of the soil sample became denser and more compacted and the amount of the pore voids decreased significantly. This can explain the achieved enhancement in the soil compressive with the using of a binder produced from the binary blending of CCR and RHA [14]. Similar findings were reported by Vichan et al. (2013) [25] after using a combination of CCR and biomass fly ash for Bangkok clay stabilization.

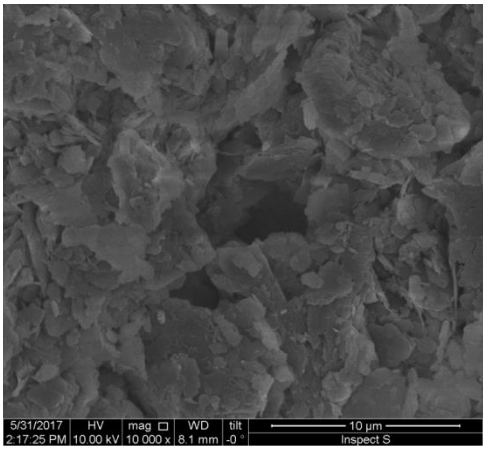

Figure 8. SEM image of compacted untreated soil

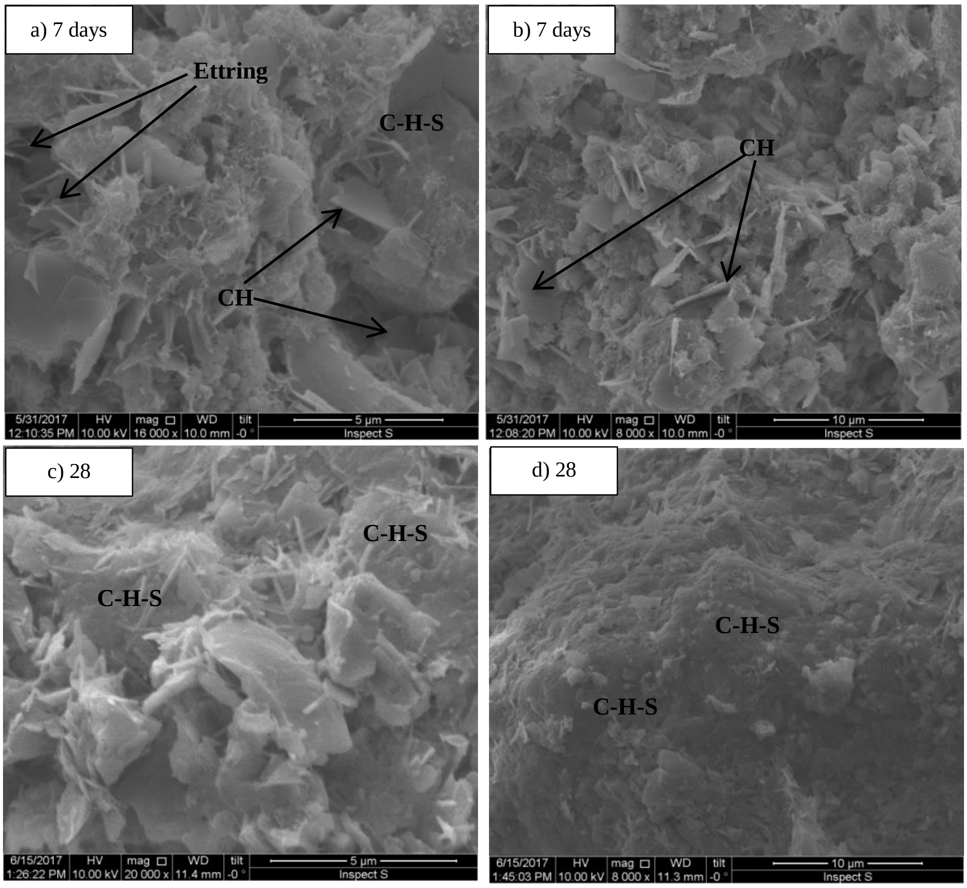

Figure 9. SEM images of cured soil samples treated with CRH40 binder. (a) & (b) 7 days, and (c) & (d) 28 days

4. Conclusion

In the current study, the effect of soil stabilization using binary blended mixtures of CCR and RHA on the engineering properties was studied along with the investigation of the microstructure using SEM analysis. According to the results obtained from this study, a binder produced from the binary blending of CCR and RHA was developed. This binder comprises from 60% CCR and 40% RHA. The consistency limits of the treated soil were improved noticeably particularly with the use of binary mixtures when compared with those of untreated and soil treated with 100% CCR. Significant improvements were achieved in the UCS of the soil with the use of binary mixtures of CCR and RHA especially CRH40 binder. The UCS was improved by 18 and 1.5 times referring to the untreated soil and soil stabilized with 100% CCR respectively. The SEM observation revealed the clear formation of hydration products with a noticeable progression of their formation throughout the hydration times elucidating the progress achieved in the mechanical properties represented by UCS in this research. Finally, the produced binder (CRHA40) can be successfully used for the stabilization of weak soil such as soft or fine-grained soils.

5. Conflicts of Interest

The authors declare no conflict of interest.

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