ZIBELINE INTERNATIONAL PUBLISHING

Engineering Heritage Journal (GWK)

DOI: http://doi.org/10.26480/gwk.01.2020.04.07

SSN: 2521-0904 (Print)
ISSN: 2521-0440 (Online)
CODEN: EHJNA9

CrossMark

RESEARCH ARTICLE

LIGHTWEIGHT SLAG, PFA COLUMN A NEW SOFT GROUND IMPROVEMENT METHOD

Hafez, M. A[a]., Sidek, H.N[b], Moustafa Z. Ibrahim[c], Almkahal, Z.[d]*

[a]Department of Civil Engineering, Universiti Uniten, Malaysia,
[b]Faculty of Civil Engineering, University of Technology MARA, Malaysia,
[c]Faculty of Civil Engineering, Alexandria University- Egypt,
[d]Department of Civil Engineering, Universiti Uniten, Malaysia,
****Corresponding Author Email: zaher.almkahal@gmail.com***

ARTICLE DETAILS

Article History:

Received 01 April 2020
Accepted 03 May 2020
Available online 20 May 2020

ABSTRACT

This study investigates how to reduce the demand on in non-renewable granite source, by replacing granite aggregate with boiler slag in the stone column. It is a fact that boiler slag is a power station waste material which causes too many environmental problems. By introducing it as a ground improvement technique, we can reduce the bulging and shear failure problems encountered on stone columns application by adding more improvement to the stone column mixture. For more enhancements to the mixture, pulverized fly ash (PFA) of Class F is added. By increasing the amount of PFA, the resistance of the stone column in term of shear and bearing capacity are increased as the PFA pozzolanic reaction begins to produce more strength during the increasing time of the curing period. Both samples of the boiler slag and PFA are taken from Sultan Salahuddin Abdul Aziz Power Station, Klang, Selangor. The materials mixed are sand, cement and water to make boiler slag aggregates -PFA (slag) mixture. This study aims to define the slag concrete performance according to the optimum configuration of the materials used in the mixture. Unconfined Compression Test (UCT) is applied to define the ideal ratio of boiler slag between 60% to 30% ratios from the total weight which applied with 2% ratio of cement from the total weight. The results of the study show that the number of boiler slags, the period of curing, and the method of curing are the most important factors in defining the slag stone column performance. Testing the samples in ordinary circumstances to entire areas can be accomplished by determining the soil properties and meeting them. The best result gained was the 40% ratio of boiler slag in a curing method that preserved the mixture moisture and temperature, which led to the optimum strength of the slag stone column.

KEYWORDS

PFA, boiler slag, stone column.

1. INTRODUCTION

Stone columns are recognized as the most common ground improvement methods to enhance soft soils. They can enhance the soil bearing capacity and provide stability. Also, they are preferred because they are easily constructed and applied. However, in the previous studies, stone column method was restricted because of the bulging issue and lower bearing capacity in extreme soft soil. Therefore, this study considers avoiding the stone column failures by improving the materials mixture and strength. The new slag column is made of boiler slag material combined with Pulverized Full Ash (PFA) and sand with the addition of cement acting as a binder for the stone column.

The pozzolanic combination of the boiler slag, cement and PFA mixture is hypothetically capable of enhancing the bearing capacity of the slag column. The importance of using PFA relies on bringing down the cost of the ground improvement of soft soil and maintaining non-renewable sources like granite products (aggregates), by replacing them with byproducts that were on their way to waste and harm both environment and human.

However, stone columns are the most common method used in ground improvement, and it still has some limitations. Since those stone columns structure includes granite, dolomite, limestone, and other rocks from the quarry, a huge concern has been raised to save those rocks as a non-renewable source that could be consumed one day, and by replacing it in the stone column structure with boiler slag aggregates that will more economically and environmentally benefits to the society.

2. OBJECTIVES

1. Evaluating the boiler slag aggregates and PFA mixture column performance compared to the current analysis of the granite stone column.
2. Replacing granite aggregates with boiler slag aggregates and converting fly ash from being a waste product to construction material.

Quick Response Code	Access this article online	
	Website: www.enggheritage.com	**DOI:** 10.26480/gwk.01.2020.04.07

Cite the Article: Hafez, M. A., Sidek, H.N, Moustafa Z. Ibrahim, Almkahal, Z. (2020). Lightweight Slag, Pfa Column A New Soft Ground Improvement Method. *Engineering Heritage Journal, 4(1): 04-07.*

2.1 Scope and limitation of the study.

To reach the study objectives, two methods of work are applied by sequence; preliminary work and laboratory work. In the preliminary work, we fill the slag columns samples with sand and fly ash mixtures. Class F fly ash is used with the amount of cement (2%) to sustain CaO in fly ash mixtures. Also, this preliminary work covers defining the soil sample cohesion and type. Otherwise, the laboratory work covers Unconfined Compression Test (UCT) on the Boiler Slag-PFA concretes which determine the boiler slag aggregates amount, the process of curing, and time of curing. The test concentrates on the most optimum configuration, which results in enhancing the slag concretes strength. Furthermore, it defines the ideal ratio of boiler slag and fly ash mixture for the coming tests.

2.2 Material preparation

Since the reaction of fly ash and soil is important to ground improvement depending on the number of pozzolanic materials used such as the amount of CaO found in class F, different mixtures tests were applied with the different per cent of fly ash and boiler slag.

2.3 Molten slag/ boiler slag

According to the boiler slag chemical characteristics, it contains mainly of silica, iron and alumina, with a little amount of magnesium, calcium, sulfates and other components. In Table 1, a comparison is made between bottom ash and the boiler slag based on the different type of coal types and different regions. We find out that molten slag has higher amounts of alumina and silicates, while in the case of lignite coal has more than 20 per cent of calcium, which is an obstacle in metal structures.

Figure 1: Boiler slag and pulverized fly ash (PFA)

Comparing the molten slag produced from coal combustion to the lignite coal, molten slag has higher amounts of alumina and silicates. In contrast, lignite coal has more than 20 per cent of calcium, which is an obstacle in metal structures.

Table 1: comparison between molten slag produced from coal combustion.

Ash Type:	**Bottom Ash**					**Boiler Slag**		
Coal type:	**Bituminous**			**Sub-bituminous**	**Lignite**	**Bituminous**		**Lignite**
Location	**West Virginia**		**Ohio**	**Texas**		**West Virginia**		**North Dakota**
SiO_2	53.6	45.9	47.1	45.4	70.0	48.9	53.6	40.5
Al_2O_3	28.3	25.1	28.3	19.3	15.9	21.9	22.7	13.8
Fe_sO_3	5.8	14.3	10.7	9.7	2.0	14.3	10.3	14.2
CaO	0.4	1.4	0.4	15.3	6.0	1.4	1.4	22.4
MgO	4.2	5.2	5.2	3.1	1.9	5.2	5.2	5.6
Na_2O	1.0	0.7	0.8	1.0	0.6	0.7	1.2	1.7
K_2O	0.3	0.2	0.2	-	0.1	0.1	0.1	1.1

2.4 Pulverized full Ash (PFA).

Pulverized full Ash (PFA) consists of two classes; Class F& Class C. Class C fly ash is generated from lignite and sub-bituminous coal. It contains calcium alumina, quartz, tricalcium aluminate and free lime. While Class F fly ash is generated from bituminous and anthracite coal. It contains alumina-silicate and quartz. A comparison between the two classes chemical properties is shown in Table 2, indicates that class F has 10 per cent of CaO.

Table 2: comparison between Class F& Class C

Component	**Bituminous**	**Subbituminous**	**Lignite**
SiO_2	20-60	40-60	15-45
Al_2O_3	5-35	20-30	10-25
Fe_sO_3	10-40	4-10	4-15
CaO	1-12	5-30	15-40
MgO	0-5	1-6	3-10
SO_3	0-4	0-2	0-10
Na_2O	0-4	0-2	0-6
K_2O	0-3	0-4	0-4
LOI	0-15	0-3	0-5

2.5 Soft soil characteristics in Malaysia

Malaysia is one of the nations that confronting with problematic soil such as soft soil and peat. At least 70% of the 5,000 km coastline of the nation make up from the soft layer. Weak soil like alluvial clayey ever-present in Malaysia, its deterrent development on the coastal line area. Soft soil layers have been forming because of quaternary deposition (Geliga E. and Ismail D. A., 2010). According to a statistic that was done by a previous study for Southeast Asia coastlines, and soft marine clay thickness can reach up to 40m from the surface layer (Abdullah et al., 1987).

2.6 Stone column as a ground improvement method.

The stone column is the first choice in the construction industry as ground improvement methods, especially in the soft soil to enhance its bearing capacity. Also, it can be constructed easily and saves time, but this simplicity on its construction is conditioned by the column effectiveness. This effectiveness relies on the column filler solidity factors like (granite, gravel) and the compaction of surrounding soil. However, stone columns have many reasons to fail. This failure comes because of the surrounding soil is too compressible or too soft. Another failure is bulging, which occurs because of lacking strength of the used materials and missing the side suppression between the surrounding and the stone. Other failures like a shear failure and punching failures are demonstrated in Figure 2.

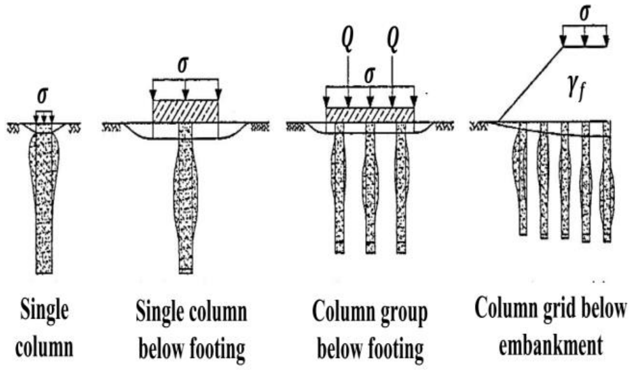

Figure 2: Typical failure of the single stone column (Ghanti & Kashiwal, 2008)

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3. Methodology

This is the laboratory work section where most of the data were collected through experimental in Universiti Tenaga Nasional soil laboratory. The experiments have been applied to four main ratios of boiler slag, which are 30%, 40%, 50%, and 60% of the total weight, and 2% cement substance to add a pozzolanic reaction with fly ash particles because of the presence of calcium oxide (Table 2). Four setups of mix design have been set to comprise 2% cement, for example, appeared in Table 3. The researcher has considered 2% cement is sufficient to improve and supply enough calcium oxide in the excepted pozzolanic reaction with fly ash particles. Also, it has been applied in soil circumstances similar to the real one to determine the soft soil chemical and physical properties.

Table 3: Four setups of mix design have been set to comprise 2% cement

Cement [%]	Molten Slag [%]	PFA [%]	Sand [%]	Water [%]
2	60	20	18	25
2	50	30	18	25
2	40	40	18	25
2	30	50	18	25

3.1 Unconfined Compression Test

Unconfined Compression Test has been applied to determine the cohesion of the soil behaviour and shear strength, following British Standard (BS1377). This test also applied for the boiler slag-PFA concrete sample to reach the compressive strength of the samples. For the preparation, the square mould of 100mm dimension was used, in which the mixed materials are poured then left for 24 hours to let the samples get into shape. Then, the boiler slag-PFA concrete was removed from the mould, and some of them were put in an empty tank after been wrapped by a layer of a 20mm thickness of wet soil to apply the actual curing conditions and period. Other samples were cured directly under the water surface. During the period of curing, which is 56 days, the soil was kept wet by watering to maintain the moisture content and prohibit the PFA concrete drainage. The unconfined compression test was applied for the 7th, 14th, 28th, and 56th days.

4. Results

In this section, a comparison was made to determine the best method of curing the materials mixture with 60% boiler slag, whether it should be under direct water curing or underneath the wet soil. The recorded data in Figure 3 states that cube samples which were cured underneath wet soil surrounding have a higher average compressive strength. It also shows that strength increases by more than 100% for the curing period.

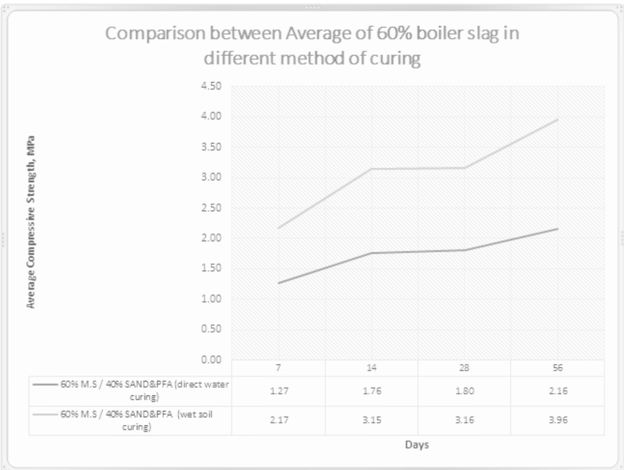

Figure 3: Comparison was made to determine the best method of curing

After applying different periods of curing based on the different amount of boiler slag(40% to 60%), the graphs recorded in Figure 4 states the 40% boiler slag ratio accomplished the highest average strength (8.4MPa) at most of the curing period, which was 56 days curing.

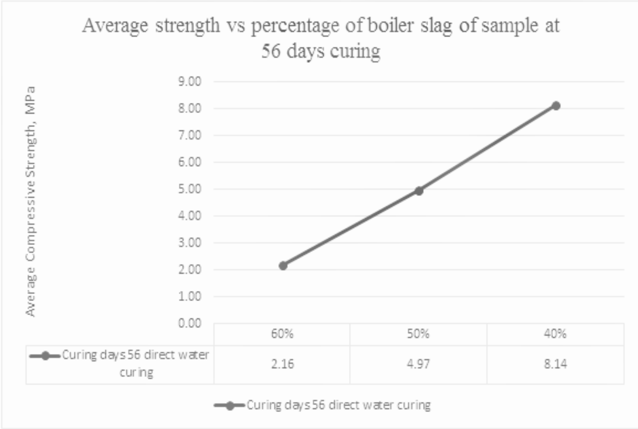

Figure 4: 40% boiler slag ratio accomplished the highest average strength.

5. Discussion

5.1 Amount of PFA Affect the Strength of Samples

Since we know the basic, by increasing the amount of PFA, the strength of the concrete will be increased as the PFA pozzolanic reaction begins to produce strength which continues to increase by longer curing period exactly after the 7th day since the production of CSH gels also continues as long as the presence of calcium hydroxide in concrete paste (Lin L. and Chang W.C., 2016).

Another basic is that neither too less PFA nor too much PFA gives higher compression strength, but a controlled limit amount of pulverized fly ash can achieve optimum strength. From this basic and by the previous experimental work, we can define the ideal ratio for boiler slag is 40% and PFA is 40%, lower or higher percentage of the PFA results on the lower compressive strength of the slag concrete sample.

Table 4: The ideal ratio for boiler slag is 40% and PFA

Cement [%]	Molten Slag [%]	PFA [%]	Sand [%]	Water [%]
2	40	40	12	25

5.2 The Change of Curing Method

The used slag concrete mixture sample in this study is only 2% cement, which equals half of the average percentage of cement in a conventional concrete mixture (14-16) %. This means that only a small amount of water needed as the cement percentage provides low CaO, which is not sufficient for the hydration process. Otherwise, too much water will cause sand to segregate, the mixture to shrink, and internal cracks to happen. Curing is applied to preserve the surrounding temperature, moisture for hydration process, and stability without cracks. To improve the curing method, it turned from immersed-in-water curing method to shading method, by which the concrete is shaded with a wet gunny maintain moisture without too much additional water and keep the surface temperature under control. Another mixture curing method was applied by keeping the soil wet by watering it to maintain the moisture content and prohibit the PFA concrete drainage. The unconfined compression test was applied for the 7th, 14th, 28th, and 56th days. The gained result is that the compressive strength of concrete increases as the water-to-cementitious material ratio decreases.

5.3 Period of Curing Promotes Further Hydration Reaction

When the period of curing of the concrete samples increases, the strength increases until it reached the optimum strength. The period of curing the concrete slag samples affects the hydration reaction which produces calcium silicate gel that binds the aggregates together leading to a rock-solid mass, increasing concrete density, and improving its physical and mechanical properties of concrete.

6. CONCLUSION

This study discusses Unconfined Compression to find the optimum strength of mixture, which can be defined by the one which has the highest value of compression. For example, 40% of boiler ratio gave the highest average compressive strength at the 56th day of curing while the 60% boiler slag ratio produced the lowest one. For the pulverized fly ash, class F was chosen as it has less CaO. The ideal ratio of pulverized fly ash in this study is 40%. Since the curing period is important, its methods also matter to maintain the soil moisture and temperatures.

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