SUSTAINABLE WASTE ALTERNATIVE AS CEMENT REPLACEMENT IN PAVEMENT STABILIZATION

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ABSTRACT

In recent years, the philosophy of recycling has taken a grip of national development all round the world. This results in a growing demand to minimise waste and foster recycling of products such as Fly-Ash. Several million tonnes of Fly-Ash is being produced every day globally and the disposal of the Fly-Ash represents a serious obstacle to the electricity industries in South Africa. Accumulations of these fly-Ash landfill dump sites have reached alarming high levels, requiring immediate attention for its disposal. Solutions to reduce landfill sites from waste by-products of coal combustion are becoming critical due to the increased growth in landfill sites yearly. This study proposes a reduction in Fly-Ash landfill waste and its suitability for use in pavement construction as a cement replacement in stabilizing subgrade, sub-base and base course layers in South African roads. The method adopted constitutes testing Fly-Ash for use as a substitute engineering material for soil stabilisation in pavement construction.

Keywords: Fly-Ash, waste disposal, stabilisation, cementitious, replacement, pavement.

1. INTRODUCTION

The global demand for coal has grown steadily over 30 years but increased rapidly over the recent years due to the influences of growth in India and China. Coal growth has been the fastest fuel source than any other fuel in the last 10 years (Hall, 2011). The Coal industry provides 80% of South Africa's total primary energy requirements and is core to economic development with 92.8% of coal use providing electricity. Fly Ash, a thermally altered mineral matter which is a waste by-product generated from the combustion of coal for power generating. The need for safe disposal has been adopted not only in South Africa but worldwide. Accumulations of Fly Ash landfill dump sites have reached alarmingly high levels; requiring immediate attention for its disposal. Disposal of Fly Ash is of major environmental concern due to the possible release of contaminants to ground and surface water after disposal (Hassett et al., 2001).

The main focus of this research is to show that Fly Ash can be used as a cement replacement in the stabilisation of road pavement materials. The purpose is to provide conclusive results by using Fly Ash to solve subgrade and sub-base problems in areas where the feasible material is not readily available and with an increase in demand for cement/lime; where little or no cement/lime is required as an additive. It will also provide an advantage in that Fly Ash, which is normally disposed of at a considerable cost, can now have an economic value.

2. FLY ASH DISPOSAL

The management and disposal of the Fly Ash produced by coal-fired power plants have caused a major problem in many parts of the world, including South Africa. Disposal of Fly Ash constitutes a problem not only because of large volumes generated but also due to the possibility of environmental impacts (National Inventory, 2001). The environmental impact study for reutilization of Fly Ash in construction has produced positive results. In its natural state, it is regarded as a hazardous material, but mixed with Bottom Ash falls in the category of non-hazardous material (Mostafa Hassan & Adedeji, 2016).

2.1 Nesting Sub-sections

Fly Ash has high amounts of silicon dioxide and calcium oxide, and as a result of these, Fly Ash is a very cementitious by-product. The main component of Fly Ash is silicon dioxide, which is present in two forms: Amorphous – rounded and smooth, Crystalline – sharp, pointed and hazardous aluminium oxide and iron oxide (Mehta, 1998; Ismail et al., 2007; FA FACTS, 2003).

Fly Ash consists of silt-sized particles, which are spherical in shape, and ranges in size from 0.5 microns to 100 microns. The unique spherical shape and particle size distribution of Fly Ash makes it good mineral filler in various engineering applications (FA FACTS, 2003). Fly Ash is commonly used as a pozzolan in Ordinary Portland Cement applications. It’s colour vary from tan to dark grey, which is dependent on chemical and mineral constituents (FA FACTS, 2003). Tan to light colours is associated with lime contents while brownish colours are associated with iron contents. Dark grey to black is attributed to high unburned carbon content (Mehta, 1998).

2.2 Mechanical Properties of Fly-Ash

During combustion at very high temperature, minerals become fluid after which the minerals are cooled rapidly at the post-combustion zone. It is generally highly heterogeneous and consists of a mixture of glassy particles with various crystalline phases and a vitreous phase (Rotaru et al., 2010). The surface area of Fly Ash increases as particle size decreases. This is due to smaller particles containing large surface concentrations of potentially toxic trace elements (Oppenshaw, 1992). Fineness is an important property of Fly Ash contributing to pozzolanic reactivity (FA FACTS, 2003; Mehta, 1998; Rotaru et al., 2010).

2.3 Chemical Properties of Fly-Ash

Fly Ash is heterogeneous, consisting of a mixture of glassy particles with various identifiable crystalline phases such as quartz, mullite and various iron oxides (Ojo, 2010). The pozzolanic property is directly proportional to the amount of free lime and indirectly proportional to the amount of unburnt Carbon. Fly Ash generated from power stations contains some soluble oxides such as CaO and MgO. The chemical composition of Fly Ash is typically made of major elements such as Si, Ca, Al, Mg, Fe, Na and K (Oppenshaw, 1992). The chemical properties and composition provide the greatest variability to Fly Ash. Studies have shown that Fly Ash samples from various areas do vary in pH levels (Oppenshaw, 1992; Gitari et al., 2009). Most of the major elements exist in the core of the Fly Ash, which is relatively stable as they have probably not been volatized in the combustion process (Oppenshaw, 1992; Rotaru et al., 2010; Reynolds et al., 2002).

2.4 Classification of Fly Ash

Fly Ash is classified, worldwide, into two classes namely: Class C and Class F. Class C is a result of burning of younger lignite or sub-bituminous coal. It is pozzolanic in nature but also contains self-cementing properties. Mixed with water, the Ash will harden and gain strength over time and contains more than 20% lime. Class C primarily consists of calcium alumino-sulphate glass, quartz, tricalcium aluminate and free lime and is also referred to as high calcium Fly Ash (FA FACTS, 2003). Class F is a result of burning of old harder anthracite and bituminous coal. The Ash is pozzolanic in nature and contains less than 20% lime. It, therefore, needs a cementing agent such as ordinary Portland Cement (OPC), quicklime or hydrated lime with the presence of water to react and produce cementitious compounds. Class F Fly Ash primarily consists of an alumino-silicate glass, quartz, mullite and magnetite, referred to as low calcium Fly Ash (FA FACTS, 2003).

3. RESEARCH METHODOLOGY

Fly Ash testing is classified according to world standard test method ASTM 618 (ASTM618, 2011). In South Africa, Fly Ash is classified according to SANS 1491-2 (SANS 1491-2, 2005). Soil stabilisation causes chemical reactions which bind Fly Ash particles; therefore, chances of pollution, due to the use of Fly Ash in road works, are negligible.

3.1 Soil Stabilization with Fly-Ash Replacement

Lime and cement stabilisation have been modified by modern laboratory and field tests to fulfill a variety of stabilisation requirements (SAPEM, 2011). Improvement in terms of compression, shear, bearing or load deflection value results to strength gain and resistance to deformation. Durability is indicated in terms of resistance to moisture absorption, softening, strength reduction, freezing and thawing, wetting and drying cycles (SAPEM, 2011). This study will look at three different types of stabiliser agents and how the combination of each of separate materials can exhibit different strength versus time characteristics. The basic design steps considered for laboratory stabilisation of the Fly Ash materials obtained includes initial consumption of lime/stabiliser, Maximum dry density and optimum moisture content of laboratory mixed cementitiously stabilised materials, indirect tensile strength, CSIR erosion test.

3.2 Laboratory Test and Evaluation

Three sources of Fly Ash have been used, two from Kendal power station and one from Lethabo power station. Two of the Fly Ashes are air classified and one type is directly sourced from the ash dump at Kendal power station. Fly Ash is air classified due to its capability of providing product quality by controlling the fineness and reducing the loss of ignition (LOI) (Ash Resources, 2012). The three Fly ashes selected are namely: Durapozz, Pozzfill and Kendal Dump Ash.

3.2.1 DURAPOZZ

DURAPOZZ air classified fly ash from Lethabo power station is an internationally recognisedhigh-quality Fly Ash. DURAPOZZ is mostly used in concrete mixes where it contributes to a reduced carbon dioxide (CO2) footprint. DURAPOZZ is spherical in particle shape, has a fine particle size and is pozzolanically reactive (Ash Resources, 2012).

3.2.2 POZZFILL

POZZFILL air classified fly ash from Kendal power station does conform to some of the requirements of (SANS 50450, 2011; SANS 50197-1, 2000; or EN450-1, 2001). POZZFILL is, extensively used as reactive cementitious filler in South Africa. The unique combination of chemical and physical properties enables the product to impart significant features and benefits in cementitious systems (Ash Resources, 2012). POZZFILL, for this study, was sourced from Kendal power station. POZZFILL is also proven in road subbase, asphalt and refractory applications.

3.2.3 KENDAL DUMP ASH

Kendal Dump Ash is directly sampled from the ash Dumps at Kendal power station. Apart from DURAPOZZ and POZZFILL, an untreated sample was taken directly from the landfill dumpsite at Kendal power station.

In this study, a high percentage of Fly Ash was required to satisfy the demand requirement for strength. Although, research has shown that the percentage of Fly Ash added for stabilisation varies between 10% to about 20% depending on the quality of Fly Ash. With this in mind, (Initial Consumption of Cement and lime) ICC test was completed with the following mixtures:

% Fly Ash: 6, 9, 12, 15, 18, 21 and 24 each mixed with 1% LAFARGE CEM II 32, 5 B-M(S-V), % Fly Ash: 6, 9, 12, 15, 18, 21 and 24 each mixed with 1% AFRISAM CEM II 32, 5 B-M(S-V).

The ICC test carried out gives an indication of the pH levels the material will stabilise to meet the required strength and satisfy demand. The ICC results for the mixture with average pH readings stabilised between 9% and 15% with 1% cement are shown (see Figure 3.1 to 3.6):

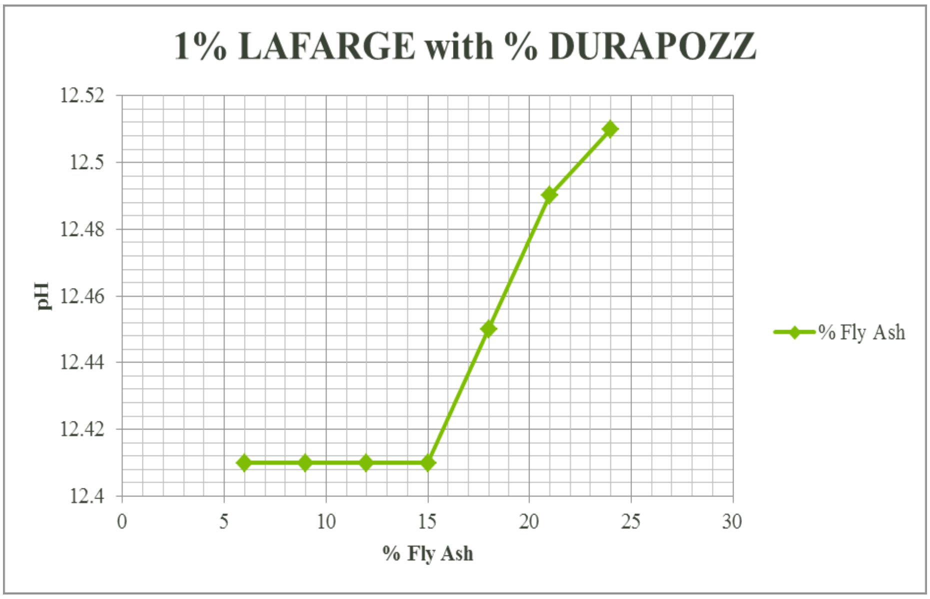

Figure 3.1 DURAPOZZ Fly Ash percentages mixed with 1% LAFARGE cement and G5 material

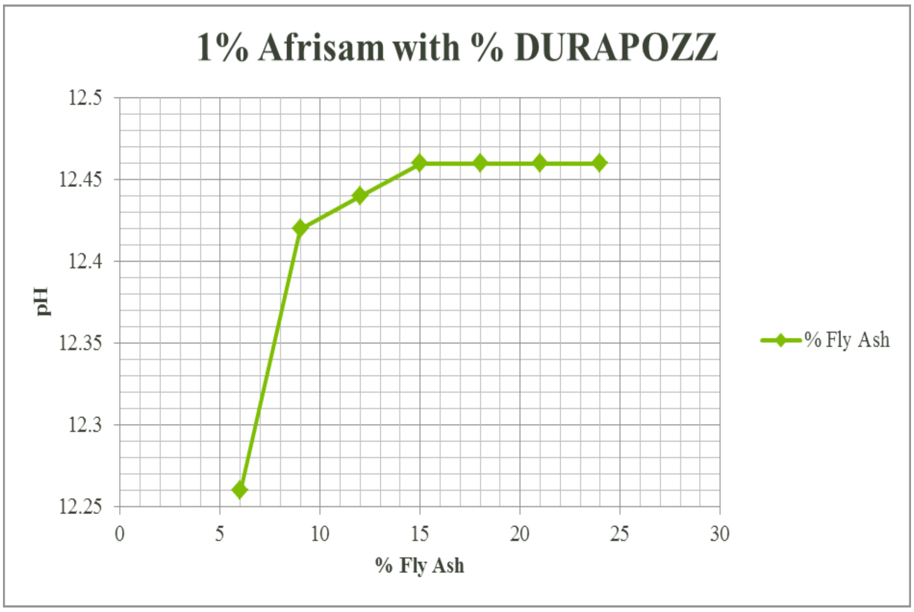

Figure 3.2 DURAPOZZ Fly Ash percentages mixed with 1% AFRISAM cement and G5 material

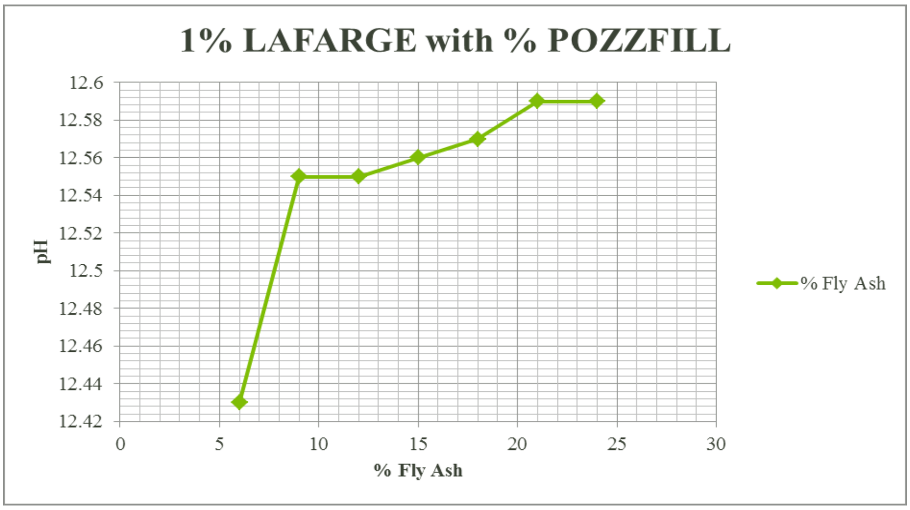

Figure 3.3 POZZFILL Fly Ash percentages mixed with 1% LAFARGE cement and G5 material

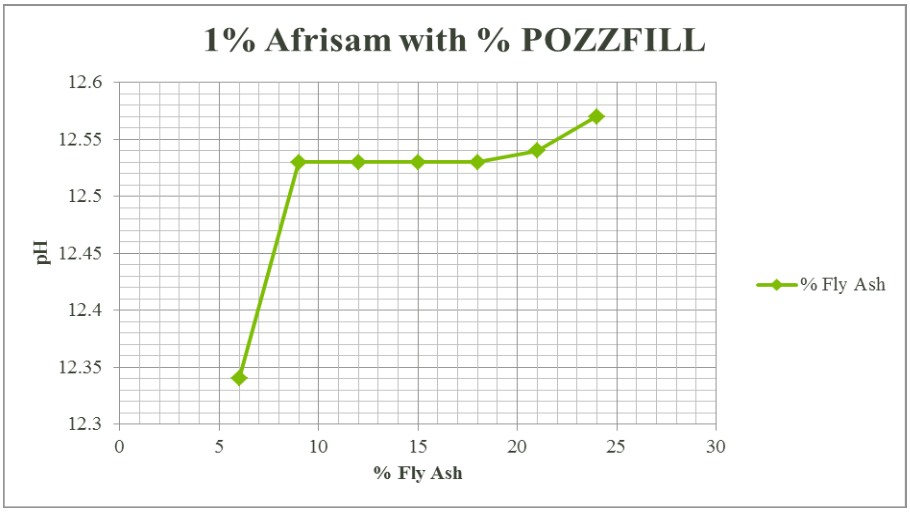

Figure 3.4 POZZFILL Fly Ash percentages mixed with 1% AFRISAM cement and G5 material

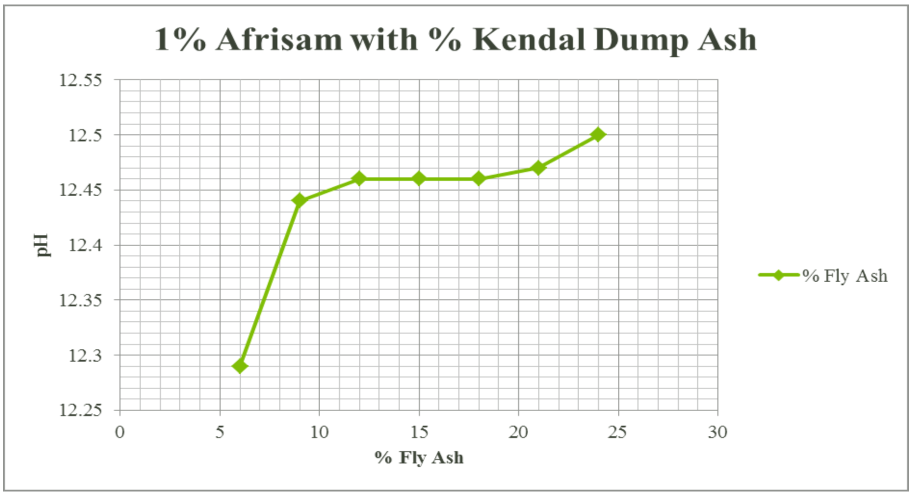

Figure 3.5 Dump Fly Ash percentages mixed with 1% AFRISAM cement and G5 material

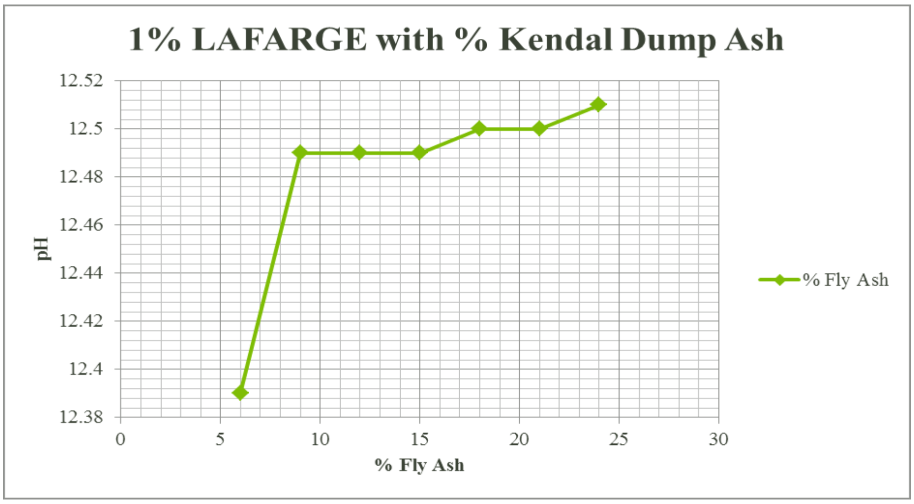

Figure 3.6 Dump Fly Ash percentages mixed with 1% LAFARGE cement and G5 material

3.3 Maximum Dry Density (MDD)

The MDD of the laboratory test results for the selected material indicates the compaction versus moisture content curve using specified compaction effort (Method A7 – TMH1, 1986). The strength test quality control of the maximum dry density and optimum moisture content of the material with Fly Ash with 16% to 22% replacement is shown in the Figure (see Figures 3.7 and 3.8):

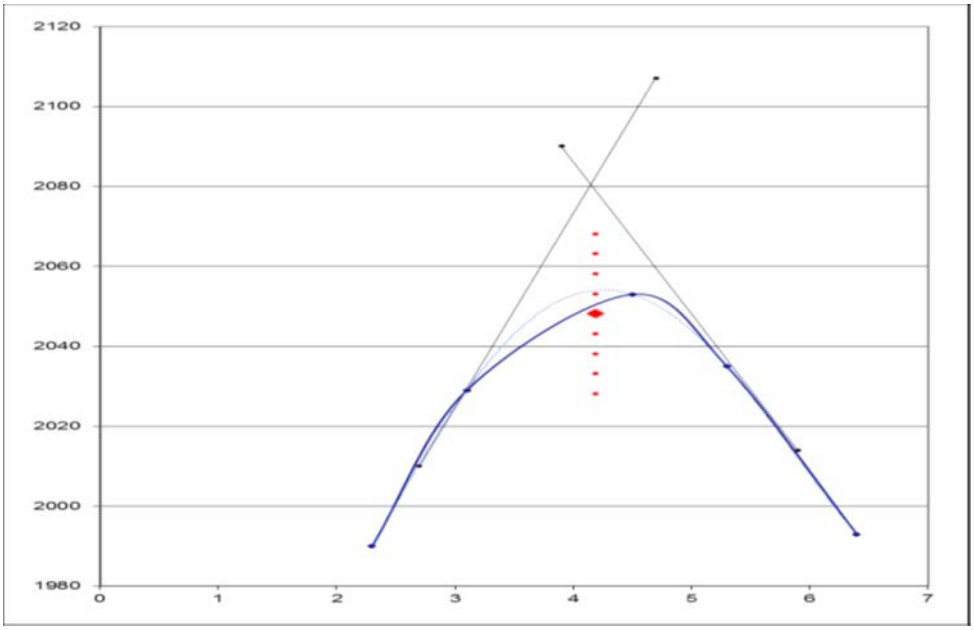

Figure 3.7 Average MDD curve for the G5 stabilised with 1% cement and 18% Fly Ash

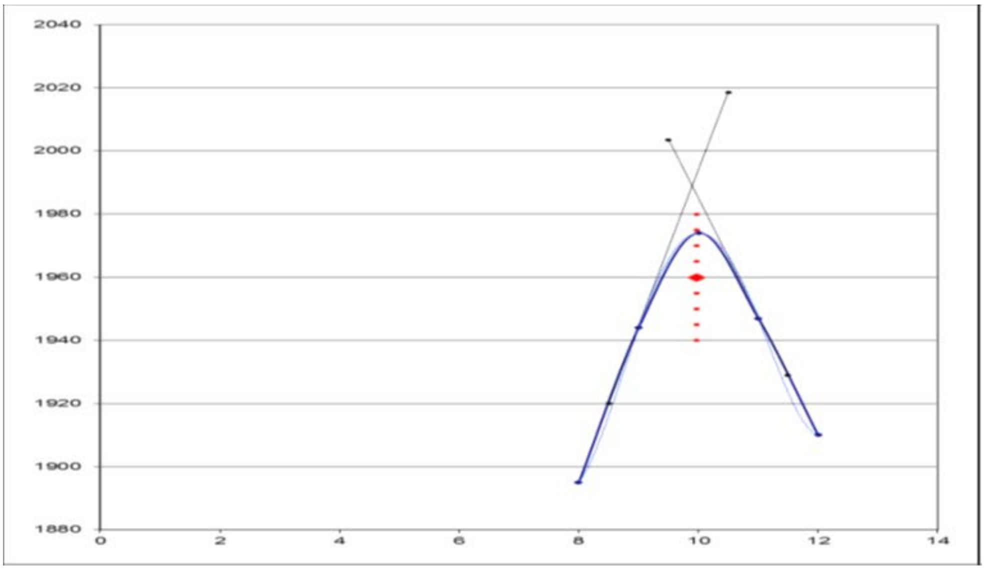

Figure 3.8 Average MDD curve for the G5 stabilised with 1% cement and 22% Fly Ash

3.4 Unconfined Compressive Strength (UCS)

The determination of the shearing resistance of the stabilised soil with percent replacement of a G5 material with 1% LAFARGE 1% AFRISAM cement was carried out to evaluate the impact Fly Ash has on the UCS/ITS of the soil as use for engineering purpose. The Tables below (see Tables 3.1 to 3.4) shows the suitability of the material and its respective classification.

Table 3.1: 16% Fly Ash with 1% Cement

	Dump Ash		Pozzfill		Durapozz	
	LAFARGE	**AFRISAM**	**LAFARGE**	**AFRISAM**	**LAFARGE**	**AFRISAM**
UCS @100%	1939	1956	3750	3310	2850	2114
ITS @100%	90	98	397	304	403	249
Classification COLTO	None	None	C3	C3	C3	C3
			Suitable for subbase construction			

Table 3.2: 18% Fly Ash with 1% Cement

	Dump Ash		Pozzfill		Durapozz	
	LAFARGE	**AFRISAM**	**LAFARGE**	**AFRISAM**	**LAFARGE**	**AFRISAM**
UCS @100%	2741	1945	3639	3539	2133	2865
ITS @100%	172	149	322	376	318	232
Classification COLTO	None	None	C3	C3	C3	C4
			Suitable for subbase construction			

Table 3.3: 20% Fly Ash with 1% Cement

	Dump Ash		Pozzfill		Durapozz	
	LAFARGE	**AFRISAM**	**LAFARGE**	**AFRISAM**	**LAFARGE**	**AFRISAM**
UCS @100%	1759	1900	3135	3830	2403	2320
ITS @100%	60	81	470	327	205	283
Classification COLTO	None	None	C3	C3	C4	C3
			Suitable for subbase construction			

Table 3.4: 22% Fly Ash with 1% Cement

	Dump Ash		Pozzfill		Durapozz	
	LAFARGE	**AFRISAM**	**LAFARGE**	**AFRISAM**	**LAFARGE**	**AFRISAM**
UCS @100%	1994	1969	2001	2298	1893	1822
ITS @100%	113	203	306	312	228	249
Classification COLTO	None	C4	C3	C3	C4	C4
			Suitable for subbase construction			

3.5 The Indirect Tensile strength test

The ITS test carried out on the Fly Ash sample was done to evaluate the tensile properties conforming to requirements for use as highway material. This was basically done to evaluate the deformation characteristics of the stabilised material. Although research has shown that cohesive or tensile characteristics of subbase significantly affect the performance of the pavement (Hudson et al., 1968). A total of twenty-four samples were tested out of which eight samples showed a decline in the ITS results while thirteen showed an improvement in the soil classification from a C4 to C3, the other four samples maintained a C4 soil classification. The Table (see Table 3.5) shows the ITS test results for Fly Ash and G5 material stabilised with cement.

Table 3.5 ITS results for G5 material stabilised with LAFARGE and AFRISAM

Cement Type	Description	%	Test	Atterberg Limits (TMH1 A2-A4) <0.425mm			UCS & ITS (TMH1 A14 & A16T)					
				LL	PI	LS	90%	93%	95%	97%	98%	100%
LAFARGE	G5 Classified Material	1.0	ITS		NP	0.0	50	79	406	143	165	223
AFRISAM	G5 Classified Material	1.0	ITS		NP	0.0	45	74	103	143	169	235

The test carried out shows that Fly Ash mixtures showed an upward trend between 16% Fly Ash and 18% Fly Ash mixtures. The LAFARGE cement shows a substantial improvement with Fly Ash mixtures mixed in 16%; the AFRISAM cement mixture showed an improvement at 18% Fly Ash mixture. This study proposes Fly Ash testing according to the following mixtures:
1% LAFARGE mixed with 16% Dump Ash, 1% LAFARGE mixed with 16% POZZFILL, 1% LAFARGE mixed with 16% DURAPOZZ, 1% AFRISAM mixed with 18% Dump Ask, 1% AFRISAM mixed with 18% POZZFILL, 1% mixed with 18% DURAPOZZ. The reason for the low percentage Fly Ash mixture is towards cost reduction in the construction phase. The less the admixture required, the less the cost implication.

3.6 Wet/dry brushing test (WDD)

The wet/dry brushing test (WDD) was performed to ensure long term durability (strength gain, permeability, dimensional stability over a long period of time under service conditions.) of the road material considered for this study. The WDD determined by the calculation of the percentage material loss after 12 cycles is shown (see Table 3.6).

Table 3.6 Wet Dry Durability Results

Wet and Dry Durability Results	
Sample Description	**% Soil Cement Loss**

1% LAFARGE + G5	23.7
1% AFRISAM + G5	20.1
1% LAFARGE + 16% DURAPOZZ	32.9
1% LAFARGE + 16% POZZFILL	10.1
1% LAFARGE + 16% DUMP ASH	29.4
1% LAFARGE + 18% DURAPOZZ	10.3
1% LAFARGE + 18% POZZFILL	9.1
1% LAFARGE + 18% DUMP ASH	54

4. RESULTS AND DISCUSSION

The results of the UCS and ITS when Fly Ash is added indicates that ITS test results on the sample has the potential to improve the tensile properties of the soil material to be used as highway construction materials. The composite mixture of the stabilising material and the soil sample indicates that the materials OMC and MDD will sustain design traffic loads through the design period of the subbase layer. The LAFARGE mixed with 16% Dump Ash showed a weaker result, but still suitable for C4 classified material. The 1% LAFARGE mixed 16% POZZFILL showed a tremendous improvement of the test results and can be used for a C3 stabilised material with substantial durability properties. Consequently, the 1% AFRISAM mixed 16% DURAPOZZ and 16% POZZFILL showed tremendous improvement in the durability and can be used as a C3 stabilised material. However, the Dump Ash fails to comply with the maximum C4 loss of 30%.

5. CONCLUSION AND RECOMMENDATION

The Fly Ash for stabilisation design was evaluated according to specifications as set out in ASTM 618, 1994. The three Fly Ash materials chosen for this study were: Kendal Dump Ash, DURAPOZZ and POZZFILL. Kendal Dump Ash was sampled directly from the dump sites while DURAPOZZ and POZZFILL were sourced from the supplier, which are processed Fly Ashes. DURAPOZZ is the highest quality processed ash that conforms to international standards, while POZZFILL only conforms to certain international standards. The Fly Ash samples obtained went through a thorough testing analysis although the results were not uniform but did have a platform for Fly Ash as a suitable choice of material for soil stabilisation due to its cementitious property especially when reacted with cement. All three Fly Ash samples showed high values of SiO2 which forms stable cementitious compounds with $Ca(OH_2)$ and allow pozzolanic reactions to continue for a longer period of time. This is critical as stabilised pavement layers are designed to remain stable for an estimated period of 20 years. Although the Dump Ash still needs to be studied in depth, it can be said that each individual stockpile needs to be assessed thoroughly.

The Dump Ash has shown that it is unpredictable and would be recommended for stabilisation of clay materials creating better working platforms to support the pavement layers above.

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