STUDY ON UNCONFINED COMPRESSIVE STRENGTH AND UNDRAINED SHEAR STRENGTH OF PFA-CEMENT-SAND MIXTURE VARIOUS CURING PERIODS

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ABSTRACT: *The effect of shear box size on the study of the shear strength characteristic is widely researched by many. Based on findings from a previous journal paper on* ***the Effects of Shear Box Size on Shear Strength between Modified Sand-Column (PFA-Sand Mixture) and Soft soil****, this research continues to study the comparison of unconfined compressive strength (q_u) and undrained shear strength (C_u) for PFA-Sand Mixture. An unconfined compressive test has been conducted since it is inexpensive and less time-consuming to determine q_u of the soil. This test can also be used to indirectly determine c_u since they are directly proportional to each other. Specimens were prepared differently by using a variable percentage of PFA, cement, and sand. For PFA, 40%, 50%, 60%, 70 %, and 80% were used while for cement, 4%, 8%, 12%, and 16% were used. As for the sand, a certain percentage is added to each mixture through the make-up of a 100% mixture of calculation. For example, 4% of cement is mixed with 40% PFA, bringing the total to 44%, so over 56% of the mixture is sand. After the specimen is prepared, it will be cured based on seven days, 14 days, 28 days, and 56 days of curing time before it has been tested. The results have shown the same as shear strength, which q_u and C_u will be increased in parallel with an increase in the percentage of PFA.*

Keywords: POFA, Compaction, Modified Sand-Column, Unconfined Compressive Strength, Undrained Shear Strength

1. INTRODUCTION

In geotechnical engineering, the knowledge and understanding of applied mechanics are essential to solve the possible geotechnical problem related to the mechanical properties of soil. Soil is a very subjective material as it can experience consequential displacement, deformation, and movement resulting from changes in loading. Based on [1, 2] it is reported that the stress-strain relationship can explain the behavior of soils. Each type of soil might exhibit several stress-stain where unconfined compressive strength is one of the valuable properties in estimating the strength of the soil. The unconfined compressive test is inexpensive and less time-consuming to determine the unconfined compressive strength (q_u) on the soil. This test can also be used to indirectly determine the undrained shear strength (c_u) since they are directly proportional to each other.

This test is suitable for fine, cohesive soil that has enough cohesion properties to allow the sample to be tested under unconfined conditions and rocks [3,4]. This is because this material cannot be maintained in shape, nor can it be molded without proper confinement. In this study, the PFA-cement-sand mixture was tested. This mixture has good cohesion properties and can be shaped and molded because the effects of cement and PFA used will cause the pozzolanic reaction in the mixture [5].

TABLE 1: CHEMICAL COMPOSITION OF PFA

Composition	Percentage, %
Silicon Dioxide, SiO_2	52.35
Aluminium Oxide, Al_2O_3	6.27
Iron Oxide, Fe_2O_3	11.72
Calcium Oxide, CaO	11.72
Sulfur Trioxide, SO_3	1.50
Potassium Oxide, K_2O	15.72
Manganese Oxide, MnO	0.11
Loss on ignition	10.1

2. SAMPLE PREPARATION AND EXPERIMENTAL DETAILS

Pulverized Fuel Ash (PFA) is a solid waste from the combustion of coal at a high temperature (about 10000 ^{0}C) in coal-based power stations. For this study, the source of the PFA has been taken from the power-plant station of Sultan Salahuddin Abdul Aziz at Kapar Selangor, Malaysia. Portland cement has been used as a type of cement based on the availability of this product, and according to [6], this type of cement has an ideal ratio of material properties needed. Sand particles passing through a 4.75 mm sieve were used to mix with other materials. The moisture content of the sand used ranges between 5.28% and 6.7% when it is in its natural state. The particle density of sand has been obtained and recorded as 2.45 Mg/m3. Thus, the soil classification of the sand used is ‘Well Graded Sand’. A summary of the chemical composition of PFA and cement has been presented in Table 1, and Table 2 shows the properties of the sand used in this study.

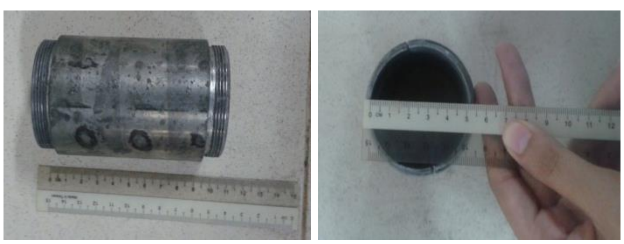
TABLE 2: PROPERTIES OF SAND

Properties	Value
Moisture content, w (%)	5.28 – 6.70
Particle density, ρ_s (Mg/m^3)	2.55
Soil Classification	Well Graded SAND

In this study, it has been decided to prepare a cylinder specimen with a diameter of 50 mm and a height of 100 mm. The specimen is prepared using a mold of the same size as shown in figure (1). Samples of PFA, cement, and sand are weighed based on design proportions which are summarised in Table 3.

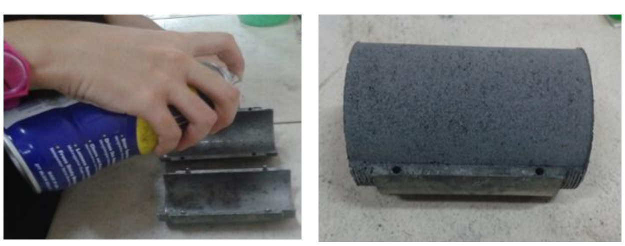
TABLE 3: PROPORTION OF CEMENT, PFA, AND SAND (BASED ON WEIGHT)

No	Cement (%)	PFA (%)	Sand (%)
1	4	40	56
2		50	46
3		60	36
4		70	26
5		80	16
6	8	40	52
7		50	42
8		60	32
9		70	22
10		80	12
11	12	40	48
12		50	38
13		60	28
14		70	18
15		80	8
16	16	40	44
17		50	34
18		60	24
19		70	14
20		80	4



(a) (b)

Fig(1) (a) Cylinder mold of 100 mm height. (b) Cylinder mold of 50 mm diameter.

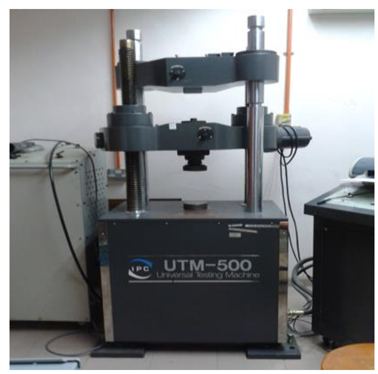


(a) (b)

Fig(2) (a) Cylinder mold of 100 mm height. (b) Cylinder mold of 50 mm diameter.

After mixing the materials, a sample of the mixture will be placed in the mold. Compaction will be applied with the desired pressure as long as the soil does not flow out of the mold. To ensure the remolded sample is extruded, the inner mold should be applied with oil as a lubricant, as shown in figure (2). The sample will be taken out of the mold, and it will be wrapped in plastic in order to preserve the moisture content of the sample.

After completing the curing process, an Unconfined Compression Test (UCT) is conducted by using a universal testing machine, as shown in figure (3). Information such as the dimension of the sample, percentage of breaks detected, material, and the number of samples should be specified and recorded accordingly. Before placing the specimen on the loading plane, recalibrate the machine body back to its original position to avoid an inaccurate reading during the application of axial load. The sample is then placed on the machine with a clean surface on both the top and bottom of the sample to ensure a smooth load application. Before starting, axial load (kN) and extension (mm) will be set at zero before the test is started. During the test conducted, the axial load is applied consistently to the sample with guidelines of the strain rate at 0.5% to 2% per minute. The load is applied until the sample meets its failure point, which is when the load applied starts to reduce and a crack appears on the sample. Figure (4) shows the sample after the test.



Fig(3) (a) Universal testing machine UTM-500 for UCT

(a) (b)

Fig(4) (a) Plane failure that can be observed after the UCS test. (b) Budging failure

The data from the Unconfined Compression Test will be used to plot a graph to determine the q_u, which can be obtained by referring to the maximum value on the graph, which q_u is calculated based on Equation 1.

$$q_u = \Delta\sigma\ [1-\Delta H/H] \qquad \text{Equation 1}$$

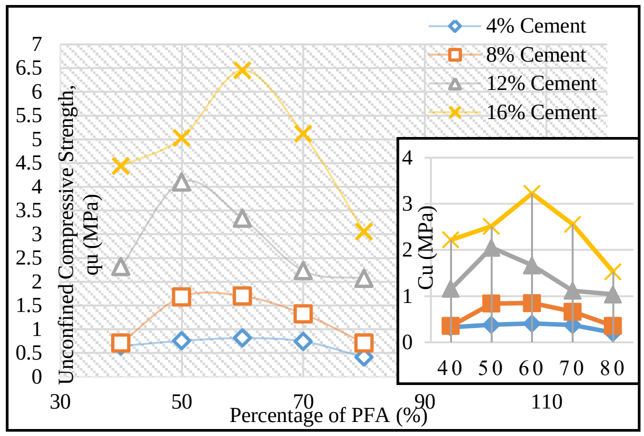
where;
qu is the unconfined compressive strength
Δσ is the maximum/peak stress applied
[1-ΔH/H] is the correction for unconfined compressive stress with:
ΔH is the displacement of the sample
H is the initial high of the sample

For correction calculating, ΔH is considered as 1.0 mm as an average for all samples since the range of displacement recorded for all samples is around 1.0 mm. c_u is also calculated based on the UCT test, in which c_u is half of the unconfined compressive strength based on Morh's circle theory.

3. RESULTS AND DISCUSSION

3.1 Comparison of Unconfined Compressive Strength (q_u) and Undrained Shear Strength (C_u) Based on Different Curing Time

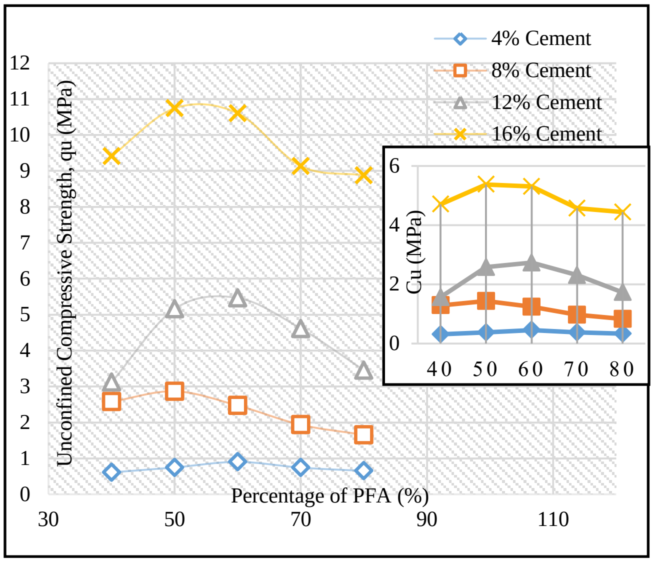
Through the graph in figures (5) to (8), it is evident that the pattern formation of the graph for unconfined compressive strength (q_u) is the same as the graph for shear strength (shear box test), where there is an optimum percentage of PFA and sand to gain maximum strength. Figures (5) to (8) show that using PFA between 50% to 70% will achieve the maximum strength. While for sand, the percentage to achieve maximum strength is in the range of 40% to 50%. Figure (5) shows a comparison of q_u and c_u based on various percentages of cement, PFA, and sand used with seven days of curing time. The graph shows that; the maximum strength was obtained when the percentage of PFA used was between 50% to 60%, with the percentage of sand being between 30% to 50% for all the percentages of cement used. Figure (5) also shows a significant difference in cement percentage increases of 8%, 12%, and 16%. This is because, based on Chin (2002), when the percentage of cement needed is above 8%, that is, 8% of cement, the mixture starts to have a good pozzolanic reaction. While for the hardening process, 12% of cement is needed. Therefore, as shown in the graph, there was a gap because of these processes, which means, above 8% cement used, the process of better pozzolanic will have occurred while above 12% hardening process will take place. That is why there is a big gap between 8% cement used and 12% cement used and 16% cement used. This pattern is also shown in Figures (6) to (8), where there is a big gap between 8%, 12%, and 16% of the cement used. This proves the percentage of cement. This proves that by increasing in percentage of cement, q_u and c_u will also increase, which proves that cement is a binder that is suitable for increasing the strength of the mixture. It can be concluded that there is no optimal level for cement due to increased. However, the purposes of this experiment are to find the total cement consumption percentage that is appropriate to help raise the strength of the material and, at the same time, reduce the cost of substance use. Therefore, using a high percentage of cement does not help in this study. Based on figures (5) to (8), the graph is formed in half-circle form, with a different percentage of cement used and curing time where the graph is moving upward in conjunction with additional binders added to produce an increase in the q_u and c_u. But when it reaches the optimum level, it begins to decline even if the percentage of PFA is further increased, and this is due to the effect of decreasing the percentage of sand used.

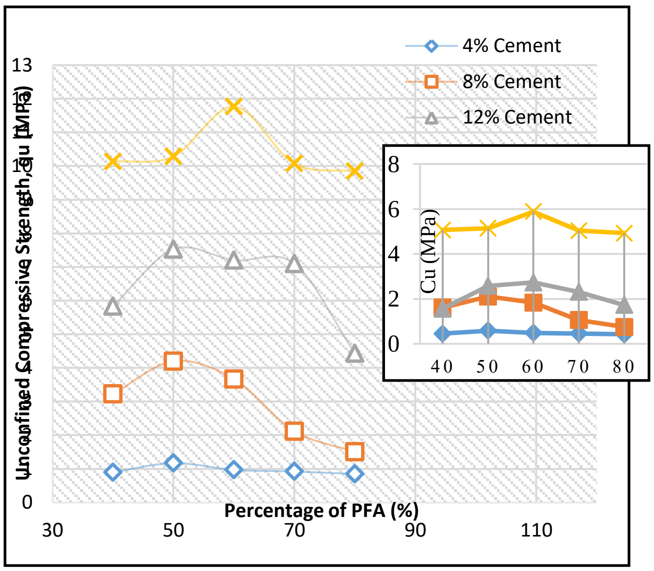


Fig(5) Summary of unconfined compressive strength (q_u) and undrained shear strength (c_u) for PFA-cement-sand mixture after seven days of curing time

This can be concluded that q_u and c_u will keep increasing by increasing of cement percentage. However, one of the purposes of this study is to decrease the cost; increasing the percentage of cement is not a good solution. While for the percentage of PFA and sand, in the calculation, in order to get a total of 100% used, the optimum percentage to get maximum q_u and c_u need to be determined. Therefore, through the Unconfined Compression Test (UCT), the optimum percentage for both materials that can get maximum q_u and c_u are around 50% to 70% for PFA and 30% to 50% for sand. This result is almost the same as the shear box test, in which maximum shear strength is obtained when the percentages of PFA and sand used for the shear box test are between 50% and 60% for PFA and between 40% and 50% for sand.

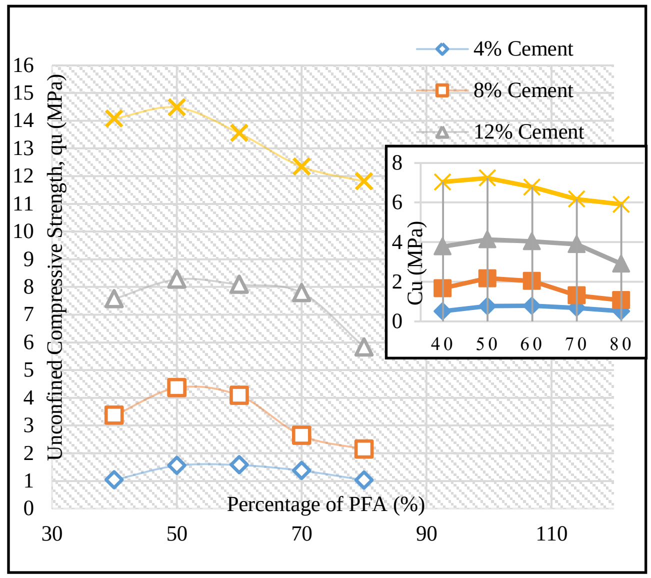
Continued from the previous journal paper on *the Effects of Shear Box Size on Shear Strength between Modified Sand-Column (PFA-Sand Mixture) and Soft Soil*, Table 4 is prepared based on a summary of results from both tests; Shear Box Test (SSB and BSB) and Unconfined Compression Test (UCT) based on a 28-day curing period.





3.2 Summary of Preliminary Study On PFA-Cement-Sand Mixture and Ratio of Materials Suggested for PFA-Cement-Sand Column

Based on Table 4, 6 configurations have been chosen 8% cement-50% PFA-42% sand (8C-50PFA-42S), 8% cement-60% PFA-32% sand (8C-60PFA-32S), 8% cement-80% PFA-12% sand (8C-80PFA-12S), 12% cement-50% PFA-38% sand (12C-50PFA-38S), 12% cement-60% PFA-28% sand (12C-60PFA-28S) and 12% cement-80% PFA-8% sand (12C-80PFA-8S). These configurations are chosen due to the high shear strength parameters provided based on 28 days curing period. The shear strength was also calculated to double confirm which 70 kPa of normal stress is used to calculate the shear strength for both small shear box (SSB) and big shear box (BSB), and as concluded in the previous journal, the range of cement between 8% to 12% are and PFA between 50% to 60% giving the highest value of shear strength. Therefore, these configurations are selected. The ACT test is also conducted, which other than external strength (shear strength) internal strength also needs to be calculated and compared before can decide the configuration is used for the modified column.



4. CONCLUSIONS

According to the UCT test results, increasing cement increases both unconfined compressive strength and undrained shear strength. Therefore, the percentage of cement is not an issue. However, due to cost and based on the study by Chin (2002), 8% of cement is enough for pozzolanic reaction, and for hardening, 12% of the cement is used, and because of that, 8% and 12% of cement are selected. While for PFA and sand, a range of 50% to 70% PFA and 30% to 50% and will provide good results. Therefore, based on the shear box and UCT test, (8C-50PFA-42S), (8C-60PFA-32S), (12C-50PFA-38S), and (12C-60PFA-28S) are suggested for modified PFA-Cement Sand Column since these four configurations are in the range that will provide good shear strength and unconfined compressive strength and also in cost.

TABLE4: SUMMARY OF RESULTS FROM SHEAR BOX TEST (SSB AND BSB) AND UNCONFINED COMPRESSION TEST (UCT) BASED ON 28 DAYS CURING PERIOD

Cement (%)	PFA (%)	Sand (%)	SBS			BSB			UCS	
			c' (kPa)	δ' (Deg)	τ (kPa)	c' (kPa)	δ' (Deg)	τ (kPa)	c_u Mpa	q_u Mpa
4	40	56	7	44.27	75.25	7.22	43.68	74.07	0.449	0.897
	50	46	8.3	45.40	79.28	8.4	45.51	79.66	0.585	1.169
	60	36	7.8	45.45	78.92	7.76	45.57	79.16	0.485	0.969
	70	26	7.5	43.23	73.3	7.7	43.41	73.92	0.46	0.92
	80	16	3.4	45.06	73.54	3.59	45.23	74.15	0.423	0.846
8	40	52	17	43.74	83.99	17.39	43.92	84.8	1.611	3.222
	50	42	23.3	43.74	93.51	23.5	43.92	93.57	2.1	4.2
	60	32	22.9	45.09	88.91	21.85	45.03	88.77	1.833	3.666
	70	22	21.55	42.89	86.58	20	43.74	86.99	1.059	2.118
	80	12	15.25	44.39	83.78	15.45	44.57	84.4	0.752	1.504
12	40	48	10.5	45.14	80.85	10.38	45.31	81.15	2.916	5.831
	50	38	19.75	46.15	92.62	20.1	45.40	91.08	3.762	7.524
	60	28	18.0	45.31	90.10	18.15	45.31	88.92	3.6	7.2
	70	18	10.5	48.01	88.27	11.45	48.04	89.29	3.548	7.096
	80	8	8	46.64	82.13	8.8	46.88	83.56	2.218	4.436
16	40	44	7.65	46.64	81.78	8.78	46.51	82.56	5.066	10.132
	50	34	14	46.40	87.5	14.99	46.20	87.98	5.143	10.285
	60	24	13.5	45.20	83.99	14.5	45.20	84.99	5.885	11.769
	70	14	12	44.19	80.04	11.6	44.36	80.06	5.038	10.076
	80	4	8.5	43.89	75.84	8.6	43.89	75.94	4.922	9.843

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