PFA-Cement Mixture for Sand Column Parameter Stabilization

S. Shakri, M. A. Hafez and S. Norbaya

Abstract Most of the waste materials produced by construction practice and factories are considered as waste products to be disposed. Disposal of these materials in landfills can inculcating ecological pollution and chemical effects on the environment. Rather than disposing and letting these waste materials unattended, finding a solution or method to recycle these waste materials are better, particularly for Fuel Ash. Therefore, this study was premeditated to investigate the effectiveness of using Pulverized Fuel Ash (PFA) in improving the geotechnical parameters. Shear Box Test and Unconfined Compression Test (UCT) were conducted on this study. Shear Box test was prepared by combining three materials; sand, cement and PFA and 7 days of curing time. The results show the average rate for the treated samples of shear strength increased in the range between 130 and 145 kPa, in parallel with the increase in percentage of sand and PFA. While for UCT test, the samples were prepared based on two different conditions: with and without lime to examine whether it would affect the strength of the cement (Sand-PFA) mixture or by using cement alone to see if it is enough to get the desired results. Samples were prepared by using various percentages of materials and 28 days of curing time. The results show the average rate of Unconfined Compression Strength (UCS) of samples are between 2 and 18 MPa which increases proportionally with increase in percentage of material. Based on data obtained from the experiments, it can be concluded that, the parameters of soil will be treated by increasing the percentage of material used. However, there are limitations on the addition of materials that are used because the graph will begin to show a decline if the percentage increase is added to the mixture exceeds the optimal dose.

Keywords Pulverized fuel ash · Pozzolanic · Ground improvement · Shear box · UCT · Chemical stabilization

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1 Introduction

Sustainable development is an important concept to be considered as a ground improvement method to replace the conventional construction practices, especially in terms of projects that impose massive impact on environment. Since 1980s, any solution introduced for ground improvement method must abide by extremities. Based on Environmental Impact Assessment (EIA), each of project undertaken should investigate the possible negative effects of a man-made structure on surrounding environment with regards to the biosphere elements. EIA might prohibit use of certain technologies and solutions to mitigate the probability of anticipated excessive noise, vibration, remolding the ground, ground water contamination and compromising available resources of material in vicinity of site. Therefore, the planning and the use of environmentally friendly methods is very important in construction practises. When considering the eco-friendly methods, materials to be used are also included in the judgment and it is a profitable bonus if the materials used are the materials from the waste disposal such as fly ashes.

In order to achieve this, one of the easiest scheme would be to salvage the way advances in reduction and saving resources is to replace the new material rather than conventional sources of construction materials. Prabakar and Dendorkar [1] reported that fly ash can be successfully used to improve the geotechnical parameters such as bearing capacity and shear strength. Guleria and Dutta [2] have been conducting research on the impact of tire chips mixed with lime, gypsum, and fly ash composites for quantification of unconfined compressive strength. Research has found that the use of the mixture can increase the potential for implementation of road sub-base medium with light traffic. Najim and Hall [3] have shown through their research, the use of pulverized fuel ash (PFA) can improve the bearing capacity and at the same time solve the problems of settlement under the road embankment clay. Most of the materials mentioned above are considered as waste products to be disposed. Disposal of these materials in landfills can deduce ecological pollution as inclusion chemistry and top of it, it becomes worst if the wastes are harmful to the environment and human health.

2 Ground Improvement and Process of Pozzolanic

Method of ground improvement has been practiced since many decades before, reported by McDowell [4] the ancient Egyptians and Mesopotamians had created and applied the stabilization methods for ground modification works to stabilize the earth roads works by increasing some of soil properties. In 1906, USA introduced the first experiment on stabilization work by studying the strength and weakness of admixing sand and clay [5], and in 1980 and 1982, the first experiment on case of deep soil stabilization was successfully reported and executed in practice by using cement powder and method adopted and this method was known as DJM (Dry Jet Mixing) method [6].

Cement and lime are the common materials that have been used as a binder under chemical stabilization to stabilize and remediate soft soil. Based on previous study, between 1 and 3 % of lime and cement is needed for stabilization process and 2–10 % for cementation process [7], and according to [8] the amount of cement between 4.5 and 5.6 % and lime between 4.5 and 6.8 % of dry soil weight are recommended among these binders as appropriate mix design to increase the UCS of remediated column. However, this percentage ratio used can be less or more based on type of soil, water ratio, chemical effect due to the material used and method of preparation.

Chemical stabilization is referred to procedures, in which chemical additives are mixed with soil to enhance a number of geotechnical characteristics such as axial and shear strength, axial and radial strains, and permeability indexes. Different chemical procedures are involved in improvement of chemical stabilization techniques including surface ion exchange of clay particle or chemical reactions to strengthen the bonding of soil elements or filling the voids with expansive nature of admixed materials [9]. Pozzolanic reaction is a process that will increase the strength and durability of the soil. Actual impact will depend on several factors such as; characteristic of stabilizing agent, characteristic and condition of soil, mixing condition and curing condition. Following are the chemical reactions under pozzolanic reaction.

$$Ca(OH)_2 + SiO_2 = CSH \tag{1}$$

$$Ca(OH)_2 + Al_2O_3 = CAH \tag{2}$$

The higher the ratio of Al, Si and Ca, the pozzolanic process will be smooth and will stabilize the soil. In addition, pozzolanic reaction also reacts with the temperature where, high temperature and fast cooling greatly affects the best material to be installed as a stabilizer to give a round shape and the nature of the particles are amphioxus.

3 Experimental Investigation

3.1 Material Used

Pulverized fuel ash (PFA), cement, lime, sand and natural soft soil were used for the experimental investigations. PFA is a solid waste from the combustion of coal with a high temperature (about 1,000 °C) in coal based power stations coal. For this study, the source of the PFA have been taken from Power-plant Stesen of Sultan Salahuddin Abdul Aziz at Kapar Selangor Malaysia. This stesen is one of the power plant under the purview of TNB Malaysia Bhd. Portland cement has

Table 1 Chemical composition of PFA, cement and lime

Component	PFA (%)	Cement (%)	Lime (PFA)
Silica (SiO_2)	40–60	20.65	12.25
Alumina (Al_3O_3)	20–30	5.87	7.78
Iron oxide (Fe_2O_3)	4–10	2.52	3.82
Calcium oxide (CaO)	5–30	63.55	69.67
Magnesium oxide (MgO)	1–6	2.75	0.88
Sulphur trioxide (SO_3)	0–2	1.63	2.77
Sodium oxide (Na_2O)	0–2	0.85	0.12
Potassium oxide (K_2O)	0–4	0.63	0.79
Loss on ignition (LOI)	0–3	1.54	1.95

Table 2 Properties of natural soft soil

Properties	Ratio
Moisture content, w_c (%)	58–60
Plastic limit, w_p (%)	30.83
Liquid limit, w_l (%)	50.52
Plastic index, Ip (%)	19.69
Parti cal density (Mg/m^3)	2.23

been used as a type of cement based on the availability of this product and according to [10] this type of cement has an ideal ratio of material properties needed for this study. Sand particles passing through 4.75 mm sieve were used to mixed with other materials. The moisture content of sand used are ranged between 5.28 and 6.7 % when it is in a natural state. The particle density of sand has been obtained and recorded as 2.45 Mg/m^3. Thus, the soil classification of sand used is Well Graded SAND. For type of lime, natural hydraulic lime was used in this study. It has been chosen due to it clay contents in the range of 10–20 % and providing flexibility on mixture and pozzolanic reaction. Summary of the chemical composition of PFA, cement and lime have been presented in Table 1. While for natural soft soil, it has been prepared as second layer for shear box test. It has been used to study the effects between sample of mixture with natural of soil. Table 2 shows the properties of soft soil used in this study.

3.2 Preparation of Shear Box Test

Shear box or direct shear box tests were performed on various mixture of samples in general accordance with [11] standard test method for direct shear tests of soils under consolidated drained conditions. According to ASTM D 3080-90, the direct shear box test has several particle-size to box size requirements when preparing specimens for testing. It is recommended that the minimum specimen width should not be less than ten times the maximum particle-size diameter and the minimum initial specimen thickness should not be less than six times the maximum particle diameter. Therefore, a 60 × 60 mm size of shear box test was used for this experiment. Samples were prepared differently by using various percentage of PFA, cement and sand. 40, 50, 60, 70 and 80 % of PFA were used while for cement 4, 8, 12 and 16 % were used. As for the sand, percentage is added to each mixture through make up of 100 % mixture of calculation, for example with 4 % of cement mixed with 40 % PFA bringing the total was 44 %, so over 56 % of the mixture is from sand. After the samples were prepared, it will be cured based on 7 days curing time period before be tested with natural soft soil collected from site.

3.3 Preparation of Unconfined Compression Test

Unconfined Compression Test (UCT) is used to mesure the unconfined compressive strength of the sample. The test was performed on various mixture of samples in general accordance with [11]. The cylinder samples with 100 mm high and 50 mm diameter were prepared differently by using various percentage of PFA, cement, lime and sand. 40, 50, 60, 70 and 80 % of PFA were used while for cement, 4, 8, 12 and 16 % of ratio have been designed. Sample for cement-lime have been prepared for comparative purposes which the ratio of 15 and 20 % were prepared and mix with sand. Similar to shear box test, the percentage of sand is added to each mixture to make up 100 % of mixture for calculation. For example with 15 % of cement/cement-lime mixed with 30 % PFA bringing the total was 45 %, so over 55 % of the mixture is from sand. After the samples were prepared, it will be cured based on 28 days curing time period before be tested.

4 Result and Discussion

The raw data were obtained from the laboratory experiments have been analyzed and conclusion has been made by referring to the method and previous theories. Results obtained have been presented in the form of graph to make it easier to be understood (Figs. 1, 2, 3 and 4).

4.1 Friction Angle Characteristic

Figures 5, 6, 7 and 8 show the shear strength characteristics of the modified samples by cement and sand improved by PFA with using various configuration. Figure 5 shows the characteristics of shear strength based on 4 % of cement and mixed by various percentage of PFA and Sand. Result showed readings for shear strength will increase parallel with rising percentage of PFA where the highest

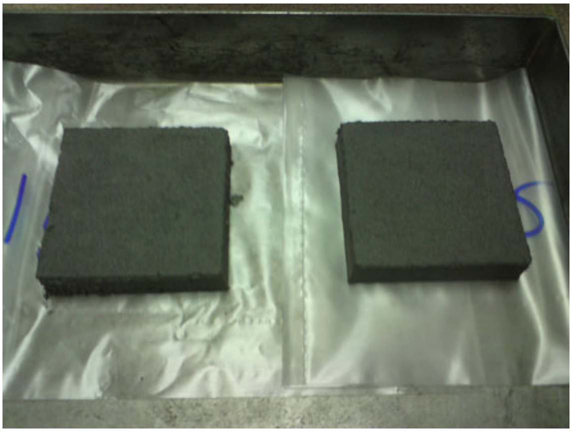


Fig. 1 Preparation of sample for shear box test

Fig. 2 Shear box test

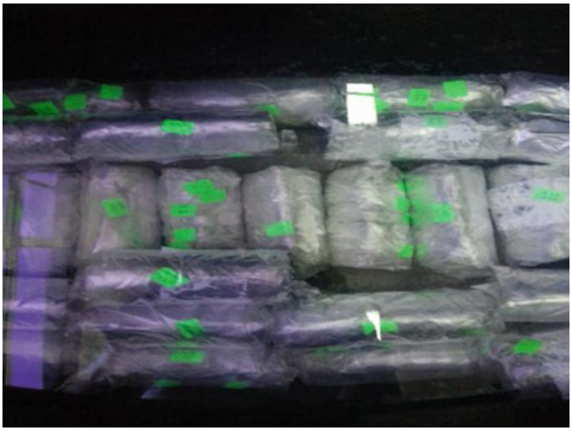


Fig. 3 Process of curing sample

Fig. 4 Sample after curing process

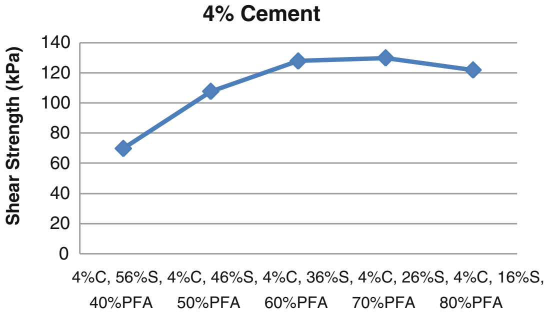


Fig. 5 Shear strength of various configuration of sand and PFA with 4 % cement

value were recorded when PFA used was 70 %, shear strength was recorded at 129.89 kPa. However, as percentage of PFA continues to increase exceed 70 %, shear strength reduced to 121.89 kPa.

In Fig. 6, percentage of cement used is 8 % and the highest value for the shear strength was recorded at 141.73 kPa, which is the percent utilization of 50 % PFA. But however when percentage of PFA exceed 5 %, the values of shear strength decreased and recorded at 106.1 kPa when percentage of PFA is 80 %. As happen in Figs. 5, 6 and 7 graph showing equation in the form of graph movement parallel with the percentage of PFA used. In Fig. 7, percentage of cement used was 12 % and it recorded the highest of shear strength at 135.88 kPa which is percentage of PFA used was 60 % and when exceed to 60 %, shear strength reduced and recorded at 126.23 kPa where percentage used of PFA was 80 %. Figure 8 also shows the same results. The highest value of shear strength recorded at 131.26 kPa where the percentage use of PFA was 60 % and reduced to 123.27 kPa when percentage of PFA used was 80 %.

Figure 9 shows the overall results of the graph to the shear strength of the sample with cement consumption is from 4 to 8 % and the use of PFA in turn is from 40 to 80 %. Apparent by observation of the formation of the pattern graph shows the use of PFA has optimum level. The addition of PFA as one of material in increasing the strength of the sample is the right choice, but it has its limit level

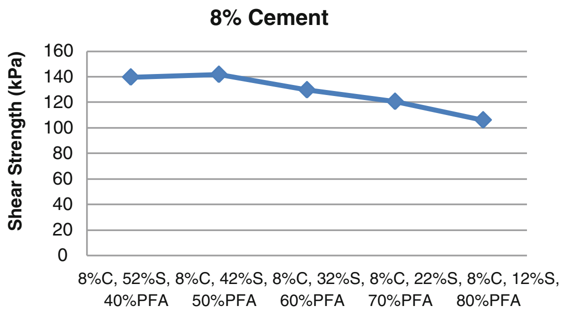


Fig. 6 Shear strength of various configuration of sand and PFA with 8 % cement

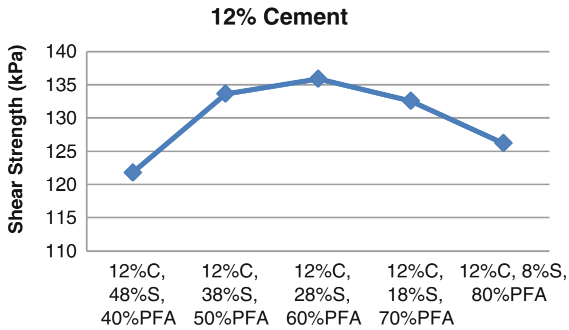


Fig. 7 Shear strength of various configuration of sand and PFA with 12 % cement

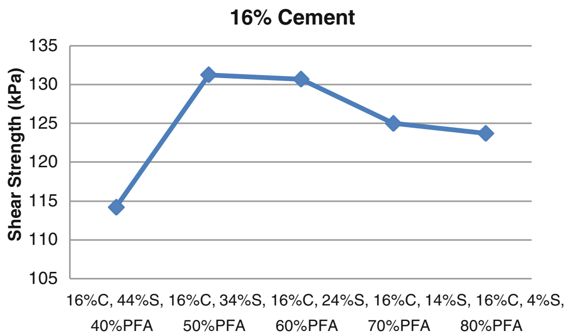


Fig. 8 Shear strength of various configuration of sand and PFA with 16 % cement

which if exceeded the limit, the decrease in shear strength of the sample will be recorded.

The same goes to the use of cement in which the use of high percentage of cement is not the right choice to increase the shear strength of the material because shear strength is related to friction of material where the whole mixture is important and optimal utilization percentage of each material is important to get the optimum shear strength.

Figure 10 shows the summary results of the highest shear strength of the cement consumption by 4, 8, 12 and 16 %. Through observation of the graph in

Fig. 9 Summary of graph of shear strength with various configuration of PFA and cement

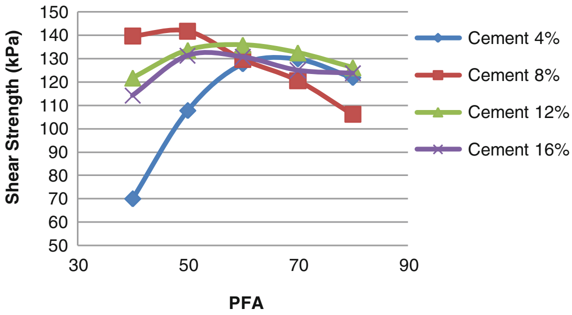


Fig. 10 Summary of the highest of shear strength recorded for different configuration of PFA and cement

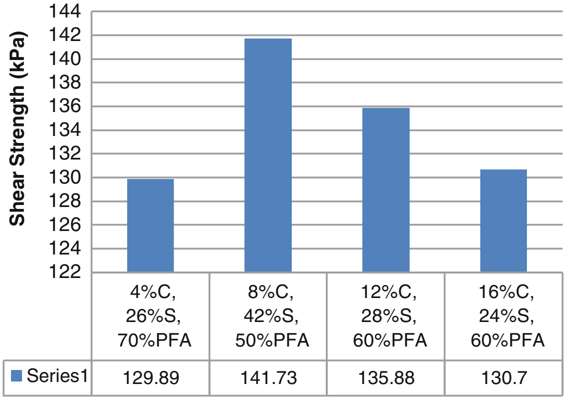


Fig. 10, the results show the percentage optimal use of PFA is between 50 and 60 % and the percentage of cement consumption is between 8 and 12 %.

4.2 *Unconfined Compression Strength Characteristic*

For most blended mixtures, the gain in strength beyond 28 days is not significant. Increasing the PFA content from 40 to 80 % further increases the uniaxial strength of the treated soil for a varied cement content of 4–16 %. When PFA is mixed with cement, the consequential increase in strength is quite striking, which reflects the self-hardening nature of cement. Figure 11 shows a pattern of formation graph of UCS of various configuration of PFA with 4, 8, 12 and 16 % cement. By observation of the graph in Fig. 11, can be expressed in the early stages of use percentage PFA is low between 40 and 50 %, cementing the specimen suffered less effective due to the increase in coarse nature, thus revealing the low early strength due to tensile cracking when uniaxial loading. This is attributed to the premature failure of these specimens due to splitting of ends and spalling of the surface

Fig. 11 UCS of various configuration of PFA with 4, 8, 12 and 16 % cement

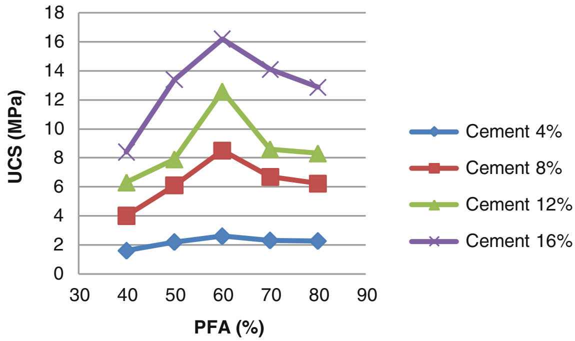
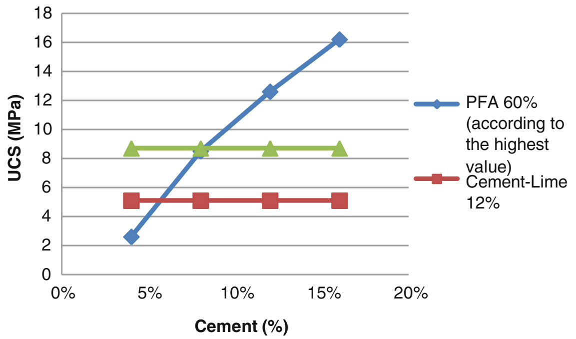


Fig. 12 Comparison of UCS of 60 % PFA used with 15 and 20 % lime-cement



probably caused by a reduction in overall effective stress cohesion; hence strength as a result of high sand-PFA content. The samples with sand-PFA lesser than 50 % developed higher shear failure and did not show premature tensile splitting and surface instability modes. In addition, after 28 days of curing, pozzolanic reactivity and cementation caused considerable improvement in their uniaxial compressive strength.

Through the graph in Fig. 11 also indicated that the pattern formation of graph is same as the graph to the formation of shear box test. Where there is an optimal level of PFA mixture within 60 %, where in the first period before the graph shows an increase in the strength of the material will then fall upon exceed the optimum level. However, the formation of cement graph is different from the formation of the PFA graph. Extension of the cement will have increased strength in parallel, Thus proves that cement is a material that is suitable for increasing the strength of the other materials. It can be concluded that no optimal level for cement due to increased percentage of cement used, but keep in mind one of the purposes of this experiment is to find the total cement consumption percentage appropriate to help raise the strength of the material and at the same time reduce the cost of substance use.

Through the graph in Fig. 12 shows the comparison of UCS with 60 % of PFA used with 15 and 20 % lime-cement. Through observation can be expressed increasing percentage of cement is one of the causes of the increasing strength of the material. In the comparison between the use of PFA-cement and lime-cement, PFA-cement consumption is more relevan than lime-cement consumption. The graph shows the use of 7 % cement and 60 % PFA are sufficient to obtain the same strength through the use of 15 % lime-cement and better than the use of 12 % lime-cement. This happens because the pozzolanic bond formation in PFA-cement mixture is more accurate than the lime-cement and this is because PFA contents higher silica and alumina compare with lime. Indeed lime has a high calcium content compared with PFA, but when lime mixed with cement, pozzolanic bond becomes less accurate due to lack of silica and alumina content and have excessive calcium content as cement itself already has a high calcium content but lack in silica and alumina content and need to be reminded pozzolanic process is the process by which the contents of calcium, silica and alumina are required evenly for the best bond. Unlike the bond for the PFA-cement mixture, although PFA containing low calcium content but higher silica and alumina, and cement even containing low silica and alumina but higher calcium and when these materials are mixed, the resulting strong bond through the contents of equal calcium, silica and alumina.

5 Conclusion and Recommendation

In this research, a series of shear box and unconfined compression tests were conducted to measure shear strength and strength (UCS) that a mixture of PFA-Cement-Sand medium, with different content of each material, can provide for further application especially the ones that are in the field of ground improvement techniques, i.e.; sand columns, DDM and embankments leveling. After the tests, it has been observed that, PFA which is a waste-by product of power plants, can be significantly associated with the increase of shear strength and UCS in this mixture, however there is a limitation for adding PFA since excessive amount of this material will generate an acidic environment which delay the formation of cementitious gels. Initial moisture content has also an important impact on the final shear strength and UCS, as if it is in the range of OMC, then the specimen were found to be higher in strength than those which were not.

Based on result from shear box test, it can be seen that the formation of graph is such as mohr-circle form in which the graph is moving upward in conjunction with additional ingredients are added to produce an increase in the shear strength. But when it reaches the optimum level, it began to decline even if the percentage of material is further increased and this is due to the strength of the friction and angle of friction is no longer manipulated by the quantity of material, but other factors may be sought through further study. From the graph, it can be concluded, the quantity of sand is not the main factor though of course the strength of the friction force is coming from the sand but it also requires a well-balanced composition with the addition of other substances, especially PFA and cement that can be formulated is a substance that also play a role major in increasing the friction force.

For UCT, after 28 days of curing, unconfined compression test of stabilized columns that contained 60 % PFA with 16 % cement gives the highest strength compared to PFA less than 60 % and exceed 60 %. Excessive sand-PFA content in stabilized columns could cause premature failure such as splitting of ends of the specimen and spalling of the surface. The discrepancy between soils with added cement and soils with added lime-cement is large.

However, the findings of the present experimental study are affected by various factors such as, effect of natural soil used for shear box test because it has been collected from site and impossible to be collected from an isotropic sample. Dimension of sample, where sample are prepared based on same mould however, during curing time it has been removed from mould and it is impossible to avoid the changes of size even 1 mm^2, curing time of preparation of sample etc. Thus, more tests with various material, sample, configuration etc. have to be conducted to make general conclusions.

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