World Academy of Science, Engineering and Technology
International Journal of Civil and Environmental Engineering
Vol:10, No:7, 2016

Open Science Index, Civil and Environmental Engineering Vol:10, No:7, 2016 publications.waset.org/10005128.pdf

The Utilisation of Two Types of Fly Ashes Used as Cement Replacement in Soft Soil Stabilisation

Hassnen M. Jafer, W. Atherton, F. Ruddock, E. Loffill

***Abstract*—**This study represents the results of an experimental work using two types of fly ashes as a cement replacement in soft soil stabilisation. The fly ashes (FA1 and FA2) used in this study are by-products resulting from an incineration processes between 800 and 1200 ˚C. The stabilised soil in this study was an intermediate plasticity silty clayey soil with medium organic matter content. The experimental works were initially conducted on soil treated with different percentages of FA1 (0, 3, 6, 9, 12, and 15%) to identify the optimum FA1 content. Then FA1 was chemically activated by FA2 which has high alkalinity by blending the optimum content of FA1 with different portions of FA2. The improvement levels were evaluated dependent on the results obtained from consistency limits and compaction tests along with the results of unconfined compressive strength (UCS) tests which were conducted on specimens of soil treated with FA1 and FA2 and exposed to different periods of curing (zero, 7, 14, and 28 days). The results indicated that the FA1 and FA2 used in this study effectively improved the physical and geotechnical properties of the soft soil where the index of plasticity (IP) was decreased significantly from 21 to 13.17 with 12% of FA1; however, there was a slight increase in IP with the use of FA2. Meanwhile, 12% of FA1 was identified as the optimum percentage improving the UCS of stabilised soil significantly. Furthermore, FA2 was found effective as a chemical activator to FA1 where the UCS was improved significantly after using FA2.

***Keywords*—**Soft soil stabilisation, waste materials, unconfined compressive strength.

I. INTRODUCTION

SOIL stabilisation was initially discovered around four thousand years ago, but it was technically introduced about eight decades ago [1]. However, chemical stabilisation is the most acceptable method to mitigate the undesirable soil properties to meet the requirements of engineering projects; this technique can be achieved by mixing weak soils with binder materials which react chemically in the presence of water to bond the soil particles to each other resulting in stronger soil structure [2].

Numerous investigations have been conducted on soft soil stabilisation using either lime or OPC as preferable chemical stabilisers due to their high reactivity and their ability to improve the physical and geotechnical properties of treated soils as indicated in [3]–[5]. However, the manufacturing of 1 tonne of OPC results in approximately 0.9 tonne of carbon dioxide emission, consumes about 5.6 GJ of energy, and requires around 1.5 tonnes of quarry materials [6]. Furthermore, it has been reported that the predicted growth in the global demand for OPC could reach 5% annually [7]. Due to the reasons mentioned above, the researchers have been motivated to find alternative solutions to reduce the use of lime and cement and one of these solutions is the use of waste or by-product materials.

Some of the waste fly ashes have self-cementing properties in addition to their pozzolanic reactivity which can be considered as base cementitious materials. This property has motivated researchers to conduct extensive experimental investigations in order to develop new cementitious materials. Researchers have been adopting binary, ternary, and even quaternary blending methods for several types of waste fly ashes to develop their cementitious materials. They also adopt different ways for activation such as mechanical activation by applying grinding energy and chemical activation by mixing different types of waste materials having different chemical properties [8]–[11].

This paper represents the results of experimental work on soft soil stabilisation using two different types of waste fly ashes (FA1 and FA2) by adopting a binary blending system. FA1 was initially optimised dependent on the results of UCS. The optimum percentage of FA1 was then chemically activated by adding FA2 with different additional percentages (1.5, 3, 4.5, and 6%). All UCS specimens were subjected to different periods of curing (0, 7, 14, and 28 days) prior to UCS testing.

II. MATERIALS

A. Soil Sample

The soil used in this study was silty clay collected from the shoulder of the River Alt which is located in High Town to the north of Liverpool City Centre in the United Kingdom. Fig. 1 show the maps of the site where the soil samples used in this study were extracted.

Table I illustrates the main physical, chemical, and geotechnical properties of the soft soil. From the curve of particle distribution, the liquid limit (LL), and PI and in accordance to the Unified Soil Classification System (USCS), the soft soil used in this study is an intermediate plasticity silty clay with sand (CI).

H. M. Jafer, Postgraduate Research Student, is with the Liverpool John Moores University, School of the Built Environment, (e-mail: H.M.Jafer@2014.ljmu.ac.uk).

Dr. W. Atherton BEng (Hons) PhD FHEA, Programme Leader, is with the Department of Civil Engineering, Liverpool John Moore's University, Peter Jost Enterprise Centre, Byrom Street, Liverpool, L3 3AF, UK.

Ms F. Ruddock, BA(Hons) MA(Ed) MPhil CEI (part II) MCIWEM AFIMA Programme Leader, is with the Department of Civil Engineering, Peter Jost Enterprise Centre, Liverpool, L3 3AF, UK.

Dr. E. Loffil, BA (Hons) MSc PhD, Senior Lecturer, is with the Department of Civil Engineering, Liverpool John Moores University, Cherie Booth Building, Liverpool, L3 3AF, UK.

Fig. 1 Satellite Images of the Site of Extraction. Location in High Town

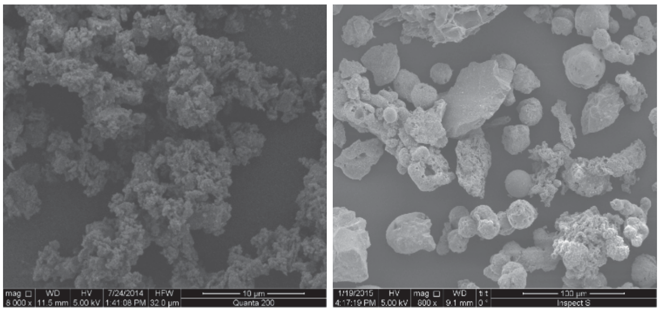
TABLE I
MAIN PHYSICAL AND ENGINEERING PROPERTIES OF THE SOFT SOIL

Property	Value
In-Situ Moisture Content %	36.8
LL %	44
PI	20.22
Sand %	13.08
Silt %	43.92
Clay %	43.00
Specific Gravity (Gs)	2.57
Maximum Dry Density (MDD) g/cm^3	1.57
Optimum moisture content OMC %	23
pH	7.78
Organic Matter Content %	7.95
UCS for Undisturbed Soil qu (kPa)	66.46

g/cm^3= gram/cubic centimetre, kPa = kilopascal.

B. Waste Materials Fly Ashes

The fly ashes used in this study (FA1 and FA2) were exported from two different industries. Figs. 2 (a) and (b) show the scanning electron microscopy (SEM) images for FA1 and FA2 respectively. The particles of FA1 are coagulated in shape and some spherical and irregular shaped particles were indicated for FA2.



(a) (b)

Fig. 2 SEM Images of the Fly Ashes Used in the Study, (a) FA1 and (b) FA2

Fig. 3 shows the comparative curves of particle size distribution for both of the fly ashes used in this study. These curves were obtained by using laser particle size analyser apparatus. The particle size distribution test indicated that FA1 has particles coarser than those for FA2 and this may affect the pozzolanic reactivity of FA1.

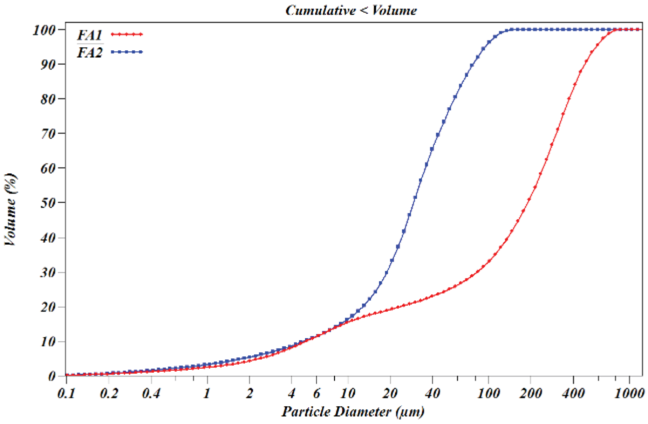


Fig. 3 Particle Size Distribution of the Fly Ashes Used in the Study

III. EXPERIMENTAL WORKS

A. Methodology

The soft soil was initially treated with FA1 using different percentages (0, 3, 6, 9, 12, and 15%) by the dry weight of the treated soil to evaluate the optimum percentage of FA1 which was found to be equal to 12%. Then, FA2 was added to the optimised FA1 samples in the order of 1.5, 3, 4.5, and 6% by the dry weight of the treated soil to produce different binary mixtures. Table II shows the mixing proportion of FA1 and FA2 which was adopted in the second stage of this study.

TABLE II
MIXING PROPORTION BETWEEN FA1 AND FA2

No	Mixture ID	FA1 %	FA2%
1	V.S.	0	0
2	U	12	0
3	CBM1	12	1.5
4	CBM2	12	3
5	CBM3	12	4.5
6	CBM4	12	6

V.S is the virgin soil, U is for unary mixture, and CBM is for complementary binary mixture.

For consistency limits (LL, PL, and PI) and compaction parameters (MDD, and OMC), the samples of untreated and soil treated with different types of mixtures were prepared by dry manually mixing for approximately 5 minutes. Then tap water was added to the mixture straight away to produce the required pastes for conducting the tests.

In terms of UCS tests, a constant volume mould was used to prepare specimens with specific dimensions (38 mm in diameter and 76 mm in height) by pressing the soil-binder paste inside the mould using a hydraulic jack. All types of specimens were cured for different periods (0, 7, 14, and 28 days) prior to being subjected to UCS testing.

B. Laboratory Test

Three main experiments were conducted in this study to evaluate the effects of unary and binary mixtures on the physical and geotechnical properties of the treated soil, and these tests are:

- Consistency limits testing - (LL, PL, and PI). This test was conducted according to British standard BS 1377-2:1990 [12]. However, the Cone Penetrometer device was used to determine LLs.
- Compaction testing which was conducted in accordance to British standard BS 1377-4:1990 [13]. The standard Proctor compaction method was adopted in this test to determine the MDD and OMC for untreated and soil treated with different types of mixture.
- UCS testing was carried out according to British standard BS 1377-7:1990 [14] on specimens of soil treated with different percentages of FA1 as well as with different types of binary mixtures produced from blending of FA1 and FA2 with different proportions.

IV. Results and Discussion

A. Optimisation for FA1

The maximum compressive strength values obtained from UCS testing of the soil treated with different percentages of FA1 and cured for different periods are shown in Fig. 4. It can be seen that the soil strength increased with the increase in FA1 content from 3% up to 12% and then the UCS decreased by using 15% of FA1. Moreover, the UCS values were also found to increase with the time of curing for all percentages of FA1. The results of UCS testing indicated that the optimum percentage of FA1 is 12% by the dry weight of the treated soil, and this percentage was considered as a unary mixture in the second stage of the experimental work.

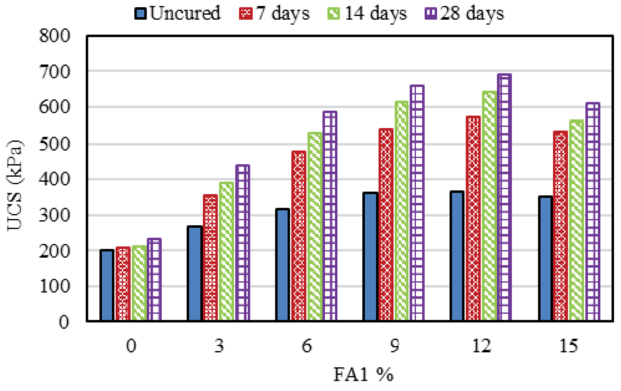


Fig. 4 Development of UCS for the Soil Treated with FA1

B. Effect of Chemical Activation by FA2

The effect of binary blending mixtures of FA1 and FA2 with different proportions on the soil consistency limits is shown in Table III. In this table, it can be seen that the use of binder with a unary mixture which is represented by 12% of FA1 increased both the LL and PL significantly and that led to decrease the PI of the treated soil from 20.22 to only 13.45. However, the results of the Atterberg limits test indicated slight reductions in both LL and PL with the use of binary mixtures but the reductions that occurred in LLs were higher than those for plastic limits which in turn led to slight continuous decrease in PI with increase of the FA2 added to the FA1.

TABLE III
EFFECT OF BINARY BLENDING MIXTURES ON ATTERBERG LIMITS

MIXTURE ID	LL %	PL %	PI
V.S.	44	23.78	20.22
U	51.3	37.85	13.45
CBM1	51.2	37.8	13.4
CBM2	50	36.63	13.37
CBM3	49.8	36.58	13.22
CBM4	49.5	36.44	13.06

Fig. 5 shows the results of compaction parameters tests for the soil treated with different types of binary mixtures in addition to the virgin soil and soil treated with the optimum percentage of FA1. It can be recognised that MDD decreased while OMC increased significantly by treating with 12% of FA1 (Unary mixture). However, there were clear reductions in OMC with the use of FA2, especially for CBM1 and CBM2 while MDD increased gradually with added FA2.

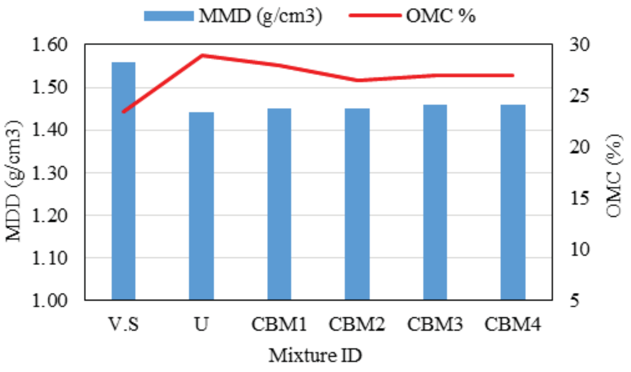


Fig. 5 MDD-OMC Relationship for the Soil Treated with Different Types of Mixtures

UCS results are shown in Fig. 6. The results indicated a significant improvement in the soil strength with the use of binary mixtures especially with respect to the soil treated with CBM2 and CBM3 which indicated very similar results. Moreover, the results indicated a gradual increase in UCS for zero days of curing with use of FA2 due to the increase in MDD of the soil as described earlier.

V. Conclusions

According to the results achieved in this study, the following conclusions can be drawn:

- The results indicated that 12% of FA1 was the optimum percentage which was enough to increase the UCS of the treated soil by an approximate factor of 3.5 after 28 days of curing.
- Atterberg limits for the soil used in this study were improved significantly with use of 12% FA1 while there

was no significant improvement with use of FA2. However, PI decrease from 20.22 for virgin soil to 13.06 by using CBM4 (12% FA1 + 6% FA2).

- With respect to UCS testing, the results indicated that treating soft soil with binary mixture improved the UCS significantly with CBM2 and CBM3 revealing similar results. However, in terms of economic savings, CBM2 can be considered as the optimum binary mixture in this study which is derived from 12% FA1 with 3% FA2. This mixture improved the UCS by factor of 5.0 after 28 days of curing.

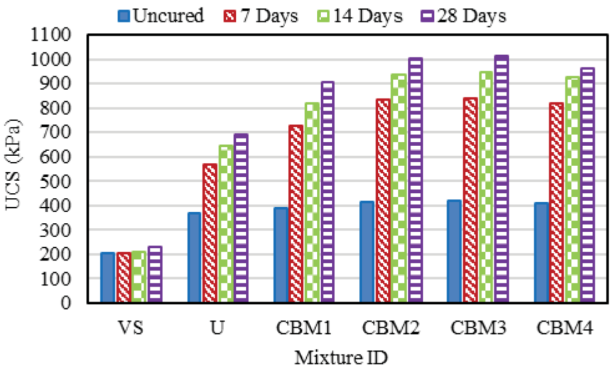


Fig. 6 Development in UCS for the Soil Treated with Different Types of Mixtures and Cured for Different Periods of Curing

ACKNOWLEDGMENT

The first author would like to express his acknowledgment to the Iraqi ministry of high education and scientific research, and the University of Babylon - college of engineering/ Babylon – Iraq for funding.

REFERENCES

[1] Kolias, S., Kasselouri, V., and Karahalios, A. (2005) ‘Stabilisation of clayey soils with high calcium fly ash and cement’. *Cement & Concrete Composites*, 27 (2005), P. 301–313.

[2] Makusa, G.P. (2012) ‘Soil Stabilisation Method and Materials in Engineering Practice’. Lulea, Sweden. Lulea University of Technology.

[3] Jauberthie, R.; Rendell, F.; Rangeard, D. and Molez, L. 2010. Stabilisation of estuarine silt with lime and/or cement. *Applied Clay Science,* 50, 395-400.

[4] Farouk, A. and Shahien, M. M. 2013. Ground improvement using soil–cement columns: Experimental investigation. *Alexandria Engineering Journal,* 52, 733-740.

[5] Modarres, A. Andnosoudy, Y. M. 2015. Clay stabilization using coal waste and lime — Technical and environmental impacts. *Applied Clay Science*.

[6] O’rourke, B.; Mcnally, C. and Richardson, M. G. 2009. Development of calcium sulfate–ggbs–Portland cement binders. *Construction and Building Materials,* 23, 340-346.

[7] Jafer, H. M., Atherton, W., Ruddock, F. M. & Loffil, E. 2015. Assessing the Potential of a Waste Material for Cement Replacement and the Effect of Its Finenness in Soft Soil Stabilisation. *International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering,* 9(8), 794-800.

[8] Blanco, F.; Garcia, M. P.; Ayala, J.; Mayoral, G. and Garcia, M. A. 2006. The effect of mechanically and chemically activated fly ashes on mortar properties. Fuel, 85, 2018-2026.

[9] Sadique, M.; Al Nageim, H.; Atherton, W.; Seton, L. and Dempster, N. 2012. A new composite cementitious material for construction. Construction and Building Materials, 35, 846-855.

[10] Dave, N.; Misra, A. K.; Srivastava, A. and Kaushik, S. K. 2016. Experimental analysis of strength and durability properties of quaternary cement binder and mortar. Construction and Building Materials, 107, 117-124.

[11] Soriano, L.; Payá, J.; Monzó, J.; Borrachero, M. V. and Tashima, M. M. 2016. High strength mortars using ordinary Portland cement–fly ash–fluid catalytic cracking catalyst residue ternary system (OPC/FA/FCC). Construction and Building Materials, 106, 228-235.

[12] British Standard 1990a. BS 1377-2:1990, Methods of test for soils for civil engineering purposes - Part 2: Classification tests. London: UK: British Standard Institution.

[13] British Standard 1990b. BS 1377-4-1990, Methods of test for Soils for civil engineering purposes - Part4: Compaction-related tests. London: UK: British Standard institute.

[14] British Standard 1990c. BS 1377-7-1990- methods of test for Soils for civil engineering purposes - Part 7: Shear strength tests (total stress). London: UK: British Standard institute