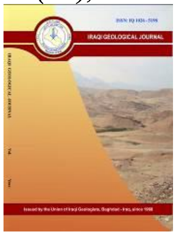
Al-Masoodi, Z, Dulaimi, AF, Jafer, H, Al-Khafaji, Z, Atherton, W and Hussien, SA

Soft Soil Treated with Waste Fluid Catalytic Cracking as a Sustainable Stabilizer Material

Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org



Soft Soil Treated with Waste Fluid Catalytic Cracking as a Sustainable Stabilizer Material

Zainab Al-Masoodi[1], Anmar Dulaimi[2], Hassnen Jafer[3], Zainab Al-Khafaji[4,5,*], William Atherton[6] and Safa A. Hussien[7]

1 The Ministry of Construction and Housing, National Center for Construction Laboratories, Karbala construction laboratory, Karbala, Iraq
2 College of Engineering, University of Warith Al Anbiyaa, Iraq
3 Department of Civil Engineering, College of Engineering, University of Babylon, Iraq
4 Al-Turath University College, Baghdad, Iraq
5 Al-Furat Al-Awsat Distribution Foundation, Ministry of Oil, Babylon, Iraq
6 Department of Civil Engineering, Liverpool John Moores University, Peter Jost Enterprise Centre, Byrom Street, Liverpool, UK.
7 Building and Construction Engineering Technology Department/ Al-Mustaqbal University College, Babylon, Iraq
* **Correspondence**: zainabcivil90@gmail.com

Received:
5 October 2021

Accepted:
7 December 2021

Published:
31 March 2022

Abstract

This research aims to stabilize clayey soil utilizing fluid catalytic cracking with an unchangeable ordinary portland cement ratio of 3 percent. A soft clayey soil was blended with 1.5, 3, 4.5, and 6 percent of fluid catalytic cracking by the dry stabilized soil weight, the ordinary portland cement amount has been fixed at 3 percent. The adding of different FCC ratios impact cement stabilized soil evaluated based on the results of unconfined-compressive-strengths test that gained after curing for 7 and 28 days. It was noticeable from the results that the best combination is the combination of soil remedied with 3 percent of each cement and FCC in improving the compressive strengths from 249.80 to 806.20k Pa for the stabilized soil after curing for 28 days. The most highlighting soil binder combination was analyzed utilizing scanning electron microscopy. It was noticed from the scanning electron microscopy results; cementitious materials were produced after 7 days of curing and improved more after curing for eight days.

Keywords: Silty clayey soil; Fluid catalytic cracking; Unconfined compressive strengths; Scanning electronic microscopy

1. Introduction

Soft clayey soils are inappropriate for construction since they lose strength and dimensional stability. Traditionally these soils were substituted with other materials to provide the required requirements. However, stabilization is the recently utilized method to improve the features of the presence of soil (Cristelo et al., 2013). Therefore, soil stabilization aims to enhance the features of weak soils, including durability, strength, and prevent soil erosion (Sen and Kashyap, 2012). Soil stabilization has been utilized for ages when the engineering skills were minimal. In addition to this, it was utilized for several years, ordinary portland cement (OPC) has been utilized worldwide in soil stabilization due to its ability to develop the physical characteristics of the remedied ground, including distributions of

DOI: 10.46717/igj.55.1C.4Ms-2022-03-23

particles size and Atterberg limits. Besides, it could improve the geotechnical characteristics of the selected soils, including strengths (Eskisar, 2015, Vakili et al., 2016, Yoobanpot et al., 2017).

Various problems associated with the use of cement as a stabilizer material. Economically, the product cost of OPC is greatly rising since of the increment in energy production. About one ton of CO_2 is released into the atmosphere for each one ton of the manufacturing OPC (Aprianti et al., 2015). Other issues include serious health issues, for example, prolonged respiratory illnesses, which can be caused by releasing Sulphur dioxides (SO2) aerosol and dust released from the cements-producing factories. Sulphur dioxides cooperates in transferring pollutants thru rainy acid. Also, the existence of heavy metals including lead in the cement manufacturing raw materials and fuels could be poisonous in the great amount. Several researchers have been focused on investigating new substances to decrease or replace the use of OPC. The investigated materials are supplementary cementitious materials (SCMs) that were by-products and occasionally named pozzolans. Although such materials produce cementitious materials when blended with cement, they do not have any cementitious features (Bye, 2011; Armanuos et al., 2021; Danandeh Mehr and Akdegirmen, 2021; Khaleefa and Kamel, 2021). Alternative wastes have been utilized in soil stabilization, including pulverized fuel ash (PFA), ground granulated blast furnace slag (GGBS), rice husk ash (RHA), silica fume (SF), and palm oil fly ash (POFA), and other additives (Hossain and Mol, 2011, Manso et al., 2013, Roy, 2014, Modarres and Nosoudy, 2015, Ozdemir, 2016). Some researchers utilize these alternatives as pozzolanic materials to improve the engineering and physical characteristics of soft soils. The specific area and fineness of the materials are considered the motives behind reducing the cohesion of soft soils and developing the density of such soils. On the other hand, SCMs are utilized to minimize lime and OPC to develop the hydration reaction. Some of these materials have an excellent activity of pozzolanic and self-cementing features-these materials include SF, coal waste, RHA, and POFA. Previous research showed that SCMs exhibited better performance in soil stabilization and the concrete industry (Fattah, et al., 2014, Jafer et al., 2015, Al-Khafaji, et al., 2018a). Fluid catalytic cracking (FCC) has been utilized as supplementary cementitious material and is produced in the petrochemical industry. About 400 000 tons of FCC is produced from this industry, and its amount increased with increasing the oil industries. FCC is utilized in the production of Portland cement clinker and as filler in asphalt concrete mixes. Recently, this material has been utilized in the alkali-activated binders (Tashima et al., 2014; Awadh and Yousif, 2021), production of geopolymers (Mas et al., 2015), utilized in the production of a new cold asphalt binder course bituminous emulsion combination (Dulaimi et al., 2017), and utilized as a raw material for great-performance concrete (Payá et al., 2001, Monzó et al., 2004). It is found that FCC showed a good activity of pozzolanic in short curing ages in mortars and concreted with excellent durability (Chen et al., 2004, Soriano et al., 2013). In this research, FCC is utilized in the stabilization of silty clayey soil for the first duration. A small and constant amount of OPC was utilized (only 3 percent by the soil dry weights), after that various ratios of FCC (1.5 percent, 3 percent, 4.5 percent, and 6 percent) were blended with the 3 percent OPC to produce various combinations. The impact of adding this waste material on the engineering and physical features of cement stabilized soil was evaluated based on the outcomes of unconfined compressive strengths (UCS) and electronic scanning microscopy (SEM) remarks obtained from specimens cured at 7 and 28 days.

2. Materials and Methods

2.1. Soil Specimen

The soil specimen has been gathered from the River Alt banks, located in the North of Liverpool, UK (Fig. 1). The soil specimens were collected from 30 – 50 cm depth below the ground level, then about 20 to 25 kg were put in plastic bags, locked carefully, and transported to the laboratory. After arriving the selected specimens at the laboratory, they were placed in the oven (110 ˚C) for 24 hours to dry the soil sample and start the experiments. Additionally, the soil was assorted depending on the findings of particle size distribution and Atterberg limits testing. The distribution was obtained using a particle size analyzer utilizing the Beckmen Coulter Laser diffraction particle size analyzer (Bell, 1993)

Fig. 1. The location of soil that is utilized in the investigation

Furthermore, other features of the tested soil, for instance, compressive strengths and compaction parameters, were also identified with conducting the chemical analysis for soil to detect the pH of the studied soil. The significant engineering characteristics for the investigated soil are provided in Table 1. It was discovered from particle size testing that the soil consisted of 15.4 percent clay, 4.2 percent sand, and 80.4 percent silt, as shown in Fig. 2. The soil will be categorized as intermediate plasticity if the LL is between 35-50 percent (Bell, 1993). Therefore, based on Atterberg limits and distribution of particles size, the explored soil could be categorized as silty-clay soil with intermediate plasticity.

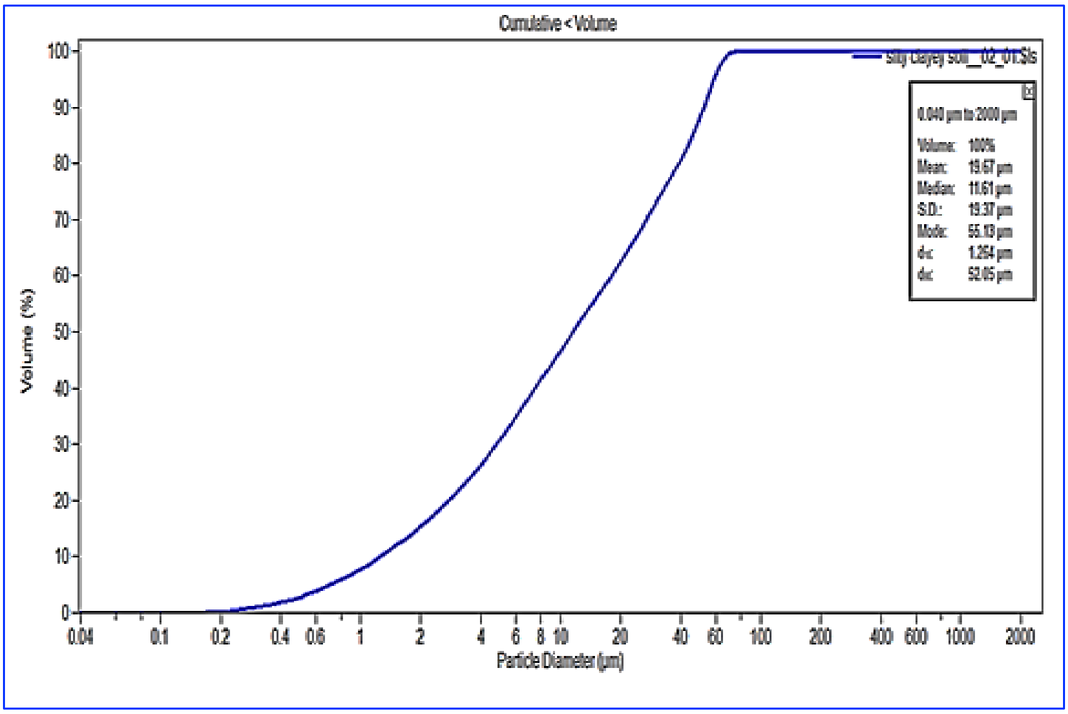


Fig. 2. The curve of the particles size distribution of the tested silty clayey soil

Table 1. The major engineering and physical characteristics of the soft soil

Characteristics	**Value**
Liquid Limit (LL)	39 percent
Plasticity Index (PI)	19.50
Sand	4.2 percent
Silt	80.4 percent
Clay	15.4 percent
Max. dry density (MDD)	1.63 g/cm³
Optimum moisture amount (OMC)	20.50 percent
PH	7.78
Unconfined Compressive strengths	249.80 kPa

2.2. Binder Materials

Two standard stabilizer binders represented by FCC and OPC were utilized, as depicted in Fig. 3. A commercial cement from CEM-II / A / LL 32.5-N) has been utilized for OPC. FCC is a waste material produced from the oil refineries and oil sectors. This material has excellent pozzolanic characteristics due to its great amount of Al2O3 and SiO2. Table (2) shows the PH and OPC chemical composition and FCC determined by energy dispersive X-ray fluorescence (EDXRF) measurements.

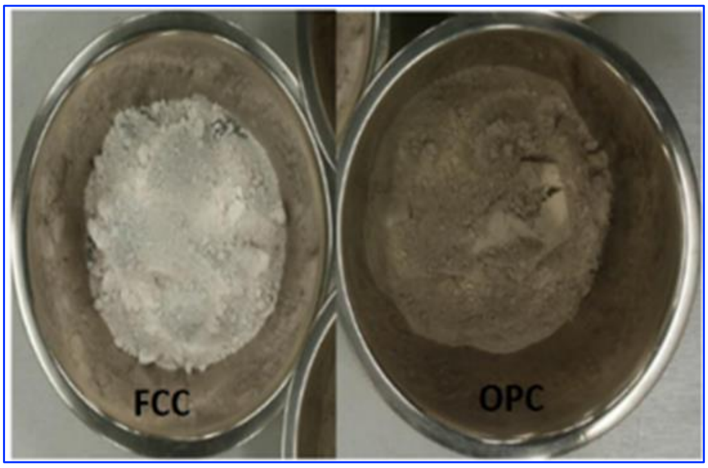


Fig. 3. The binder materials

3. The Preparing and Curing of Specimens

Firstly, the selected soil sample was dried then crushed to break down any big particles. After adding water and a binder, the experiments were performed immediately. The binder ranged from just 3 percent OPC to 3 percent OPC blended with 1.5, 3, 4.5, and 6 percent FCC by the stabilized soil's dry weight, as shown in Table 3. Compaction tests for every percentage of the used binder yielded specimens with specified densities based on the matching max dry density and the optimal moisture level. Hence, the materials have been first blended for five minutes by manual dry mixing; then, the specified water was added to achieve the demand pastes for conducting the experiments.

Table 2. The essential chemical characteristics of the utilized binder materials

Binders	**pH**	**CaO percent**	**SiO_2 percent**	**Al_2O_3 percent**	**Fe_2O_3 percent**	**MgO percent**	**K_2O percent**	**SO_3 percent**	**Na_2O percent**
OPC	13.04	65.21	24.56	1.7	1.64	1.3	0.82	2.62	1.34
FCC	6.09	0.047	35.452	44.167	0.368	0.684	0.049	0	0

Table 3. The proportions of the combination utilized in this study

Mix ID	Soil percent	OPC percent	FCC percent
RE	100	0	0
Mix I	100	3	0
Mix II	100	3	1.5
Mix III	100	3	3
Mix IV	100	3	4.5
Mix V	100	3	6

The experiment of UCS was then carried out using a fixed volume mold with particular sizes of volume that has 3.8 cm in diameter and height=7.6 cm. A manual hydraulic jack (Fig. 4), was then utilized to press the specimens inside the mold, then the specimens have been cured at 7 and 28 days before they were exposed to UCS. Specimens were cured and stored in the room at a temp of 20 ± 2 ˚ C. The UCS specimens were prepared for each percentage of the binder utilized based on optimal compaction criteria.

Fig. 4. Hydraulic jack

After UCS Trials, the RE, Mix I, and Mix III specimens were prepared for SEM evaluation. SEM specimens were prepared in the same manner as UCS specimens. At 7 and 28 days, the specimens were then healed to evaluate the microstructure of the specimens tested.

4. Laboratory Experiments

4.1. Unconfined Compressive strengths Test

UCS testing is a triaxial test where no confining pressure or horizontal forces are applied to the investigated soil specimens. This experiment is normally utilized to evaluate the strength of the remedied soil and to recognize the most optimum binder that is demanded in the stabilization of soil. The UCS test was carried out in this investigation depending on BS 1377-7:1990 (Institution, 1990). Two sets of specimens have been produced and cured at 7 and 28 days.

4.2. Scanning Electron Microscope (SEM)

SEM is a technique of great-resolution imaging of surfaces utilized to examine the morphology of the object. It can provide an immediate method of visualizing cementation processes within stabilized specimens and identifying recently formed cementitious gels. SEM was utilized for testing the microstructure of the most influence binder combination in the stabilized soil; this comprised testing the RE, Mix I, and Mix III specimens after curing for 7 and 28 days. The utilized equipment in SEM analyses was Philips XL30 ESEM-FEG and produced by the Inspect and Quanta scanning electron microscope company. SEM specimens were prepared in the same way as the preparation of UCS specimens. SEM images were gathered at great voltage (HV) of 10 kV to visualize both the microstructure of unremedied and remedied specimens and any cementitious bonding between the soil particles and the binder. Precise segments were taken from the central part of the prepared specimens at ages of 7 and 28 days for the SEM remarks.

5. Results and Discussion

5.1. Unconfined Compressive strengths (UCS)

The stress-strain association for the cement stabilized soil with and without FCC for specimens cured at 7 and 28 days are illustrated in Figs. 5 and 6 respectively. The results showed that after seven days of curing, the compressive strengths of cement stabilized soil cured with various proportions of FCC increased significantly. The UCS findings at seven days indicated that 6 percent FCC revealed a greater compressive strength. Meanwhile, the specimens tested at 28 days revealed a major development in the compressive strengths compared with the specimens of 7 days curing. Also, the Mix III sample gave a greater compressive strength, as shown in Fig. 6. It can also be noticed that Mix V specimen revealed a greater compressive strengths after7 days of curing where the UCS raised from 249.80 for RE sample to 543.55kPa for Mix I sample 645.78kPa for Mix V. While the UCS for the other FCC percentages varied from 581.03kPa to 642.17kPa.

The unconfined compressive strengths values for cement stabilized soil remedied with various percentages of FCC at 7 and 28 curing periods are shown in Fig. 7. it is clear that the optimum ratio is 4.5 percent FCC since it gave compressive strengths very close to 6 percent FCC (642.17 and 645.78kPa) for Mix IV and Mix V, respectively, as depicted in Fig. 7. However, after 28 curing days, the compressive strengths of Mix IV and Mix V were very akin to each other. Thus, it was found that cement stabilized soil remedied with 3 percent FCC revealed the greatest compressive strengths at 28 days of curing. FCC has excellent pozzolanic features since it contains a great amount of silica and alumina. It has a activity of pozzolanic with calcium hydroxide [Ca(OH)2] and produces further (C-A-H) and (C-S-H) gels to the cementitious system, and they also accelerate the cement hydration (Dulaimi et al., 2017).

In addition to that, FCC's amorphous and fines features, resulting in speeding up the cement reaction, resulting in improving the compressive strengths in cement mortar and concrete (Tashima et al., 2014, Mas et al., 2015). A similar concept also happens in soil stabilization. Thus, FCC combined with cement stabilized soil improved the UCS at 7 and 28 curing ages. Normally, the compressive strengths seems to be increased with the ages of curing and the amount of the stabilizer (Hossain and Mol, 2011). In this research, it was noticed that with raising the FCC to cement stabilized soil percentages, the UCS developed that happens probably as a result of extra water required for the activity of pozzolanic of FCC due to its fineness and porous characteristics. Moreover, that is agreed with the results of Basha et al. (2005) revealed that the combination of either 4 percent or 8 percent OPC with (10-40) percent RHA resulted in increasing the optimum moisture amount (OMC) and subsequently enhancing the compressive strengths. Hence, some of the water is utilized up throughout the activity of pozzolanic when $Ca(OH)_2$ is transferred the water and blended with siliceous and aluminate minerals, which dissolve, creating strengthening gels.

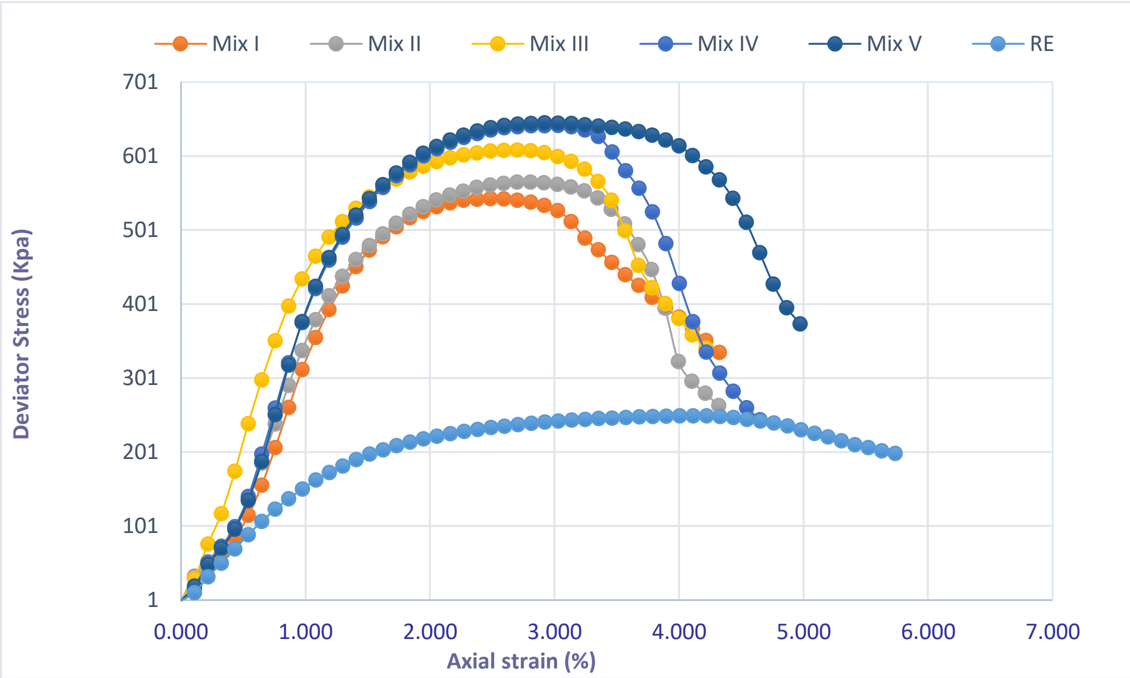


Fig. 5. Stress-strain diagram of the UCS test for cement stabilized soil after FCC remediation at 28 days

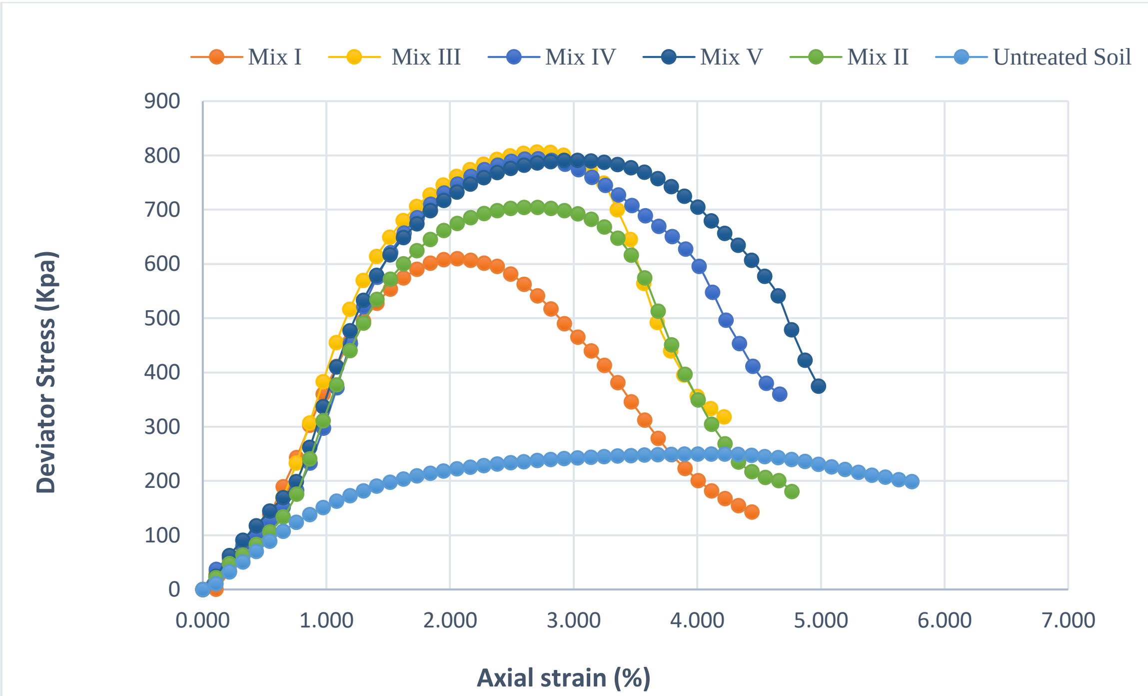


Fig. 6. Stress-strain diagram of the UCS test for cement stabilized soil after FCC remediation at 28 days

5.2. Scan Electrons Microscopy (SEM)

Specimens of RE, Mix I, and Mix III was prepared for SEM testing. The specimens were undergone 7 and 28 days pre-examined to inspect the serial changes in the remedied soil's microstructures throughout the curing duration. The SEM images for unremedied soil as illustrated in Fig. 8 that depicts the prevalent presence of darks grey–colored silt particles and coarse-particle sand, the massive quantity of these creates either internal-particle edges to edge or edge to face contacting. Meanwhile, the light and colored particles showed clay grains, which either covered the silt and clay surfaces or the space between their particles. Regarding the surfaces and edges of the clay, sand and silt particles appeared clean and clear, which means they were no-physical bonds.

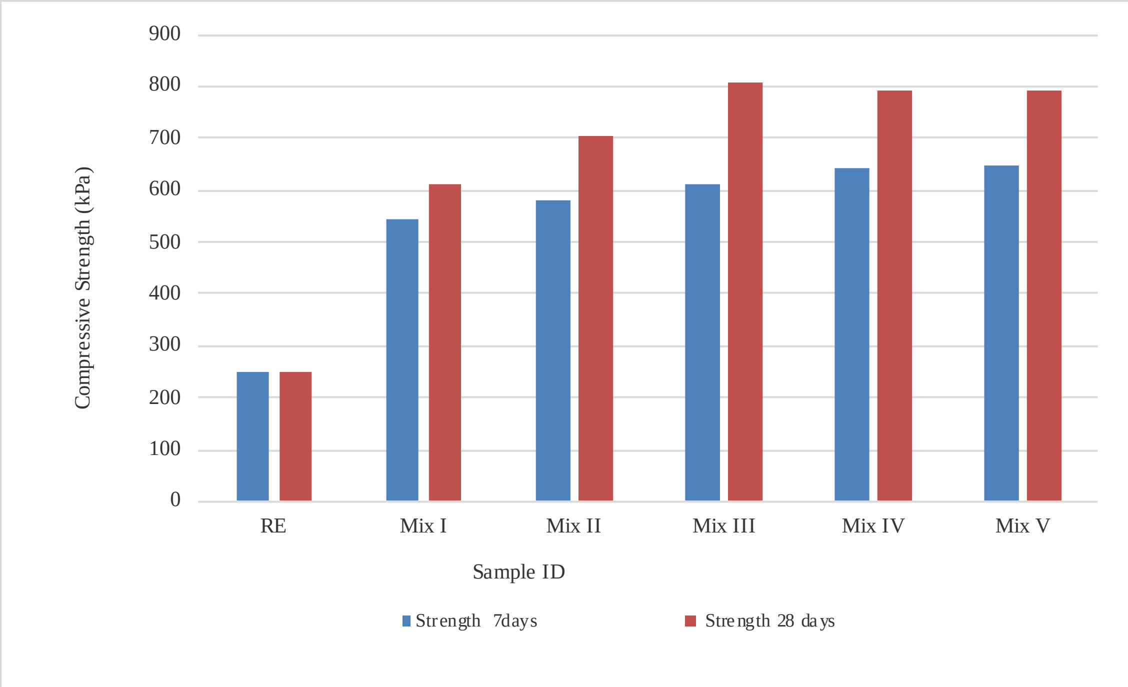


Fig. 7. The unconfined compressive strengths of the tested specimens after curing for 7 and 28 days

Additionally, it was noticed that the unremedied soil texture is composed of several spaces between the soil particles, making the soil greatly compressible. Noticeable alterations were observed in soil structure after UCS testing since of the cement hydration in cement stabilized soil, and an activity of pozzolanic of FCC in cement stabilized soil remedied with FCC. After seven days of curing, it was observed the creation of cementitious materials CH and C-S-H with a low amount of ettringite, as shown in Figs. 9 & 10. The lowest ettringite amount could be formed due to the lowest amount of sulfate in the ordinary Portland cement that is inconsistent with the findings of Nair and little (Nair and Little, 2009) found that the ettringite creation in stabilized soils is lower compared with cement pastes. Due to the ions' number in the stabilized soil solutions being smaller than ions' number in cement pastes, soil particles have a greater heterogeneity level than cement.

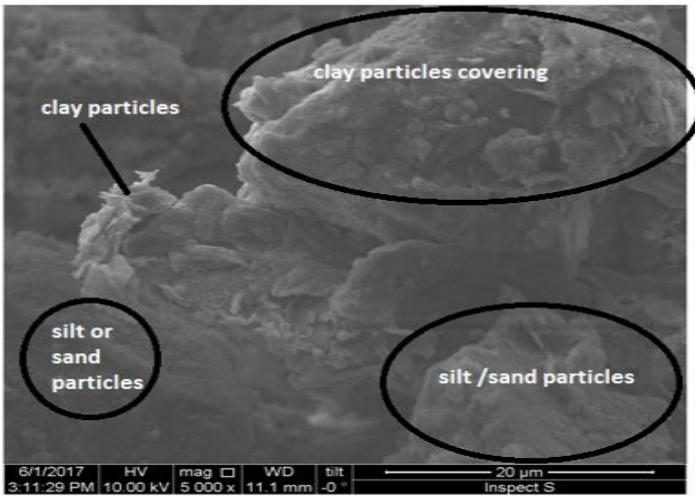


Fig. 8. SEM inspection of the tested soil

The ettringite seems to strengthen the soil instead of weakening it, which is agreed with the results of Nair and Little (Nair and Little, 2009) proved that the ettringite formed in the initially hydrating has not bad effects. The structures that like a needle were not found in the unremedied soil images and vanished after curing for 28 days. It is expected to disappear in late curing, which occurs since the ettringite's creation in the system of cement is fundamentally based on the ratio of calcium sulfate to tri-calcium aluminates (C3A). The OPC utilized in this study has small Sulphate amount, and FCC is free from the sulfate. Therefore, ettringite proportion seems to be low. Based on this, the ettringite creates at the early curing age after that disappear due to their transformation to calcium aluminate monosulfate. This transformation happens only in small SO_3 amount solutions and not with great SO_3 (Edmeades and Hewlett, 1998, Khan and Kayali, 2013). The formed monosulfate is steady, provided that the combination has low sulfate. Therefore, it was not observed impact on the gained compressive strengths of the stabilized soil. Despite this, and after curing for 28 days, the essential growth of reaction products can be observed in Figs. 9 & 10. It was presumed that the production and the growth of these reaction products make the structure of the stabilized soil dense and strong, enhancing the strength.

Moreover, these products fill the soil voids, thus decreasing the totally volume of pore, which in turn improves the compressive strengths, and that is agreed with Tyrer results (Tyrer, 1989) showed that the cement creates a gel surround the grains of mineral clay after that crystalline out, creating new crystalline and cementitious materials. The notable increase in UCS findings was due to the gradual crystallization of cement with the reaction products. It can be observed from Fig. 10 that denser structure is obtained within cement stabilized soil remedied with 3 percent FCC and the density of soil develops further after curing for 28 days, which can be associated with the truth that FCC is a quite pozzolanic materials with great reactivity at initial stages of curing. Thus, the combination of FCC with OPC helps in further developing the mechanical features. C-S-H, C-A-H, and calcium alumino-silicates hydration (C-A-S-H) are observed to be the primary hydration products of OPC-FCC reaction (Pacewska et al., 2004, Payá et al., 2009, Costa et al. 2012). It has been found that after curing for 28 days, further C-S-H and less calcium hydroxide were produced (Wu et al., 2003). Furthermore, that occurs since the remained $Ca(OH)_2$ from the initial hydration processing is used in the activity of pozzolanic creating further cementitious materials. The cementitious materials are the main cause for developing the soil features since they provide the cohesion property and the crucial cementitious blending to the overall production (Al Masoodi et al., 2017, Al-Khafaji et al., 2018b, Hussain, 2020).

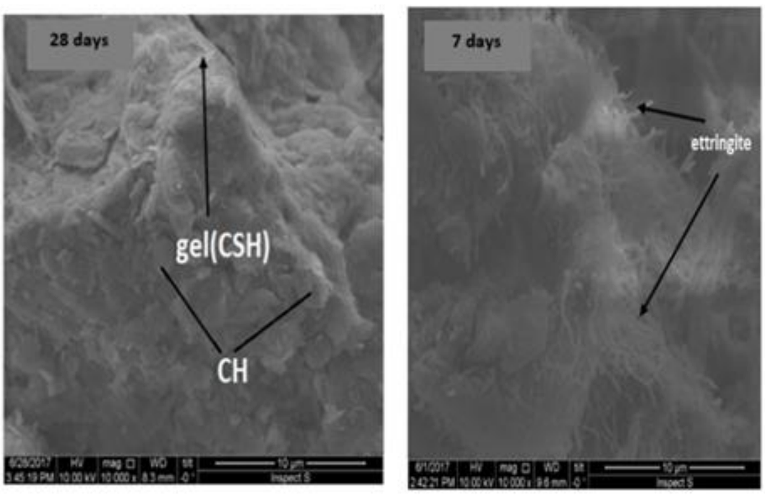


Fig. 9. Cement stabilized soil cured at 7 and 28 days

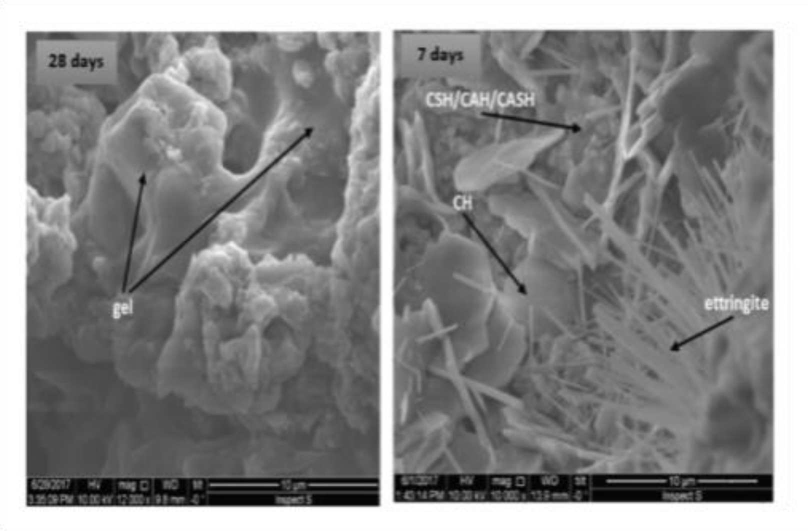


Fig. 10. SEM remarks of CSS remedied with 3 percent FCC after curing for 7 and 28 days

6. Conclusions

The impact of adding fluid catalytic cracking (FCC) on the engineering characteristics of cement stabilized soil was studied in this research. It can be concluded that FCC has a good impact on developing the UCS of the tested soil and the optimal combination is 3 percent FCC combined with 3 percent OPC since the previous combination gave the highest compressive strengths after curing for 28 days since the excellent pozzolanic features. Hence, it participates in producing further gels (C-S-H) and (C-A-H) from the activity of pozzolanic with calcium hydroxide [Ca (OH)2], leading to enhancing the compressive strengths of the examined specimens.

The results of UCS corresponded with SEM remarks since the cementitious materials became visible at early stages and improved mor after curing for 28 days. However, ettringite disappears thoroughly after 28 curing days since the low amount of sulfate in binder combination. Produced del were mainly liable for developing soil features since they give a cohesion feature and the crucial cementitious blending to the overall production. Overall, cement stabilized soil remedied with 3 percent FCC showed good performance under various engineering characteristics tests of silty clayey soil, including developing the compressive strengths after 28 days. Furthermore, that could encourage the stabilization using only a low cement amounts, reducing the construction cost since FCC is considered cheaper than cement and FCC decreasing the environmental problems.

Acknowledgements

Great thanks to the laboratory of Liverpool, John Moores University. The authors are very grateful to the reviewers, Editor in Chief Prof. Dr. Salih M. Awadh, the Secretary of Journal Mr. Samir R. Hijab, and the Technical Editors for their great efforts and valuable comments.

References

Al Masoodi, Z. O., Al-Khafaji, Z., Jafer, H., Dulaimi, W.A., 2017. The effect of a high alumina silica waste material on the engineering properties of a cement-stabilised soft soil. In: The 3rd BUiD Doctoral Research Conference. Dubai, AUE.

Al-Khafaji, Z. S., Al Masoodi, Z., Jafer, H., Dulaimi, A. & Atherton, W., 2018b. The effect of using fluid catalytic cracking catalyst residue (FC3R) as a cement replacement in soft soil stabilisation. International Journal Civil Engineerings Technology, 9, 522–533.

Al-Khafaji, Z. S., AL-Naely, H.K. & Al-Najar, A. E., 2018a. A review applying industrial waste materials in stabilisation of soft soil. Electron Journal Structural Engineerings, 18, 2.

Aprianti, E., Shafigh, P., Bahri, S. & Farahani, J.N., 2015. Supplementary cementitious materials origin from agricultural wastes. A review. Construction Build Material, 74, 176-187.

Armanuos, A., Ahmed, K., Sanusi Shiru, M. & Jamei, M., 2021. Impact of increasing pumping discharge on groundwater level in the Nile Delta Aquifer, Egypt. Knowledge-Based Engineering Science, 2, 13–23.

Awadh, S. & Yousif, A. 2021. Lead sorption from aqueous solutions by kaolinite: laboratory experiments. Knowledge-Based Engineering Science, 2, 1-8.

Basha, E.A., Hashim, R., Mahmud, H.B. & Muntohar, A.S., 2005. Stabilization of residual soil with rice husk ash and cement. Construction Building Materials, 19, 448-453.

Bell, F., 1993. Engineering Treatment of Soils. CRC Press.

Bye, G., 2011. The hydration of Portland cement. In: Portland Cement: Third edition. ICE Publishing, 89-121.

Chen, H.L., Tseng, Y.S. & Hsu, K.C., 2004. Spent FCC catalyst as a pozzolanic material for high-performance mortars. Cem Concr Compos, 26, 657–664.

Costa, C., Marques, P. & Carvalho, P.A., 2012. An SEM Investigation of the Pozzolanic Activity of a Waste Catalyst from Oil Refinery. Microsc Microanal, 18, 75-76.

Cristelo, N., Glendinning, S., Fernandes, L. & Pinto, A.T., 2013. Effects of alkaline-activated fly ash and Portland cement on soft soil stabilisation. Acta Geotech, 8, 395-405.

Danandeh Mehr, A. & Akdegirmen, O., 2021. Estimation of urban imperviousness and its impacts on flashfloods in Gazipaşa, Turkey. Knowledge-Based Enginerring Science, 2, 9-17.

Dulaimi, A., Nageim, H. Al, Ruddock, F. & Seton, L., 2017. Laboratory studies to examine the properties of a Novel Cold-asphalt concrete binder course mixture containing binary blended cementitious filler. Journal Material Civil Engineering, 29, 4017139.

Edmeades, R.M. & Hewlett, P.C., 1998. Cement admixtures. In: Lea's chemistry of cement and concrete. Elsevier, 841-905.

Eskisar, T., 2015. Influence of cement treatment on unconfined compressive strength and compressibility of lean clay with medium plasticity. Arabian Journal Science Engineering, 40, 763-772.

Fattah, M.Y., Al-Saidi, A.A. & Jaber, M.M., 2014. Consolidation properties of compacted soft soil stabilized with lime-silica fume mix. International Journal Science Engineering Resources, 5, 1675–1682.

Hossain, K.M.A. & Mol, L., 2011. Some engineering properties of stabilized clayey soils incorporating natural pozzolans and industrial wastes. Construction Building Materials, 25, 3495-3501.

Hussain, D.A.J., 2020. The fields of applying the recycled and used oils by the internal combustion engines for purposes of protecting the environment against pollutions. J Adv Res Dyn Control Syst, 12, 698-706.

Institution, B.S., 1990. Methods of test for soils for civil engineering purposes: Classification tests. British Standards Institution.

Jafer, H.M., Atherton, W., Ruddock, F. & Loffill, E., 2015. Assessing the potential of a waste material for cement replacement and the effect of its finennes in soft soil stabilisation. International Journal Environmental Chemical Ecological Geological Geophysical Engineering, 9, 877–883.

Khaleefa, O. & Kamel, A.H., 2021. On the evaluation of water quality index: case study of euphrates river, iraq. Knowledge-Based Engineering Sci, 2, 35–43.

Khan, M.S.H. & Kayali, O., 2013. Effect of NaOH activation on ettringite in concrete containing ground granulated blast furnace slag. In: Third international conference on sustainable construction materials and technologies, 1–11.

Manso, J.M., Ortega-López, V., Polanco, J.A. & Setién, J., 2013. The use of ladle furnace slag in soil stabilization. Construction Building Materials, 40, 126–134.

Mas, M.A., Tashima, M.M., Payá, J., Borrachero, M. V, Soriano, L. & Monzó, J.M., 2015. A Binder from Alkali Activation of FCC Waste: Use in Roof Tiles Fabrication. Key Eng Mater, 668, 411–418.

Modarres, A. & Nosoudy, Y.M., 2015. Clay stabilization using coal waste and lime, technical and environmental impacts. Applied Clay Sciences, 116, 281–288.

Monzó, J., Payá, J., Borrachero, M. V, Velázquez, S., Soriano, L., Serna, P., et al., 2004. Reusing of spent FCC catalyst as a very reactive pozzolanic material: Formulation of high performance concretes. In: International RILEM Conference on the Use of Recycled Materials in Buildings and Structures, Spain. Citeseer, 8-11.

Nair, S. & Little, D., 2009. Water as the key to expansion of ettringite in cementitious materials. Journal of Transportaion Resource Record. 55-62.

Ozdemir, M.A., 2016. Improvement in bearing capacity of a soft soil by addition of fly ash. Procedia Engineering, 143, 498–505.

Pacewska, B., Wilińska, I., Bukowska, M., Blonkowski, G. & Nocuń-Wczelik, W., 2004. An attempt to improve the pozzolanic activity of waste aluminosilicate catalyst. Journal of Thermal Analysis Calorimetry, 77, 133–142.

Payá, J., Monzó, J. & Borrachero, M. V., 2001. Physical, chemical and mechanical properties of fluid catalytic cracking catalyst residue (FC3R) blended cements. Cement Concrete Research, 31, 57–61.

Payá, J., Monzó, J., Borrachero, M. V, Garcés, P., Mellado, A., Velázquez, S., et al., 2009. Outstanding aspects on the use of spent FCC catalyst in binders.

Roy, A., 2014. Soil stabilization using rice husk ash and cement. International Journal Civil Engineering Research, 5, 49–54.

Sen, A. & Kashyap, R., 2012. Soil stabilization using waste fiber materials, Ph. D thesis.

Soriano, L., Monzó, J., Bonilla, M., Tashima, M.M., Payá, J. & Borrachero, M. V., 2013. Effect of pozzolans on the hydration process of Portland cement cured at low temperatures. Cement Concrete Composition, 42, 41-48.

Tashima, M.M., Soriano, L., Akasaki, J.L., Castaldelli, V.N., Monzó, J.M., Payá, J., 2014. Spent FCC Catalyst for Preparing Alkali-Activated Binders: An Opportunity for a High-Degree Valorization. Key Engineering Material, 600, 709-716.

Tyrer, M.J., 1989. Stabilisation of Clay Type Soils With Cementitious Material.

Vakili, M.V., Chegenizadeh, A., Nikraz, H. & Keramatikerman, M., 2016. Investigation on shear strength of stabilised clay using cement, sodium silicate and slag. Applied Clay Science, 243-251.

Wu, J.H., Wu, W.L. & Hsu, K.C., 2003. The effect of waste oil-cracking catalyst on the compressive strength of cement pastes and mortars. Cement Concrete Resource, 33, 245-253.

Yoobanpot, N., Jamsawang, P. & Horpibulsuk, S., 2017. Strength behavior and microstructural characteristics of soft clay stabilized with cement kiln dust and fly ash residue. Applied Clay Science, 141, 146-156.