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RESEARCH ARTICLE

PHYSICAL PROPERTIES AND SHEAR STRENGTH OF BOILER SLAG

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ABSTRACT

This study is about the determination of the physical and engineering properties of boiler slag. The boiler slag is a by-product that is obtained from the Tanjung Bin power plant. The source of reference for the use of boiler slag is minimal for this type of applications. However, this is an environmental suggestion to utilise the disposed of by-product from the ash pond. In this study, the properties of boiler slag are determined, such as the specific gravity, particle size distribution and shear strength. The specific gravity of boiler slag obtained was found to be 2.45, falls in the range provided by User Guidelines for Waste and By-product Materials in Pavement Construction by Federal Highway Administration. While, the shear strength for three samples tested were 73.78kN, 141.2kPa, and 285.9kPa. The internal friction angle of the sample obtained by the plotted graph of shear stress vs normal stress is 55°. The result obtained was analysed and concluded to acknowledge the capability of boiler slag as a construction material to be used in construction, mainly in pavement industries.

KEYWORDS

boiler slag, shear strength, physical properties.

1. Introduction

Boiler slag is one of the by-products of electric power plant that are primarily produced. Same goes with the fly-ash. Locally, all thermal power stations have a significant amount of by-product reach nearly to 15% of the total coal yearly consumption, causing a storage and maintenance problem in the station. In some cases, the boiler slag was disposed to the landfills. Generally, the production and disposal ratio for fly ash and bottom ash are approximately 80:20. According to TNB handbook for the year 2017, the total consumption coal in the thermal power stations has reached to 28.1 million tons with about 15% are waste by-product. It is expected the coal consumption to get to 36 million tonnes by 2025 as the electricity demand is increasing every year. The storage of the thermal waste products is occupying a large area in the power plants, and the area is increasing year after year. Meanwhile, the by-products can be recycled as a construction material to minimize its harm to the environment. Reusing such waste is essential. Otherwise, it will be sent to landfills as an environmental-friendly option. Table 1 shows the utilisation of ashes produces by the coal-fired power plant.

Table 1: The Application of Bottom Ash In Construction (Abubakar and Baharudin, 2012)

Application	Bottom Ash (tonnes)
Concrete/ concrete product/ grout	720, 948
Blended cement/ raw feeder for clinker	610, 194
Structural fill/ embankment	2, 996, 388
Road bases/ sub-bases	767, 013
Aggregate	727, 048

Typically, boiler slag is a type of wet-bottom boilers that consists of two types which are slag-tap boilers and cyclone boiler. The bottom ash was kept in the molten state which will then come in contact with quenching water that allows it to fractures and crystalises becoming a coarse, black and hard angular material, called as boiler slag. Some country has already implemented the materials in their construction projects. The properties and composition of this material allow them to be used in highway construction, stabilization of soil, embankments, pollution control, etc (Prasad and Kumar, 2015). It is exposed that the utilization of by-products is the practical solution towards the sustainability of the environment. Also, states that they found an alternative by using agricultural wastes or by-products, which will be more effective in cost for constructions (Mandal et al., 2016).

In highway and soil engineering application, a characteristic of a material is one of the significant elements that must be checked and investigate and to use boiler slag for road constructions in Malaysia. This research is done to investigate the ability of boiler slag in terms of its compaction characteristic, and its strength. However, this study has a limitation. As there is no previous researcher who researched the same topic, the result obtained must be analyzed deeper by doing other relevant tests to support this study. Thus, further research is needed to gain more information regarding boiler slag applications and ability.

2. Literature Review

2.1 Boiler Slag

According to Benson and Bradshaw, boiler slag is angular in shape and has a very porous surface texture. It is usually a well-graded although the particle size distribution comes in variation even from the same power plant. The surface texture of boiler slag is smooth, however, becomes

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porous if they met quenching water at the bottom boiler. This is due to the gasses trapped inside the boiler slag during water quenching. Boiler slag is essentially a course to medium residual soil with 90 – 100% passing a 4.75 mm (No. 4) sieve, 40 – 60% passing 2.0mm, 10% passing 0.42mm, and 5 per cent or less passing a 0.075 mm (No. 200) sieve.

In the current situation, two ways are adopted in managing this waste. The first one is by recycling. Recycling can be conducted by utilising the by-products in construction. This includes subbase and base of pavement construction, embankment, soil stabilisation, concrete admixture, etc. In 1996 statistic, around 93.3% of these by-products are recycled as stated in the Federal Highway Administration in the USA Department of Transportation User Guidelines. This shows that the by-products have a high potential to be used as a primary material in engineering construction. However, in Malaysia, there is still a lack of full utilisation of these by-products, especially the boiler slag.

Figure 1: Boiler Slag

As boiler slag comes from the same source as fly ash; however, there are many differences between these two types. In a simple word, fly ash is the ashes that suspended in the boiler furnace due to its lightweight during combustion, while boiler slag is a coarse particle that settles down due to gravity at the bottom of the boiler (Kim et al., 2008). Thus, it is clear that the physical properties of boiler slag are not the same as fly ash as both vary in many ways. Currently, the application of boiler slag is not as much as fly ash. Based on User Guideline for Waste By-product Materials from U.S.A Federal Highway Administration, boiler slag usually used in asphalt concrete aggregates, residual base, and also stabilise base aggregates. In this study, the boiler slag is to be used in road construction as a replacement for unsuitable soils.

2.2 Specific Gravity

For ashes, generally, the specific gravity of ashes varies (around 2.0 but to some extent, may reach 1.6 – 3.1). Coal ash specific gravity, in general, are lower than that of soils (2.6-2.8) (Kim et al., 2006). This results in a low dry density of ash. The variation of specific gravity is affected by its chemical composition and structure of the material, the gradation and the particle shape. The specific gravity of ash is low; it might be due to the existing of plenty of natural ecospheres, the hollow body of the particle itself. There is some hollow part in the particle which trapped air cannot be removed.

2.3 Shear Strength

The strength of the soil is portrayed by shear strength. Shear strength is the maximum value of shear stress-induced within its mass before the soil yields. This yielding may lead to shear slip surface, where a sliding takes over. This may cause failure such as landslips, slope rotational, and excavation failure (Roy Whitlow et al., 2004). Shear strength parameters are defined as its friction angle and cohesion. Also, shear strength is affected by the effective stress, drainage conditions, density of particles, rate of strain, and also the direction of the strain (Roy et al., 2017). For this research, to determine the shear strength, the direct shear test is used.

The purpose of determining shear strength is to check the strength of the boiler slag itself. To be able to use in road construction, it is essential to analyse the strength to ensure whether it is safe to apply or not. This is because shear strength controls the stability of soil mass under the structural load (Dirgelienė et al.,2017). As boiler slag is an angular shape particle, there are possibilities that boiler slag possess higher shearing strength compared to the less angular particles. The direct shear test is one of a test to determine the shear strength of the soil mixture. It determines the ability of the material to resist the shearing process. Mohr (1900) gives a theory of rupture in materials that contended that a material fails because of normal stress and not from either maximum normal or shear stress alone (Braja M.Das et al., 2014).

During the direct shear test, there is a rotation of the principal stress. Also, failure may not occur on the weak plane as the failure is forced to occur on or near the horizontal plane at the middle of the sample. Shear stresses and displacements are non-uniformly distributed within the sample. For this direct shear test, boiler slag is used in dry condition, and it is cohesionless. Thus, the value of effective cohesion is zero ($c' = 0$). Also, the effective stress, σ' is equal to total stress σ as the pore water pressure is negligible due to the dry condition of the sample. ($\sigma = \sigma' - u$). The two terms are the sum of the peak shear strength:

$$\tau = c + \sigma \tan \emptyset$$

3. Test Procedure

3.1 Physical Properties

In this research, specific gravity and particle size distribution is obtained. The test involves specific gravity is by using a large pycnometer method for boiler slag. The specific gravity test is done according to BS 1377: Part 2. The specific gravity of soil is commonly determined through the data of the weight of solid soil constituents and their volume. The specific gravity of soil data was able to use in the calculation of porosity or degree of saturation of soil and void ratio. Other than that, the parameter of specific gravity able to calculate permeability, consolidation, and compaction. In specific gravity determination, the sample is oven-dried to remove the water content. Specific gravity test requires the mass and volume to be measure accurately. Another properties test that is done in this study is a particle size distribution. A dry sieving method is used to obtain the particle size distribution.

3.2 Shear Strength by Direct Shear Test

In determining the shear strength of boiler slag, a direct shear test is conducted. This direct shear test gives the value of the internal friction angle of the material. In many engineering constructions such as the design of foundation, and retaining walls, the value of the angle of internal friction and cohesion of the soil is needed for the design. This test is done according to BS1377: Part 7.

4. Result and Discussion

4.1 Specific Gravity

The specific gravity of boiler slag was found to be 2.45. According to User Guidelines for Waste and By-product Materials in Pavement Construction by Federal Highway Administration, 2016, and also from Benson & Bradshaw, 2011, the specific gravity of boiler slag is in the range of 2.3 – 2.9. This study gives the value of 2.45, which falls in the range by guideline.

4.2 Particle Size Distribution

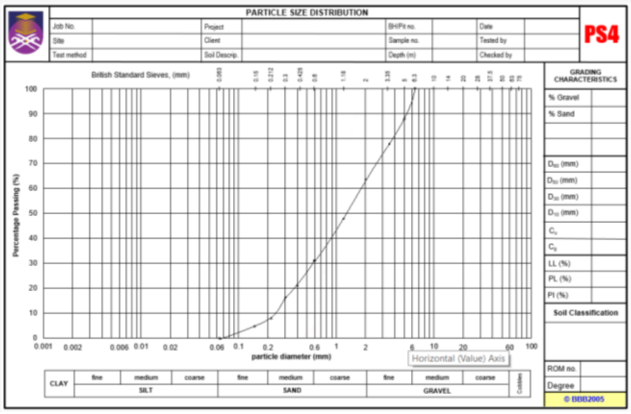

Figure 2: The particle size distribution of boiler slag

Figure 2, shows the particle size distribution of boiler slag obtained by using a dry sieving method. From the Particle Size Distribution curve plotted in Figure 3, it can be seen that the boiler slag in this research consist of 36% gravel (14% medium gravel, 22% fine gravel), and 64% of sand soil (33% coarse, 22.6% of medium sand soil, 8.4% of fine sand soil). The classification of boiler slag is well-graded SANDY SOIL. Boiler slag is essentially a coarse to medium granular soil type of material.

The particle size distribution of boiler slag can be analysed by comparing with previous researcher's result. From the research by Abdullah et al., they use bottom ash from the same source, which is Tanjung Bin (Abdullah et al., 2018). The characteristic of the particle size distribution for the bottom ash and boiler slag shows slightly different. This is might due to the properties of bottom ash and boiler slag that has not much different as both are obtained from the bottom boiler. Also included a particle size distribution for boiler slag from other locations to be compared.

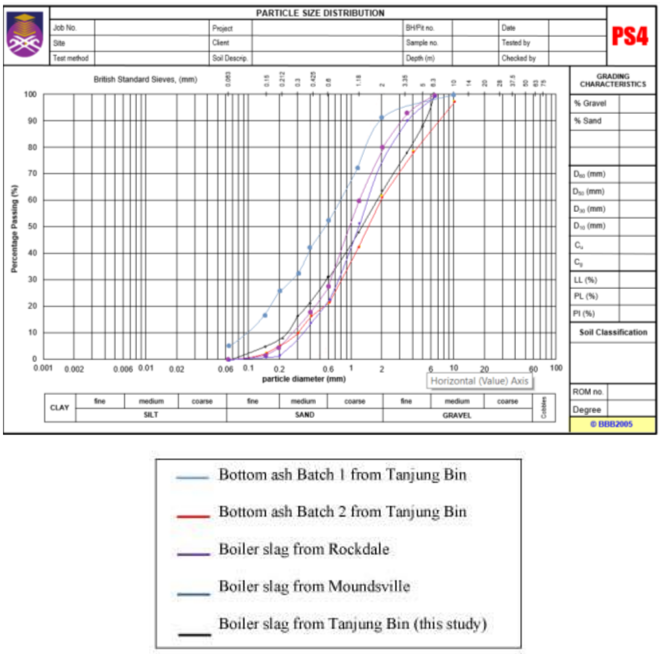

Figure 3: Variety of Particle Size Distribution

The variation of particle size distribution is affected by the type of material, the properties and also the location of the material obtained. However, in this research, it can be seen that the particle size distribution does not vary much as the materials have a quiet similar physical property even though from a different source.

4.3 Shear Strength

For this test, three samples were prepared to undergo a direct shear test. Each sample was tested by using different everyday stress with a constant rate of strain. Shear box A was tested using 50kPa of normal stress, 100kPa for shear box B, and 200kPa for shear box C.

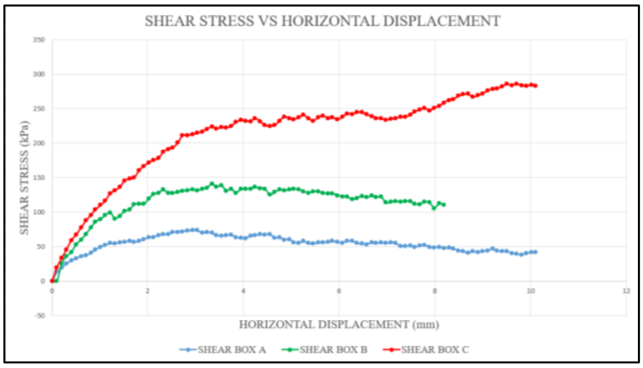

Figure 4: Shear Stress vs Displacement Graph for Shear Box A, B, and C

From Figure 4, the value of normal stress applied for shear box A was 50kPa along with a constant horizontal displacement rate of 0.0286mm/min. The pattern of the graph shows the horizontal displacement increases along with the shear stress. The increment continues and slightly falls at 1.72mm of horizontal displacement but then continues to increase until 2.93mm. That is the peak of the graph. The peak strength for shear box A is recorded as 73.78kN. The post-peak value is called as ultimate strength where for loose type soil, it is constant.

The graph also represents the shear stress vs horizontal displacement for Shear Box B. The value of normal stress applied for this second sample was 100kPa along with the same constant horizontal displacement rate of 0.0286mm/min. The pattern of the graph shows the horizontal displacement increases along with the shear stress as in the previous sample. However, at 1.314mm horizontal displacement, the shear stress falls to 91kPa and then continues to increase until it reaches peak value where the shear stress fail. The peak strength value is 141.2kPa. The post-peak value is constant.

For shear box C, the value of normal stress applied for this third sample was 200kPa along with the same a constant horizontal displacement rate of 0.0286mm/min. The pattern of the graph shows the horizontal displacement increases along with the shear stress. There are some points where the shear stress tends to fall but the rise again until it reaches its peak strength value of 285.9kPa. The values after the peak slightly fall but still in a constant pattern. Based on all three-shear box test, the data output for each shear box can be tabulated as in Table 2.

Table 2: Conditions at Failure

Conditions at Failure			
	Shear Box A	**Shear Box B**	**Shear Box C**
Applied Normal Stress	50.0 kPa	100.0 kPa	200.0 kPa
Maximum Shear Stress	73.8 kPa	141.2 kPa	285.9 kPa

From Table 2, the applied normal stress gives an effect on the maximum shear stress at failure for each sample. As the normal stress applied increases from 50kPa to 200kPa, the value of maximum shear stress also increases from 73.8kPa to 285.9kPa. It shows an increment of shear strength as the normal stress applied is increased. Thus, for boiler slag, the higher the normal stress used, the higher the shear strength. Figure 5, shows the values of shear stress at failure and normal stress are plotted into a graph of shear stress vs normal stress to determine the value of shear strength (internal friction angle).

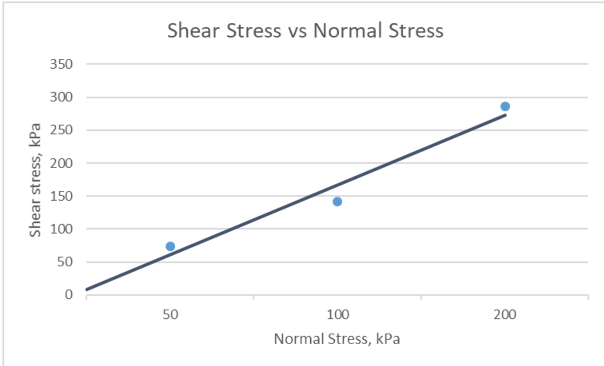

Figure 5: Graph of Shear Stress at Failure Vs Normal Stress

The value of c' is equal to zero as the condition of boiler slag is dry. As the boiler slag is completely dry, it is known that the value of total stress is equal to the effective stress because only with the presence of water can cause a difference between the total stress and the effective stress. In the graph, only the value of internal friction, ϕ' can be obtained. The value of ϕ' is 55°. The shear strength parameters for this boiler slag is c'=0, and ϕ'=55°.

The value of internal friction of 55° can be used for the design purpose. Based on the User Guidelines for Waste and By-product Materials in Pavement Construction by Federal Highway Administration, the internal friction angle of boiler slag is in the range of 36° – 46°. In this study, the value of the internal friction angle is 55° which is not in the range as per guideline. This could possibly due to the environment or the location of the source obtained. The site for the tested boiler slag and the procedure refers to other country's power plant in overseas compared to the boiler slag in this study, which is obtained from the power plant in Malaysia. The surroundings may affect the mechanical properties of boiler slag at different location and environment.

5. Conclusion

This study is conducted to dig out the potential of power plant by-product named as boiler slag that is obtained from Tanjung Bin Power Plant. The physical properties of boiler slag are determined to know the specific gravity and particle size distribution. The specific gravity obtained is 2.45. The particle size distribution of boiler slag from this study shows that it is well-graded sand. The shear strength obtained from the laboratory experiments gives the value of 55° for the internal friction angle. It proves that boiler slag has its own strength which supports its usage in construction industries. The internal friction value for boiler slag can be used in the calculation for building retaining walls, embankment, etc.

This material can be applied in many construction parts. In the construction industry, it is essential to apply a sustainable material. Boiler slag is one of the by-products that can be widely used in the engineering sector. Although the usage has been known for other countries, however in Malaysia the usage remains unexposed. Thus, this study helps in introducing the benefits and ability of boiler slag to be applied in constructions. Boiler slag can be used as a backfill material, and also as a residual base for road constructions. The well-defined shear strength helps to support the usage of boiler slag as a potential construction material. Lastly, this study is expected to be one of a resourceful reference for any further studies on boiler slag.

References

Abdullah, M.H., Abuelgasim, R., Rashid, A.S.A., Mohdyunus, N.Z., 2018. Engineering Properties of Tanjung Bin Bottom Ash. MATEC Web of Conferences, 250, Pp. 01006. https://doi.org/10.1051/matecconf/201825001006

Abubakar, A.U., Baharudin, K.S., 2012. Potential Use of Malaysian Thermal Power Plants. International Journal of Sustainable Construction Engineering & Technology, 3 (2), Pp. 25–37.

Benson, C.H., Bradshaw, S., 2011. User Guideline for Coal Bottom Ash and Boiler Slag in Green Infrastructure Construction. User Guideline for Coal Bottom Ash and Boiler Slag in Green Infrastructure Construction, 1 (12), Pp. 1–32.

Braja, M., Das, 2014. Principles of Geotechnical Engineering Eighth Edition, US: Cengage Learning.

Dirgelienė, N., Skuodis, Š., Grigusevičius, A., 2017. Experimental and Numerical Analysis of Direct Shear Test. Procedia Engineering, 172, Pp. 218–225. https://doi.org/10.1016/j.proeng.2017.02.052

Mandal, S., Singh, J.P., General, A., 2016. Stabilisation of Soil using Ground Granulated Blast Furnace Slag and Fly Ash, Pp. 21121–21126. https://doi.org/10.15680/IJIRSET.2016.0512038

Prasad, R., Kumar, D., 2015. Laboratory Investigation of Compaction Characteristics of Flyash-Granular Soil, Pp. 9868–9874. https://doi.org/10.15680/IJIRSET.2015.0410077

Rashidi, N.A., Yusup, S., 2016. Overview on the Potential of Coal-Based Bottom Ash as Low-Cost Adsorbents. ACS Sustainable Chemistry and Engineering, 4 (4), Pp. 1870–1884. https://doi.org/10.1021/acssuschemeng.5b01437

Roy, S., Bhalla, Sanjeev, K., 2017. Role of Geotechnical Properties of Soil on Civil Engineering Structures. Resources and Environment, 7 (4), Pp. 103–109. https://doi.org/10.5923/j.re.20170704.03

Roy, W., 2004. Basic Soil Mechanics, SG: Pearson/Prentice Hall

User Guidelines for Waste and By-product Materials in Pavement Construction. 2016. Retrieved from https://www.fhwa.dot.gov/publications/research/infrastructure/structures/97148/cbabs1.cfm.