An Investigation of the Geotechnical Properties of Coal Combustion By-products from Matimba Power Station in Lephalale, South Africa

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1 Introduction

Coal fly ash is a by-product of pulverised coal in an electrical generating station. Thomas (2007) pointed out that coal fly considered to be an unburned residue, which was carried away within the burning zone/area the boiler by the flue gases and eventually collected by one of the separators either mechanical or electrostatic. However, the quantity of coal ash produced depends upon the quality of coal and the method of burning the coal. Most of the fly ash is commonly used in a dry state. Most of the researchers such as Thomas (2007) and Dilip et al. (2012) indicated that fly ash disposal found to be on the wet state, which made the mode of disposal easy. Based on Thomas (2007) and Dilip et al. (2012) studies, fly ash found to be successfully used mostly in constructions projects such as road construction and also used as a supplementary cementations material for the purpose of producing cement concrete.

Bottom ash is also one of the by-products, which is generated during the process of burning coal in different thermal power plant (Dilip et al. 2012). As compared to fly ash, bottom ash has proven to be of coarse grain to fly ash, with an angular shape and mostly porous (Vijaya Sekhar Reddy et al. 2016). Furthermore, Vijaya Sekhar Reddy et al. (2016) pointed out that the bottom ash has high shear and with less compressibility. However, the proper engineering of bottom ash allows it to be used in engineering applications such as dam construction and other civil engineering-related aspects.

Eskom generates almost 95% of electricity used in South Africa. The Matimba power station is a plant that is operating under Eskom in South Africa.

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The production of electricity at Matimba power station has been increasing over the years. Matimba power station recently produced large amount of electricity, which in turn leads to the disposal of lot of fly ash. The major problems faced by coal-based thermal power plant are handling and disposal of the coal fly (Eskom Integrated Report 2015).

There are several environmental crises associated with both fly and bottom ash, and these crises affect the life of the community members and animals around the vicinity of the thermal power stations.

This study aims to highlight some of the cardinal points that can be used to resolve the environmental crisis raised by disposal of both bottom and fly ash. The main objective of the study was achieved through detail analysis of the geotechnical properties of coal fly ash and bottom ash at Matimba power station, with purpose of utilising the ashes for construction use.

1.1 Problem Statement

In the production of electricity through the combustion of coal, Matimba power station is producing huge amount of fly ash and bottom ash. The major problems faced at the Matimba power station is the disposal and the handling of the coal combustion by-product which are the fly ash and the bottom ash whereby safe disposal and handling of large quantities of fly ash and bottom ash have not only become tedious but also expensive. To resolve the problem, strategic decision on the utilisation of coal ash has to be developed.

1.2 Objectives of the Study

The main objective of the research was to investigate the geotechnical properties of fly and bottom ash to establish their potential utilisation as a construction material. The specific objectives were to determine the grain size distribution of the fly ash, to conduct geotechnical analysis associated with soil strength and also evaluate its usability within the construction industry.

2 Research Approach

2.1 Material Sampling

Sampling was conducted of fly ash, bottom ash and the mixture of bottom and fly ash for laboratory tests. These samples were investigated to determine grain size distribution and Atterberg limits. The main purpose was to identify different types of ashes and the analysis of their geotechnical properties.

The ash samples were attained by initially augering to the depth of about 50 cm from the surface to remove the disturbed and mixed ashes. After reaching the desired depth, the auger was slowly removed from the hole and the samples were collected immediately after the removal of the auger from the hole. Samples from different locations were collected randomly. The sampling plastic bags were labelled with names, sampling date and location. The samples collected from the fly ash pipe were labelled FLY 01 and FLY 02, samples from the bottom ash chamber were labelled as BA 01 and BA 02, samples from the dump site were labelled as AD 01, AD 02 and AD 03, and, lastly, the plastering sand that was collected from the construction site was labelled as PS01.

Soil samples collected during site investigation were wrapped in plastic bags to preserve and protect them from any possible mixing or moisture changes. The samples were eventually sent to the laboratory for index tests.

2.2 Laboratory Work

The laboratory work was conducted towards an understanding of material behaviour, to determine the nature of the ashes and how they perform under the imposed conditions such as the presence of water, temperature and pressure. Analysis of site samples with respect to how conditions would change over the time provided an understanding of the existing and future conditions, as well as the suitability of material for construction purposes.

2.3 Sample Preparation

Samples that were collected from the field were initially weighed using scale balance approximately 500 g from each bag of ash samples. The samples were then taken to the oven for drying in which 110 °C temperature was used to completely remove the moisture for 24 h. The bag of samples was left for a while to cool out immediately when removed from the oven. The dried samples were then weighed and the weight was recorded for each sample. The main objective of weighing sample before drying and weighing them after drying was to determine the total moisture content of each measured sample.

2.4 Sieve Analysis

The main purpose of carrying out particle size distribution was to classify the sample materials into different categories as well as to determine their texture. This was because one of the major factors that affect the behaviour of the soil mass is the size of the grains. The apparatus used was a stack of sieves with the pan at the bottom and the cover on the upper sieve, Sartorius balance with an accuracy of 0.01 g, mechanical sieve shaker, plate and the drying oven.

To determine the grain size distribution, the samples were placed in a Vacutec oven overnight. The weight of each empty clean sieve was recorded in a notebook. The sieves were then set in a descending order starting with a 4-mm sieve on top to 0.075 mm on the bottom and a pan as the last plate at the bottom. The dried material from each bag was weighed into 500 g each. The 500 g from each sample bag was sieved through a stack of sieves with each successive screen in the stack from top to bottom having a smaller opening to capture progressively smaller particles. The materials were mechanically shaken using the sieving machine for an hour at an amplitude of 40 m. The amount retained on each sieve was collected and weighed to determine the amount of material passing each sieve size as a percentage of the total sample being sieved.

3 Results and Discussion

This chapter presents the data which were collected from the study area to achieve the objectives of the research. The data interpretation and analysis are also presented in this chapter. The results obtained from the laboratory work were used to design graphs and tables.

3.1 Water Content Test Results

Table 1 shows the percentage moisture content of different fly ashes and bottom ashes. Sample FLY 01 and FLY 02 contain a small amount of water as shown from the results in comparison with other sample ashes. This led to the conclusion that coal fly ash cannot hold much water. The results show that pure fly ashes contain on average 1% of water.

Bottom ashes, on the other hand, give different results compared to the fly ashes. In Table 1, BA 01 and BA 02 show a higher percentage of water content. The average water content for the bottom ashes shows a percentage above 40% water availability in the material. Coarse-grained materials tend to have high void spaces compared to fine grained which can contain lot of water. Therefore, it can be concluded that the bottom ashes are composed of coarse-grained materials and the

Table 1 Total moisture content

Sample no.	Mass of wet sample	Mass of dry sample	Mass of water	Moisture content (%)
FLY 01	500.01	498.41	1.6	0.32
FLY 02	503.74	503.12	0.62	0.12
BA 01	505.43	331.52	173.91	52.46
BA 02	507.06	341.76	165.3	48.37
AD 01	504.77	440.60	64.17	14.56
AD 02	513.79	445.73	68.06	15.27
AD 03	503.44	463.32	40.12	8.66
PS 01	566.26	480.95	85.31	17.74
PS 02	529.02	400.29	106.73	26.66

particle size of the sample can resemble the individual grain size of the sample based on the physical observations.

The material that is composed of the mixture of bottom ash and fly ash AD 01, AD 02 and AD 03 was collected from the damp ash. The results in Table 1 show the average percentage of the water content of the sample ranging from 8% and above. The average water content of the mixture depends from the ratio of the fly ash and bottom ash in the sample. The samples collected show that there was a higher percentage of fly ash as compared to bottom ashes.

A reasonable mixture of bottom ashes and fly ashes can make an excellent engineering property that can be used for construction and building. The mixture of ashes with a reasonable water content can provide material with good strength and stability based on the previous studies associated with performance of construction material.

3.2 Particle Size Distribution Results

The percentage passing of the materials on each sieve shows a gradual decrease in the overall material with decrease in the sieve sizes. The results represented in Table 2 show percentage of the samples analysed during this research. The results show that the coal fly ashes have 100% passing from the sieve size 4 to 1 mm as the material descends in the successive sieves. The 100% passing rate in these sizes proves that the materials are dominated with fine-grained materials.

The percentage passing of the bottom ashes shows gradual decrease from the upper sieve to the pan as the successive sieve size descends. The results show that the material is composed of varying grain sizes. The gradual decrease in material shows that the material is a mixture of fine-grained materials and coarsed material. The material can be concluded is composed of silt- to sand-sized materials, and this conclusion was based on grain size analysis.

Table 2 Percentage passing through each sieve

Sieve size (mm)	Percentage passing (%)							
	FLY 01	FLY 02	BA 01	BA 02	AD 01	AD 02	AD 03	PS
4	100	100	98	95	100	100	100	100
2	100	100	88	85	99	99	99	99
1	100	100	80	79	98	99	99	98
M	99	99	70	69	98	97	98	84
0.25	96	97	53	53	94	94	94	50
0.125	82	82	31	50	78	77	78	18
0.075	66	65	19	19	60	58	62	9

The mixture of fly and bottom ashes, which was collected in the damp site, shows slight decrease in percentage passing as the sieve size descends. The results from the table show that the amount of the fly ashes is greater than the amount of bottom ashes mixed. The material is dominated with fine-grained material of other coarse ones.

The mixture of materials to a reasonable extent can have advantages in terms of strength and stability in civil engineering purposes. The mixed material tends to have better sorting and decreased void spaces, which in turns increase the strength and suitability of the material for building purposes. The gradation curve of the coal fly ash, as shown in Fig. 1, shows that the material is mostly dominated by clay materials with very fine sizes. The percentage passing of the material tends to be higher from the upper sieve to the pan. The percentage passing of the material ranges ranges from 65 to 100% (Fig. 1).

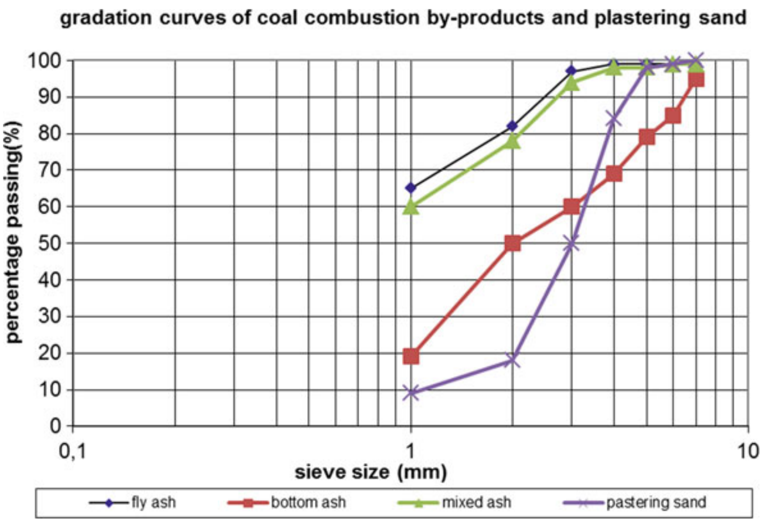

Fig. 1 Gradation curves of coal combustion by-products and plastering sand

The results of percentage passing of bottom ash are shown in the gradation curve (Fig. 1). The results show that the material is composed of silt- to sand-sized materials as the percentage passing is starting from 19 to 96%. The results of percentage passing of mixed ashes are shown in the gradation curve in Fig. 1, where the material passing is starting from above 50 to 100% from the descending sieves. The material is mostly dominated by fine clay material and a small proportion of silt-sized material. The results of plastering sand show that the material is mostly composed of silt- to fine-sand material as the gradation curve shows the size of material ranging from 9 to 100%.

3.3 Atterberg Limits

Pandian (2004) says that Atterberg limits are known to be the basic measures of water content within fine-grained soil; however, Pandian (2004) includes the following aspects: shrinkage limit, plastic limit and liquid limit.

3.3.1 Liquid Limit

The liquid limits of the coal fly ash, bottom ash and mixture of the two are presented in Table 1. The average liquid limit of coal fly ash was calculated to be 29%, which shows that coal fly ash does not contains high volume of water. The liquid limit of fly ash also shows that the material is mainly composed of fine-grained materials. The average liquid limit for bottom ash was calculated to be 71%, which means that the bottom ashes are mostly dominated by coarse-grained or sand-sized materials that contain significant amount of water. The mixture of the bottom and fly ash was calculated to be 34%. This depends on the proportion of each material added in the mixture. The average liquid limit of the mixture shows that there is higher proportion of coal fly ash compared to bottom ash. The mixture also shows that the material is mostly composed of more fine materials compared to bottom ash. The standard plastering sand shows the lowest liquid limit with an average of 15%.

3.3.2 Plastic Limits

Table 3 contains the results of the analysis of plastic limits. The average plastic limit of the coal fly ash was calculated to be 7%, which shows that the fly ash is slightly plastic (Table 3). The bottom ash has an average of 37% (Table 3). The results show that the material is highly plastic, and it is mostly dominated by silt-sized materials. The results of mixture of bottom and fly ash were determined to be 10%, which shows that there is a more fly ash than bottom ash. The material can be grouped as slightly plastic due to the proportion of fly ash in the mixture. The plastering sand is non-plastic where the plastic limit was 4%.

Table 3 Atterberg results

Samples	Average liquid limit (%)	Plastic limit	Plasticity index	Description
FLY 01 and FLY 02	29	7	22	Medium plastic
BA 01 and BA 02	71	37	34	High plastic
AD 01, AD 02 and AD 03	34	10	23	Medium plastic
PS01 and PS02	15	4	11	Slightly plastic

3.3.3 Plasticity Index

The highest plasticity index was of bottom ash which was calculated to be 34%. Bottom ash exhibits the high plasticity compared to other materials. The plasticity index of fly ash was calculated to be 22%, and the plasticity index of the mixed ashes was calculated to be 23% as shown in Table 3. The fly ash shows that the material is slightly plastic.

The plasticity index charts of fly ash, bottom ash and mixed ashes are shown in Fig. 2. Figure 2a shows the plasticity index of fly ash in which material is slightly plastic with clay nature. Figure 2b shows the plasticity of mixed material with the same plastic nature. Figure 2c shows the plasticity of bottom ash with the medium plastic nature. Figure 2d shows that bottom ash has organic silt clay material with low to medium plastic nature. The plastering sand shows that the material has low liquid limit and low plastic limit as shown in the chart above with low clay material as indicated by the A-line.

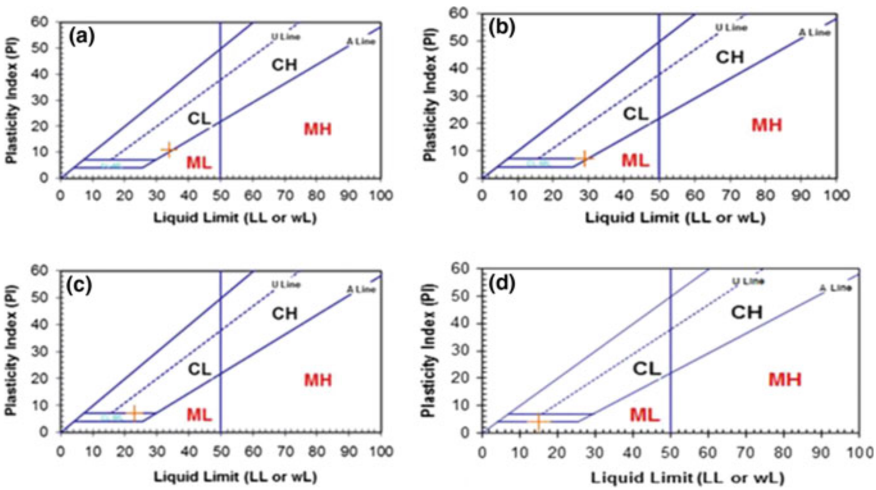

Fig. 2 Plasticity index of **a** fly ash, **b** mixed material with the same plastic nature, **c** bottom ash with the medium plastic nature and **d** bottom ash with organic silt clay material with low to medium plastic nature

Table 4 Summary of sieve analysis data and classification

Sample number	Gravel (%)	Sand (%)	Silt/clay (%)	AASHTO CLASS
FLY 01	0	34	66	A-7-6
FLY 02	0	35	65	A-7-6
BA 01	0	81	19	A-7-5
BA 02	0	81	19	A-7-5
AD 01	0	40	60	A-7-6
AD 02	0	42	58	A-7-6
AD 03	0	38	62	A-7-6
PS	0	91	9	A-7-6

3.3.4 AASHTO

The material samples were comprised of sand and clay or silt particles according to AASHTO classification of the grain sizes. The highest amount of particles in fly ash samples in silt clay is 66%, in bottom ash is 19% while in mixed ash was calculated to 60%. According to this classification system, the fly ash can be classified as clay material while bottom ash can be classified as silt to clay material. The plastering sand has a minimum of 9% clay content and 91% sandy material, as shown in Table 4.

4 Conclusions

The purpose of this research was to determine the geotechnical properties of coal fly ash and bottom ash to determine whether the material will be suitable to be used as building material. Coal fly ash at Matimba power station was determined to be clay material while bottom ash was established to be silt to clay material.

Laboratory tests conducted on material samples showed that the coal fly ash has very low moisture content, while bottom ash has high water content. Liquid limit of fly ash is 29%, bottom ash with 71% and the mixed ashes with 34%. Plastic limit of coal fly ash was calculated to be 7%, bottom ash with 34% and the mixed ashes with 10%. Low moisture content of coal fly ash renders high shear strength while bottom ash shows moderate shear strength.

Coal fly ash can be a resource rather than being an environmental problem due to its suitability for use as building material. The material has good geotechnical engineering properties, and it can be used as building material for construction purposes, specifically as plaster replacement as well as an additive to plastering material.

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