FACULTY OF ENGINEERING & TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING

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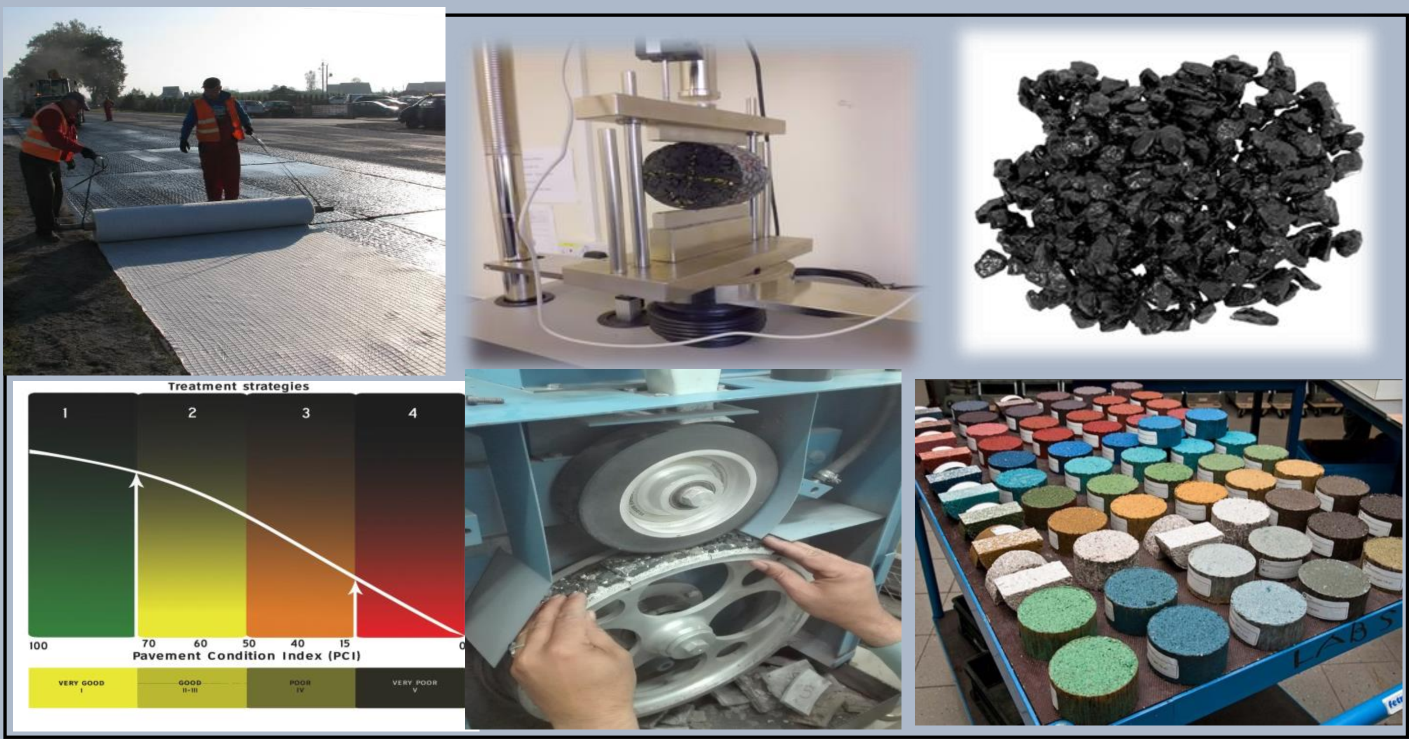
16th Annual International Conference on Asphalt, Pavement Engineering and Infrastructure

22-23 February, 2017, Britannia Adelphi Hotel, Liverpool, UK



Editor
Professor Hassan Al Nageim
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WELCOME FROM THE CONFERENCE DIRECTOR AND CHAIRMAN

The two-day conference team of speakers represent experts from a range of organizations including; academic institutions, bitumen, emulsion and chemical producers, government regulatory and advisory bodies, material suppliers, consultants, research centers, laboratory equipment suppliers and contractors who will address a broad range of topics related to road surfacing materials.

The conference programme is organized into paper presentation sessions and exhibition breaks to help elucidate the scope of the conference and provide a useful networking arena. This will enable delegates to make new national and international contacts, to be brought up to speed with the latest industry and academic developments and bridge the gap between the various parties and help to transfer research into practice.

The conference will be held at the Adelphi Britannia Hotel, Liverpool, European City of Culture 2008, City of Health and Wellbeing 2010/2015. The very name of Liverpool conjures up images of a glorious maritime history, world-beating musical heritage, two of the Premiership's biggest football teams and not one, but two majestically different Cathedrals. This Northwest city and the surrounding City Region is certainly all those things, but it is also so much more. It is now bulging with fabulous new shops, has buzzing new restaurants, hip hotels and trendy wine bars, as well as a world class cultural offering with more museums and galleries anywhere outside of London. Not forgetting its inhabitants, of course, who are famously friendly and will welcome you with pride.

We would like to extend our heart-felt thanks to your participation in this conference, particularly those who have traveled far to our city. We are extremely fortunate to have speakers and delegates from many countries including many specialists and experts in their own right to share with us their knowledge and experience on all aspects of sustainable aggregates, asphalt technology, pavement engineering and highways maintenance.

The Conference Organizing Committee wishes to express their gratitude to the sponsoring companies and institutions that have supported the conference financially and helped in one way or another to make this conference a success.

We would particularly like to acknowledge and thank Professor Howard Robinson, Chief Executive, RSTA and Conference Chairman, the Chairmen of the two days conference sessions and the speakers for their outstanding contributions which reflect the scientific and technological character of their work. The excellent work of Anmar Dulaimi, Manar Herez

and Atif Rasheed from the LCMT, LJMU Conference and Event Services team is highly acknowledged.

We are confident that the 16th LJMU annual international conference will be informative and rewarding to all the participants through providing new ideas, new contacts or new enthusiasm not just from UK but also from Europe, the Middle East, Far East.

Professor Hassan Al Nageim
Professor of Structural Engineering
Head of Liverpool Centre for Materials Technology
Conference Director

Professor Howard Robinson
LJMU Visiting Professor, Chief Executive, RSTA
Conference Chairman

DAY ONE - CONFERENCE PROGRAMME

DAY 1 – Wednesday 22th February 2017

Venue: BRITANNIA ADELPHI HOTEL, LIVERPOOL L3 5UL, UK

08:30 Registration, Refreshment and Exhibition

09:00	Welcome by the Conference Chairman, Professor Howard Robinson, Road Surface Treatments Association, RSTA, **UK**.
09:10	Opening Address, Professor Ahmed Al-Shamma'a, Executive Dean, Faculty of Engineering & Technology, Liverpool John Moores University, **UK**.

Morning Programme

Session 1, Chairman: Professor Howard Robinson, Chief Executive, RSTA, UK

09:15	"Pavement Engineering & Highways: Standards/Specifications and the Unique Approval Process": Arash Khojinian, Highways England, **UK**
09:35	"New Istanbul Airport: Pavement Design Optimisation": Dr Bachar Hakim, AECOM, **UK**
09:55	"Asphalt Preservation Systems - New Industry Guidance and Case Studies": Craig Marshall, ASI Solutions Ltd, **UK**
10:15	"Innovative Patching Techniques - New British Standard and Case Studies": Sonny Singh, Nu-phalt Contracting Ltd, **UK**

10:35 Questions & Discussion

10:40 Refreshments and Exhibition

Session 2, Chairman: John Richardson, Colas Ltd, UK

11:25	"Developing the Next Generation of Asphalt Surfacing: Design, Construction and Research Experience": Dr Chibuzor Ojum, AECOM, **UK**
11:45	"Skidding Resistance: Measurement And Use Of Data": Mark Stephenson, WDM Ltd, **UK**
12:05	"Compliance in Testing Hand Laid Bituminous Materials for Utility Reinstatements": Karl Stopps, Carillion Telent, **UK**
12:25	"Nottingham Asphalt Research Consortium (NARC)'": Prof. Gordon Airey, University of Nottingham, **UK**

12:45 Questions & Discussion

12:50 Lunch and Exhibition

Afternoon Programme

Session 3, Chairman: Professor Marco Pasetto, University of Padua, Italy

13:50	"Required Mechanical Properties of a Clear Binder for Coloured Asphalt Concrete": Kees Plug, **Netherlands**
14:10	"Incorporation of Waste Pet in Bituminous Concrete Mixes": Rajan Choudhary, Indian Institute of Technology, **India**
14:30	"Nanotechnology-based Waste Materials as a Replacement of Cement in Rigid Pavements": Mostafa Abo-Hashema, Fayoum University, **Egypt**
14:50	"A New and Innovative Steel based Anti-Reflective Cracking Interlayer for the Asphalt Overlays": Frederik Vervaecke, Bekaert Nv, **Belgium**

15:10 Questions & Discussion

15:15 Refreshments and Exhibition

Session 4, Chairman: Mostafa Abo-Hashema, Fayoum University, Egypt

15:45	"Application of Fast Falling Weight Deflectometer (FastFwd) for Accelerated Pavement Testing (APT)": Marco Francesconi, Dynatest International A/S, **Denmark**
16:05	"Warm Chemical Additive to Improve Water Resistance of Asphalt Mixtures Containing Steel Slags: A Multi-Scale Approach": Marco Pasetto, University of Padua, **Italy**
16:25	"Accelerated Durability Testing using the Immersion Ageing Test": Chibuzor Ojum, AECOM, **UK**
16:45	"Introduction and Role of CIHT": Alistair Haydock and Terri Myers, The Chartered Institution of Highways & Transportation, **UK**
17:05	**Questions and Closing Remarks by the Conference Director Professor Hassan Al Nageim, UK**

DAY TWO - CONFERENCE PROGRAMME

DAY 2 – Thursday 23th February 2017

Venue: BRITANNIA ADELPHI HOTEL, LIVERPOOL L3 5UL, UK

08:30 Registration, Refreshment and Exhibition

Morning Programme

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09:00	"Effect of Aggregate Physical Properties on Frictional Resistance of OGFC Mixes", Rajan Choudhary, Indian Institute of Technology, **India**
09:20	"Development of In-Situ Asphalt Dynamic Modulus Master Curves using Falling Weight Deflectometer in Hot Climate Areas": Amir Kavussi, Tarbiat Modares University, **Iran**
09:40	"Skid Resistance of Asphalt Mixtures prepared using different Aggregate Sources and Gradations": M. A. Kamal, University of Engineering & Technology, **Pakistan**
10:00	"Effect Of Laboratory Compaction Method On The Mechanical Properties Of Bituminous Materials": Chris Allpress, Aggregate Industries Ltd, **UK**

10:20 Questions & Discussion

10:25 Refreshments and Exhibition

Session 2, Chairman: Amir Kavussi, Tarbiat Modares University, Iran

10:55	"Studies on Performance of Bituminous Mixes Containing Hard Grade Bitumen and Implications on Pavement Design": Khusboo Arora, Central Road Research Institute, **India**
11:15	"Microwave Technique to Develop Cold Bituminous Emulsion Asphalt Concrete Mixture using New Cementitious Filler" **and** "Performance Assessment and Microstructure of New Cold Asphalt Concrete Binder Course Mixture using GGBS and CKD": Anmar Dulaimi, Liverpool John Moores University, **UK**
11:35	"Evaluation of Field Performance of Pavements Constructed using Cold Mix Technology": Gajendra Kumar, Central Road Research Institute, **India**
11:55	"Evaluation of Rutting Resistance of Micro-asphalt Incorporating Recycled Asphalt Pavement (RAP) Using a Cementitious Filler": Manar Herez, Liverpool John Moores University, **UK**

12:15 Questions & Discussion

12:20 Lunch and Exhibition

Afternoon Programme

Session 3, Chairman: Rajan Choudhary, Indian Institute of Technology, India

13:30	"Benchmarking of Functional and Structural Analytics for Pavement Condition Classification in Indonesia: A Case Study": Marsinta Simamora, State Polytechnic of Kupang, **Indonesia**
13:50	"Retardation of Reflection Cracks in Composite Pavements with Use of Fibres Modified Bituminous Mixes": Manoj Kumar, Central Road Research Institute, **India**
14:10	"Automated Paving Technology/BIM for Highways": Robert Noakes, CES Norfolk County Council, **UK**
14:30	"Mechanical Properties of using Cement Kiln Dust in Cold Bituminous Emulsion Asphalt": Sajjad Al-Merzah, University of Kerbala, **Iraq**

14:50 Questions & Discussion

14:55 Refreshments and Exhibition

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15:45	"Freeze-Thaw Resistance of Recycled Aggregate Concrete": Atef Badr, Military Technological College, **Oman**
16:05	"The Application of High Recycled Content Mixtures on Strategic Roads": Helen Bailey and Mark Flint, FM Conway Ltd, **UK**
16:25	"An Experimental Comparison between Surface Cold Mix Asphalt with Egyptian and UK Gradations": Talaat Abdelwahed, Sohag University, **Egypt**
16:45	**Questions and Closing Remarks by the Conference Director Professor Hassan Al-Nageim, UK.**

Hassnen M. Jafer

MSc in geotechnical Engineering- University of Technology, Baghdad-Iraq, 2006. Currently: PhD student in Liverpool John Moores University, Civil Engineering Department. In Iraq: A lecturer in the University of Babylon, College of Engineering- Babylon, Iraq.

My current project deals with the use of different waste materials fly ashes to develop a new cementitious material produced from a free-cement blending method. The evaluation of the binder developed performance is dependent on the results obtained from the unconfined compressive strength of the stabilised soil.

THE CHARACTERISATION OF THE STRENGTH DEVELOPMENT OF A CEMENT-STABILISED SOFT SOIL TREATED WITH TWO DIFFERENT TYPES OF FLY ASHES

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[4]MSc Student, Liverpool John Moores University, Department of Civil Engineering.

ABSTRACT

There are several problems associated with soft soils such as the low strength, high compressibility and the sensitivity with the changes in the water content. In order to mitigate such undesirable properties, soft soils are often improved and stabilised either mechanically chemically. However, chemical stabilisation is the most effective technique to improve the geotechnical properties of the soft soil. This study aims to improve the properties of a soft soil regarding the consistency and compressive strength by using a small amount of cement (5% OPC by the dry weight of the treated soil). Then two different types of fly ash were examined for pozzolanic activation of the cement treated soil. These fly ashes were pulverised fuel ash (PFA) and palm oil fuel ash (POFA). Initially, trial specimens containing 5% OPC with 5% of PFA or POFA were prepared for unconfined compressive strength testing (UCS) conducted at 7 days of curing. These trial specimens were manufactured to indicate with which type of fly ash the future research should be based on. The results of UCS test revealed that PFA indicated higher strength than that for POFA after 7 days of curing. Thus PFA was considered in this study as a pozzolanic activator for further experimental works. Additionally, the cement-stabilised soil (CSS) mixture was mixed with PFA with different proportions where OPC was kept as 5% and PFA was varied from 5–15% by the dry weight of the stabilised soil. The improvement levels in the stabilised soil were evaluated dependent on the results of UCS test conducted on specimens of CSS treated with different percentages of PFA and subjected to two different periods of curing (7 and 28 days). The effect of PFA on the compaction parameters (maximum dry density (MDD), optimum moisture content (OMC)) and Atterberg limits (liquid limit (LL), plastic limit (PL), along with the plasticity index (PI)) of the CSS soil was also explored in this study. The plasticity characteristic of the treated soil was found to decrease with continuous increments of PFA. The PI decreased from 20.3 for the untreated soil to 13.75 for the cement stabilised soil treated with 10% PFA. The optimised mixture in this research was found to be (soil + 5% OPC + 10% PFA) which increased the UCS of the soil from 134kPa for the virgin soil (VS) and 732kPa for the soil treated with only 5% OPC cured for 28 days to 946kPa at an equivalent 28 days of curing.

Keywords: Soil stabilisation, OPC, Fly ashes, Pozzolanic activation, and unconfined compressive strength.

INTRODUCTION

Soil stabilisation is a technique introduced several decades ago. It is aimed to render a soil to be suitable for an engineering project with specific requirements (Kolias et al., 2005). However, this technique was available since 4000 or 5000 BC when the Romans used volcanic ash as a binder material for soils in road pavement (Paulo J. Venda Oliveira et al., 2012). More precisely, soil stabilisation is suggested to help the engineer in being able to reuse the in-situ soil as an engineering material with specific properties, such as strength, volume stability, permeability and durability (Tyrer, 1987). The stabilisation of soft soils has been traditionally achieved using Ordinary Portland Cement (OPC) and lime, which are the most usual materials, used as primary binders. However, they are sometimes mixed with special additives such as pozzolanic materials which are rich in silica (SiO2). There are numerous publications and research projects that have involved lime and OPC as binder materials in soft soil stabilisation. OPC and lime are preferred due to their ability to bind the soil particles with each other forming a stronger soil structure as indicated in Farouk and Shahien (2013), Modarres and Nosoudy (2015), Jafer et al. (2016b).

Ordinary Portland Cement has been used as a preferable soil stabiliser for many years. It can be employed for soil modification to improve the physical properties of treated soils such as the Atterberg limits and particle size distribution, and in soil stabilisation to alter the geotechnical properties such as soil resistance against swell-shrink stresses and to increase soil strength (Jauberthie et al., 2010, Yi et al., 2015, Vakili et al., 2016). However, there are several drawbacks associated with the use of cement such as the negative environmental impact due to the emission of carbon dioxide (CO_2) and the consumption of natural resources. Therefore, researchers have been motivated to carry out intensive studies to develop alternative binders in order to reduce the use of cement (Jafer et al., 2016a). One of the promising solutions is the use of supplementary cementitious materials (SCMs). These materials are in general by-product or waste materials and are sometimes called fly ashes (FA). These materials are most likely to have pozzolanic properties, which by themselves do not have any cementitious properties, but when they are added to cement, react to boost the hydration processes and these materials are categorised as FA class F. Moreover, some of the fly ashes have an adequate calcium content which makes them highly reactive when mixed with water, and this type of FA is called FA class C (Ghosh and Subbarao, 2007).

Several studies were carried out on CSS using different types of SCMs such as palm oil fly ash (POFA), rice husk ash (RHA), pulverised fuel ash (PFA), ground granulated blast furnace slag (GGBS), silica fume (SF), etc. These materials have been used as pozzolanic additives to boost the hydration of cement as well as to increase the production of cementitious gel which so called either calcium silicate hydrated (C-S-H) or calcium aluminate hydrated (C-A-H). This cementitious product has the ability to increase the stabilised soil strength significantly (Yadu and Tripathi, 2013, Mujah et al., 2015, Modarres and Nosoudy, 2015).

This paper presents the results of experimental works for the pozzolanic activation of CSS using two different types of fly ash (PFA and POFA). The OPC dosage was fixed as a small amount (5% by the dry weight of the soil), and then the effect of pozzolanic activation using 5% of two different types of fly ash (PFA and POFA) was evaluated initially dependent on the results achieved from UCS testing of samples subject to 7 days of curing at ambient temperature. Subsequently, the fly ash that provided higher compressive strength was selected as a pozzolanic activator for further experiments. The selected fly ash was added to the CSS in percentages ranged between 5 and 15% with UCS testing performed again on specimens subject to 7 and 28 days of curing. The effect of the pozzolanic activation of the cement-stabilised soft soil on the compaction parameters and consistency limits was also investigated.

MATERIALS AND METHODOLOGY

Soil sample:

The soil used in this study was collected from the shoulders of the River Alt which is located in Hightown to the north of Liverpool. The soil samples were taken from a depth ranging between 0.3m and 0.5m below the ground level. The collected samples were placed in plastic bags of approximately 20-25kg each, and then sealed before they were sent to the laboratory. Figure 1 shows the aerial photograph of the site where the soil samples tested in this study were taken. Once the samples arrived at the laboratory, specimens of soil were taken to determine the natural moisture content (NMC), and the remaining soil was oven dried at 110°C to be used for further experiments. Initially, the soil was classified by conducting the required experiments for soil classification, such as particle size distribution and the consistency limits tests. Additionally, the strength characterisation of the virgin soil was evaluated by performing the unconfined compressive strength test (UCS) for specimens of untreated compacted soil. A chemical analysis was also carried out to identify the main chemical properties of the soil. Table 1 illustrates the main properties of the soft soil used in this study. The results of the soil classification showed that it contained 12.07%, 75.03%, and 12.9% of sand, silt and clay respectively. While the liquid limit, plastic limit and index of plasticity were found to be equal to 42, 21.7 and 20.3 respectively.

Figure 1. The aerial photograph image of the extraction location of the soil used in the study.

According to the main properties of the soil shown in Table 1 along with Unified Soil Classification System (USCS), the soil used in this study was an intermediate plasticity clayey silt with sand (CI).

Table 1 Main engineering properties of the virgin soil used in this study

Property	Value
Natural Moisture Content NMC %	37.5
Liquid Limit LL %	42
Index of Plasticity IP	20.3
Sand %	12.07
Silt %	75.03
Clay %	12.9
Specific Gravity (Gs)	2.67
$\gamma_{d\,max}$ Mg/m^3	1.59
Optimum moisture content OMC %	22
pH	7.78
Organic Matter Content %	7.95
Unconfined Compressive Strength qu (kPa)	134

Mg/m^3= Mega gram/cubic metre, kPa = kilopascal.

Binder Materials:

The materials used as binders in this study were as follows:

- ***Ordinary Portland Cement (OPC):*** a commercially available OPC type CEM-II/A/LL 32.5-N was used which was supplied by Cemex Company in Warwickshire, UK.
- ***Pulverised Fuel Ash (PFA):*** a trial sample of PFA was provided for the academic research by SSE.com from the Fiddlers Power station, Cuerdley, Warrington, UK.
- ***Palm Oil Fuel Ash (POFA):*** Waste material produced from the incineration processes of palm oil fibres at a temperature ranging between 800 and 1000°C was imported from Sg. Tengi Palm Oil Factory at Kuala Kubu Bharu, Selangor, Malaysia.

The particle size distribution (PSD) curves of the materials used as binders in this study and obtained from the laser particle size analyser are shown in Figure 2. From Figure 2, it can be seen that the PSD of the PFA was similar to that of OPC and it was finer than that for POFA. This means that the PFA has a higher pozzolanic reactivity than the POFA for the first instance because it has a higher specific surface area (Kumar et al., 2008, Zhao et al., 2016). The results of the scanning electronic microscopy (SEM) imaging test agreed with the PSD results and revealed that the particles of PFA were almost spherical, while the particles of OPC and POFA were angular, and spherical respectively, with a few of irregular shaped particles as shown in Figure 3. The main chemical properties and compositions are listed in Table 2. It can be observed that the POFA has a significant value of pH which is may be due to its high content of sodium and potassium oxides. Alternatively, the results of the chemical analysis indicated a high alumina content for PFA which would accelerate the development of the early strength.

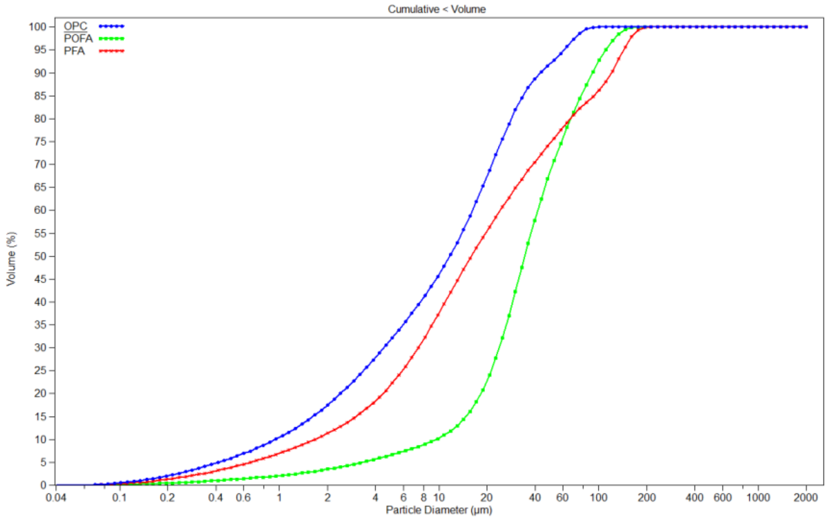

Figure 2. Particles size distribution curves of the binder materials used in this study.

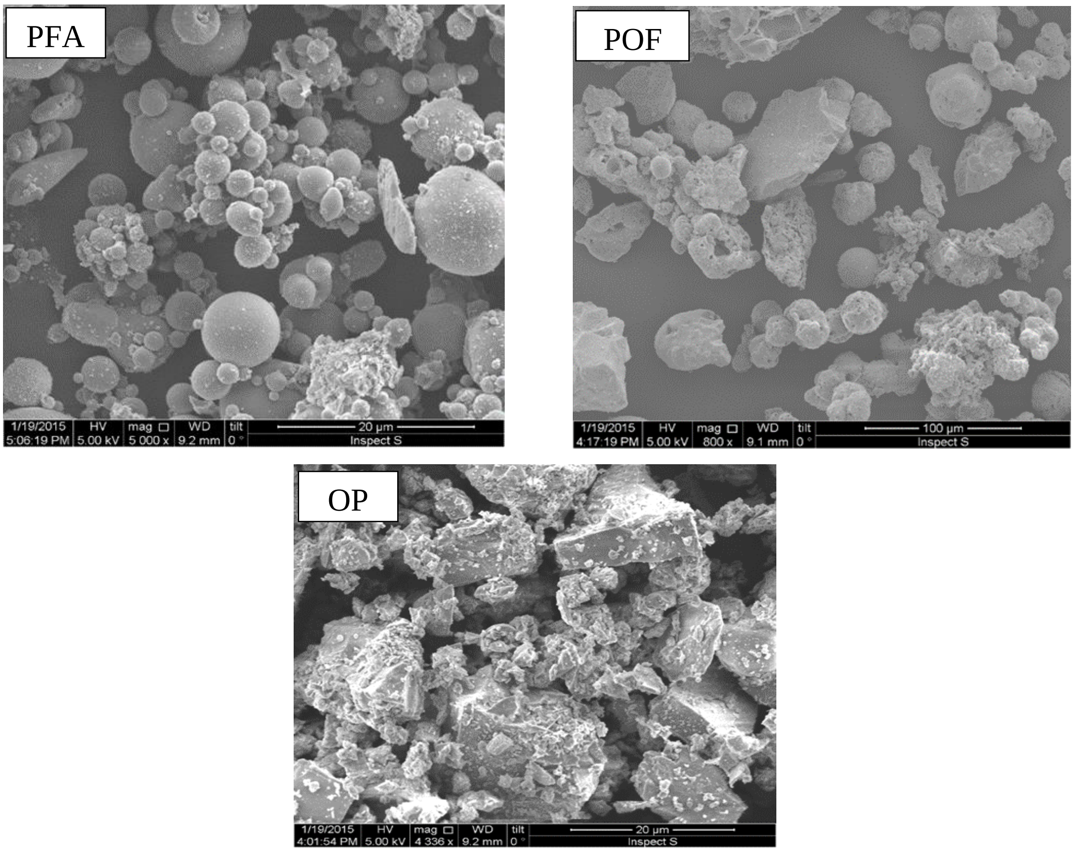

Figure 3. SEM testing images of the binder materials.

Table 2 Main chemical properties of the binder materials used in this study.

Item	LOI %	pH	CaO%	SiO_2 %	Al_2O_3 %	MgO %	Fe_2O_3 %	K_2O %	SO_3 %	Na_2O %
OPC	0.28	13.04	65.21	24.56	1.7	1.3	1.64	0.82	2.62	1.34
PFA	9.64	6.4	4.31	51.83	15.3	3.34	5.44	2.04	1.06	1.17
POFA	2.78	13.04	10.47	61.36	7.51	5.64	1.54	7.53	2.93	1.73.

EXPERIMENTAL WORKS

Sample Preparation and Conditioning:

After the drying process, the soil samples were pulverised to break any lumps and then prepared for the Atterberg limits test along with compaction parameters test. These tests were performed directly after adding the binder and water. The binder differed from 5% OPC only to 5% OPC+ different percentages of PFA ranged from 5 to 15% by the dry weight of the treated soil.

The specimens for the UCS test were prepared by pressing the soil-binder paste inside a fixed volume mould shown in Figure 4. The specimens produced by this mould were 38mm in diameter and 76mm in height according to the standard requirements. Moreover, the specimens were manufactured with specific densities dependent on the corresponding maximum dry density (MDD) and optimum moisture content (OMC) for each type of the binder used. The UCS test was conducted by using a computerised triaxial machine and the values of UCS were determined by applying vertical load only and removing the horizontal stress in the triaxial cell ($\sigma 3 = 0$) as shown in Figure 5. The specimens of the treated soil were cured for 7 and 28 days before they were subject to the UCS tests.

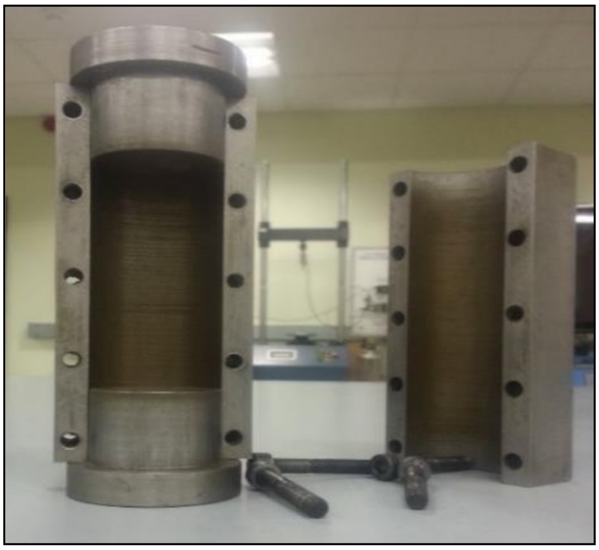

Figure 4. Fixed volume mould used in this study.

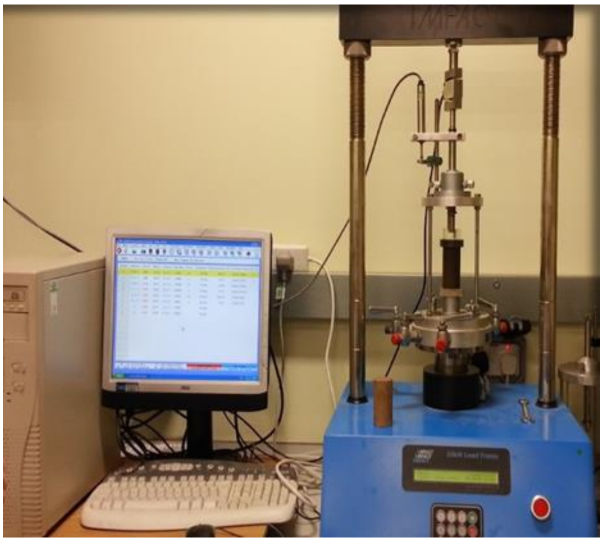

Figure 5. The computerised machine used for UCS test.

Laboratory Tests:
The following experiments and curing conditions were utilised in this research project:

- Atterberg limits tests - (Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI)). These limits were determined according to the British Standard BS 1377-2:1990 (British Standard, 1990a). The cone penetration method was considered to determine the liquid limits using Cone Penetrometer device.
- Compaction parameters tests were carried out to evaluate the maximum dry density (MDD) and optimum moisture content (OMC). The Standard Proctor compaction method was adopted in this study in accordance to the British Standard BS 1377-4:1990 (British Standard, 1990b). A sample of approximately 2000g of the dry soil or soil-binder passed through a sieve size 3.35mm was prepared then moulded inside the standard mould in three layers after adding the water. Each layer was subjected to 25 blows using a 2.5kg hammer of an electrical compaction machine.
- Unconfined Compressive Strength testing was performed according to British Standard BS 1377-7:1990 (British Standard, 1990c). At least two specimens were prepared for each corresponding percentage of the binder added to the soil and were tested for different periods of curing (7 and 28 days). Soil-binder mixtures were compacted inside the fixed volume mould, after adding the necessary water content, using hydraulic load. Then the specimens were extruded, weighed then covered in cling film, enclosed in well-sealed plastic bags, and stored for curing at room temperature at approximately 20 ± 2^{o}C.

RESULTS AND DISCUSSION

Trial Study Results:

Figure 6 shows the results of compaction testing of the soil treated with 10% of binders produced from 5% OPC + 5% PFA and 5% OPC + 5% POFA along with the soil treated with 5% OPC as a reference mixture. It can be seen that the MDD increased and OMC decreased with the use of both types of fly ashes. However, the PFA indicated a higher MDD than that for POFA. This behaviour may be attributed to the higher fineness of PFA which increased the workability of the soil-binder mixture which led to reduced water demand. The results indicated that the MDD increased from 1.57Mg/cm^3 for the CSS to 1.585Mg/cm^3 after adding 5% PFA to the cement-treated soil.

For the same mixtures, the results of the unconfined compressive strength (UCS) test at 7 days curing shown in Figure 7 indicated that with the use of 5% OPC there was a significant improvement in the compressive strength of the soft soil. The UCS increased from 134kPa for the virgin soil (VS) to 673kPa with the use of 5% OPC and after 7 days of curing. Additionally, the results shown in Figure 7 indicated that the CSS treated with 5% PFA exhibited a slightly higher compressive strength than that for the CSS treated with 5% POFA where the compressive strengths were 673kPa and 669kPa for the specimens treated with PFA and POFA respectively. However, the cement-soil specimens treated with the fly ashes indicated an increment in the soil strength, which can be attributed to the pozzolanic reaction which took place between the hydrated lime of cement and the silicates compounds of the fly ashes (Aïtcin, 2016). As a result of the trial study, PFA was selected in this study for further investigation by adding a range of percentages 5 – 15 % to the CSS. The effect of PFA treatment on the compaction parameters, Atternerg limits and the compressive strength of the CSS was investigated later on in this study.

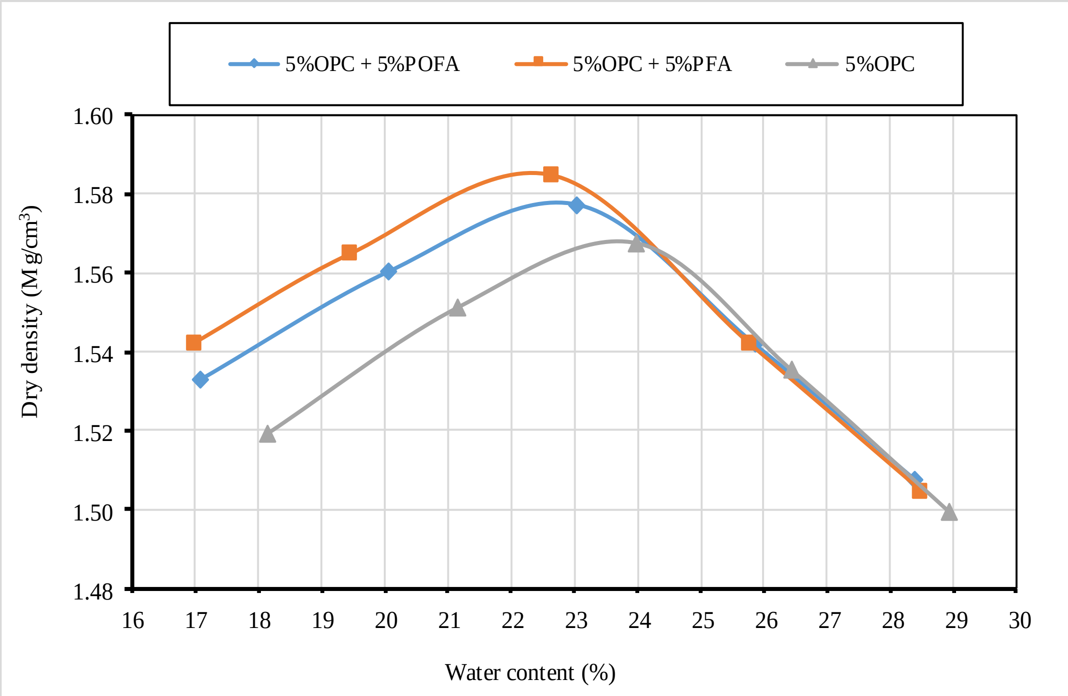

Figure 6. Dry density - moisture content relationship of the CSS before and after treating with 5% of PFA and POFA.

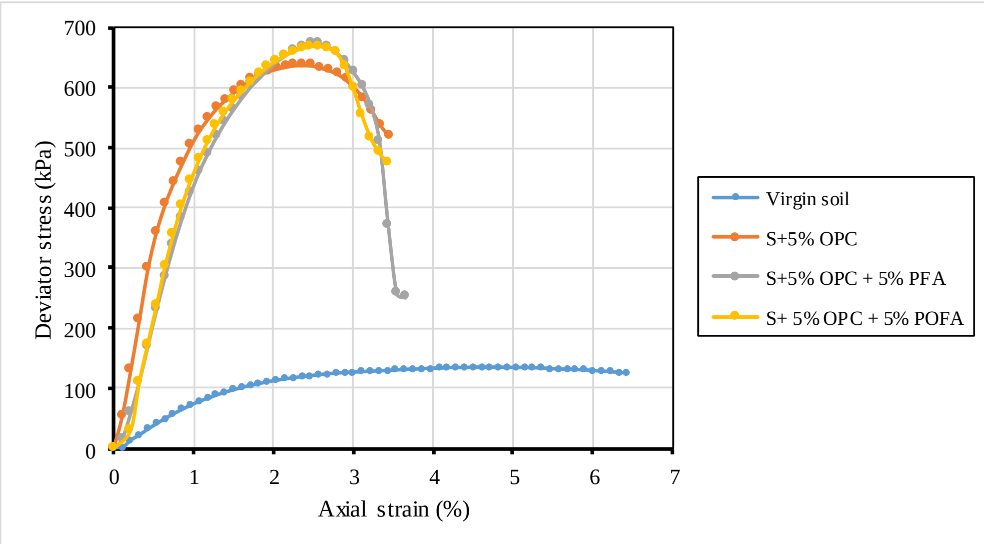

Figure 7. Stress axial stain diagrams for the virgin and stabilised soil at 7 days.

Results of the Cement-Stabilised Soil after PFA Treatment:

Atterberg limits:

The effect of cement treatment with 5% and then the effect of PFA treatment by 5, 7.5, 10, 12.5, and 15% by the dry weight of the treated soil is shown in Figure 8. It can be observed that the LL increased with the cement treatment and then started to decrease after adding PFA with different percentages. Moreover, the PI decreased significantly with the use of cement and a further noticeable reduction was achieved with the use of 5% PFA. The decrease in PI continued in decline for the PFA dosages beyond 5% but the reduction became gradual. Table 3 illustrates the values of LL, PL and PI achieved from the Atterberg limits test, it can be recognised that the PI was decreased significantly from 20.3 for the virgin soil to 17.8 after treating with 5% OPC. Additionally, PI was reduced to its lowest value (13.2) by adding 12.5% PFA to the CSS. The reduction occurred in the PI after PFA treatment was due to the reduction in the LL accompanied with the slight increase in PL as shown in Table 3.

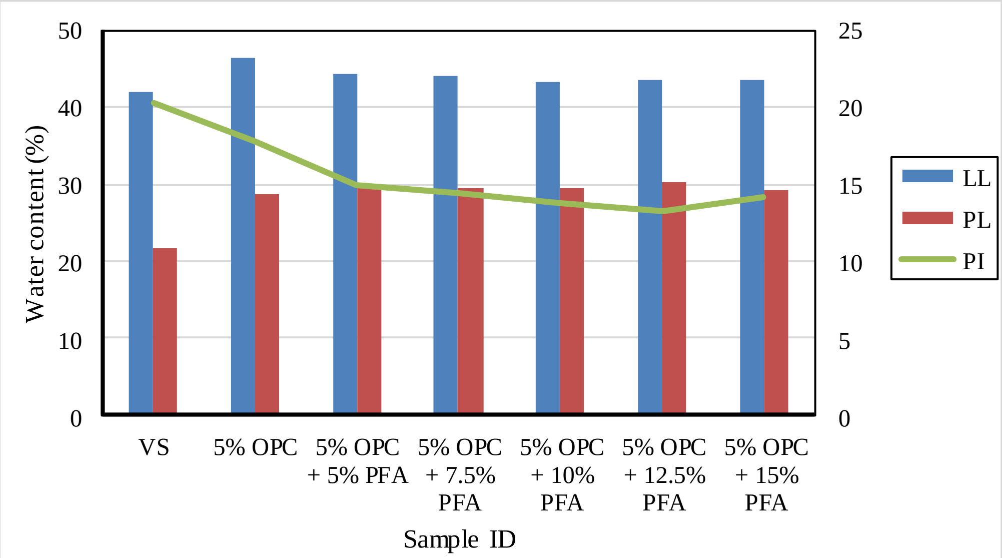

Figure 8. Atterberg limits after cement and PFA treatment.

Table 3 The results of Atterberg limits after cement and PFA treatment

Item	LL	PL	PI
VS	42	21.7	20.3
5% OPC	46.5	28.7	17.8
5% OPC + 5% PFA	44.3	29.4	14.9
5% OPC + 7.5% PFA	44	29.6	14.4
5% OPC + 10% PFA	43.4	29.6	13.8
5% OPC + 12.5% PFA	43.6	30.4	13.2
5% OPC + 15% PFA	43.5	29.3	14.2

Compaction Parameters Test:

The results of the compaction parameters test after PFA treatment shown in Figure 9 indicated that the MDD increased and the OMC decreased with continuous increase in PFA content. The results showed that the MDD increased noticeably from 1.585Mg/cm^3 to 1.6Mg/cm^3 when the PFA content increased from 5% to 7.5% respectively. After that, the increment in the dry density became stable. Meanwhile, the OMC decreased from approximately 22.5% to less than 22%. The increase in MDD may contribute to an increase in the compressive strength of the CSS. With respect to the OMC, the reduction occurred gives an indication of the increase of the workability of the cement-soil mixture treated with PFA. This behaviour of the compaction parameters of the CSS after PFA treatment could be attributed to the decrease in the water demand of the soil-binder mixtures after adding the PFA, which replaced a part of the soil that is associated with higher water demand due to the clay minerals in the treated soil. Moreover, the increase occurred in the dry density maybe attributable to the fineness of PFA particles which filled the air voids and led to a resulting denser structure.

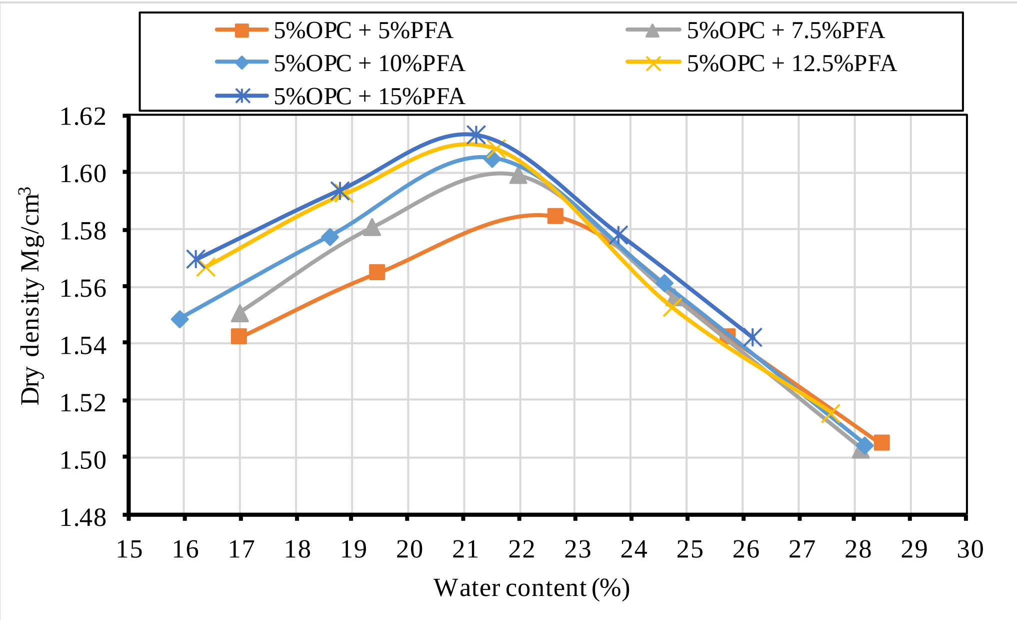

Figure 9. Dry density - Moisture content relationship of the CSS after PFA treatment.

Unconfined Compressive Strength Test (UCS):

The stress-strain diagrams of the CSS with and without PFA treatment for both ages of curing 7 and 28 days are demonstrated in Figure 10. It can be seen that after 7 days of curing all PFA percentages indicated slight increments in the compressive strength of CSS. However, the results of UCS at 7 days showed that 7.5% PFA indicated a higher compressive strength. The specimens tested after 28 days revealed that there was a significant increment in the soil compressive strength in comparison to that for CSS. As shown in Figure 10 – 28 days curing results, the specimens of CSS treated with 10 and 12.5% PFA exhibited similar stress-strain diagrams as well as indicating the higher compressive strength amongst the other samples.

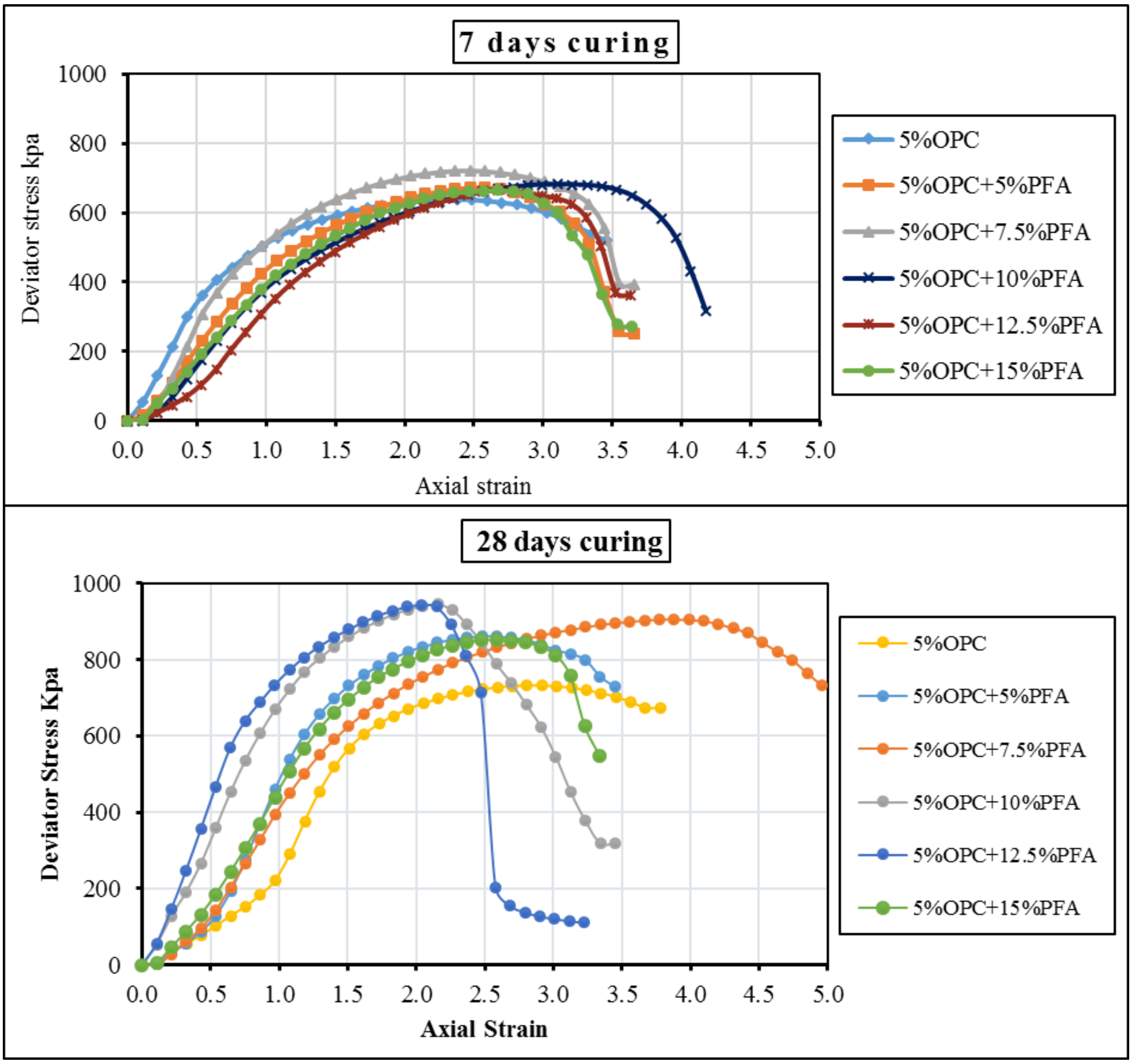

Figure 10. Stress-strain diagrams of the UCS test after PFA treatment.

Figure 11 presents the average maximum compressive strength of the untreated soil, CSS and CSS treated with different percentages of PFA. It can be recognised that CSS treated with 7.5% PFA indicated a higher UCS at 7 days age where the compressive strength increased from 638kPa for CSS to 722kPa, while the other percentages of PFA indicated UCSs akin to each other which ranged between 640 and 680kPa. However, the percentages of the PFA beyond 7.5% indicated higher compressive strengths after 28 days, especially 10% and 12.5% PFA as shown in Figure 11. The specimens of the CSS treated with 10% PFA exhibited the highest compressive strength which was 946kPa while it was 877kPa with the use of 7.5% PFA. Overall, the treatment with the PFA indicated a very advantageous development of the CSS. The increment achieved in the compressive strength after using PFA as a pozzolanic activator can be attributed to the silicates materials provided from the PFA which reacted with cement and led to an increase the formation of the cementitious products which led to the increased compressive strength of the treated soil (Puppala et al., 2015).

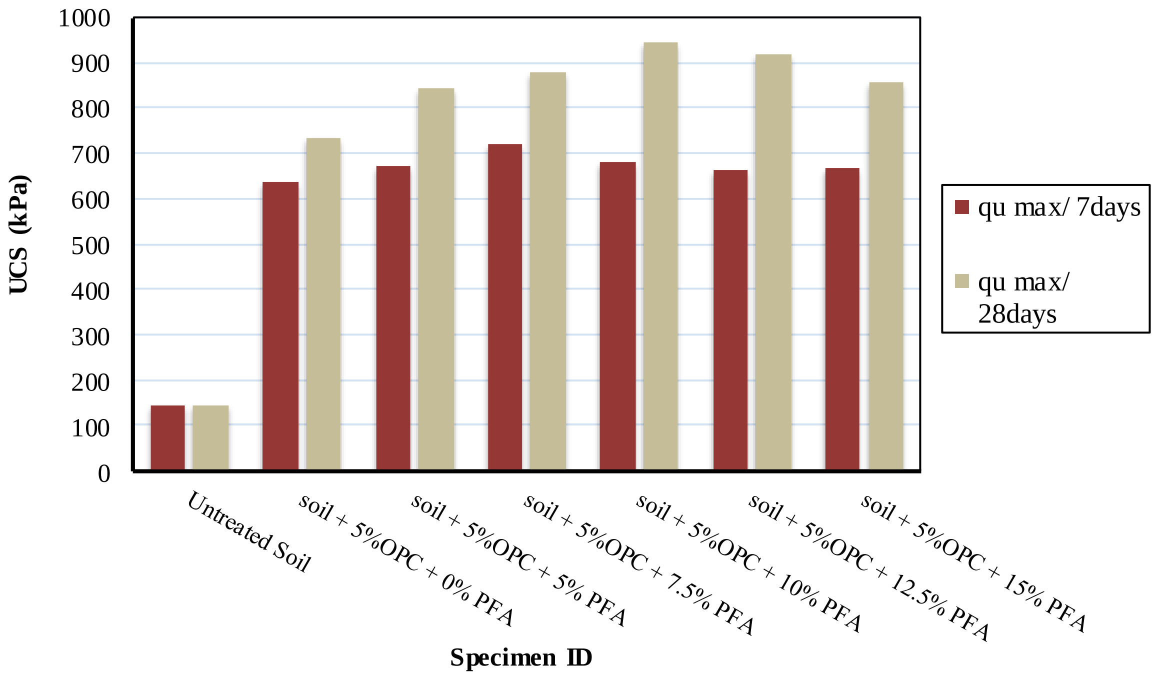

Figure 11. UCS results of the CSS after PFA treatment.

CONCLUSION

In this study, the compressive strength of a 5% cement-stabilised soft soil treated with POFA and PFA was evaluated initially to select one type of fly ash for the pozzolanic activation. The CSS was treated with different percentages of PFA to study the engineering properties of the CSS such as the compaction parameters and consistency limits along with unconfined compressive strength. According to the findings of this study, the following conclusions can be drawn:

- The results of the trial study for the UCS of the CSS treated with 5% of both PFA and POFA indicated that the specimen treated with PFA showed a compressive strength higher than that treated with POFA at 7 days of curing. Therefore, PFA was selected as the pozzolanic activator for further experiments in this study.
- The use of PFA as a pozzolanic activator was found very effective to decrease the plasticity index PI. The results of Atterberg limits tests indicated that, with the use of 12.5% PFA, the PI decreased significantly from 20.3 for the virgin soil to 13.2. This reduction would improve the soil resistance against swelling-shrinkage stresses significantly.
- Regarding the compaction parameters, the results indicated that the MDD increased and OMC decreased with the increase of PFA content in the CSS. This behaviour helps in improving the workability of the soil-binder mixture and contributes to the compressive

strength increasing due to the increase in density.

- PFA treatment was found very useful and effective to increase the UCS of the CSS. The UCS raised from 134kPa for the virgin soil to 732kPa with the use of 5% OPC and 28 days curing. Then UCS was increased significantly to 946kPa with adding 10% PFA to the CSS. This percentage of the PFA indicated the highest results in this study which increased the UCS by 6.8 and 1.25 times of the UCS of the virgin soil and CSS respectively.

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REFERENCES

AÏTCIN, P. C. 2016. Supplementary cementitious materials and blended cements. 53-73.

BRITISH STANDARD 1990a. BS 1377-2, Methods of test for soils for civil engineering purposes - Part 2: Classification tests. london: UK: British Standard Institution.

BRITISH STANDARD 1990b. BS 1377-4, Methods of test for Soils for civil engineering purposes - Part4: Compaction-related tests. London: UK: British Standard institut.

BRITISH STANDARD 1990c. BS 1377-7, Methods of test for Soils for civil engineering purposes - Part 7: Shear strength tests (total stress). London: UK: British Standard istitute

FAROUK, A. & SHAHIEN, M. M. 2013. Ground improvement using soil–cement columns: Experimental investigation. *Alexandria Engineering Journal,* 52**,** 733-740.

GHOSH, A. & SUBBARAO, C. 2007. Strength Characteristics of Class F Fly Ash Modified with Lime and Gypsum. *JOURNAL OF GEOTECHNICAL AND GEOENVIRONMENTAL ENGINEERING,* 7**,** 757 - 766.

JAFER, H. M., ATHERTON, W., RUDDOCK, F. M. & LOFFILL, E. 2016a. The Utilisation of Two Types of Fly Ashes Used as Cement Replacement in Soft Soil Stabilisation. *International Journal of Advanced Structure and Geotechnical Engineering,* 10**,** 896-899.

JAFER, H. M., HASHIM, K. S., ATHERTON, W. & ALATTABI, A. W. 2016b. A Statistical Model for the Geotechnical Parameters of Cement-stabilised Hightown's Soft Soil: A Case Study of Liverpool, UK. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering,* 10**,** 892 - 897.

JAUBERTHIE, R., RENDELL, F., RANGEARD, D. & MOLEZ, L. 2010. Stabilisation of estuarine silt with lime and/or cement. *Applied Clay Science,* 50**,** 395-400.

KOLIAS, S., KASSELOURI-RIGOPOULOU, V. & KARAHALIOS, A. 2005. Stabilisation of clayey soils with high calcium fly ash and cement. *Cement and Concrete Composites,* 27**,** 301-313.

KUMAR, S., KUMAR, R., BANDOPADHYAY, A., ALEX, T. C., RAVI KUMAR, B., DAS, S. K. & MEHROTRA, S. P. 2008. Mechanical activation of granulated blast furnace slag and its effect on the properties and structure of portland slag cement. *Cement and Concrete Composites,* 30**,** 679-685.

MODARRES, A. & NOSOUDY, Y. M. 2015. Clay stabilization using coal waste and lime — Technical and environmental impacts. *Applied Clay Science,* 116-117**,** 281-288.

MUJAH, D., RAHMAN, M. E. & ZAIN, N. H. M. 2015. Performance evaluation of the soft soil reinforced ground palm oil fuel ash layer composite. *Journal of Cleaner Production,* 95**,** 89-100.

PAULO J. VENDA OLIVEIRA, ANTÓNIO A. S. CORREIA & GARCIA, A. M. R. 2012. Effect of Organic Matter Content and Curing Conditions on the Creep Behavior of an Artificially Stabilized Soil. *JOURNAL OF MATERIALS IN CIVIL ENGINEERING,* 24**,** 868–875.

PUPPALA, A. J., PEDARLA, A. & BHEEMASETTI, T. 2015. Soil Modification by Admixtures. 291-309.

TYRER, M. J. 1987. *Stabilisation of Clay Type Soils With Cementitious Material.* PhD, Cleveland University.

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,* 124-125**,** 243-251.

YADU, L. & TRIPATHI, R. K. 2013. STABILIZATION OF SOFT SOIL WITH GRANULATED BLAST FURNACE SLAG AND FLY ASH. *IJRET | FEB,* 2**,** 115 - 119

YI, Y., ZHENG, X., LIU, S. & AL-TABBAA, A. 2015. Comparison of reactive magnesia- and carbide slag-activated ground granulated blastfurnace slag and Portland cement for stabilisation of a natural soil. *Applied Clay Science,* 111**,** 21-26.

ZHAO, J., WANG, D., YAN, P., ZHAO, S. & ZHANG, D. 2016. Particle characteristics and hydration activity of ground granulated blast furnace slag powder containing industrial crude glycerol-based grinding aids. *Construction and Building Materials,* 104**,** 134-141.

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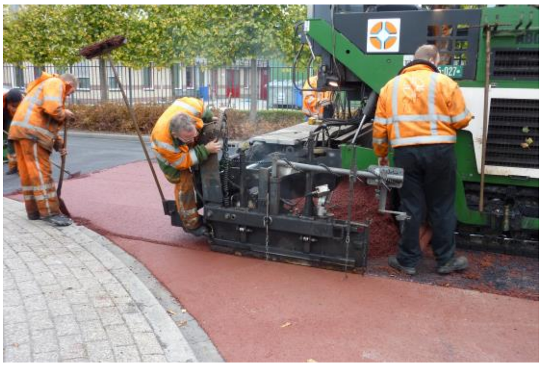

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