# Utilization of Fly Ash in Road Construction in South Africa: Environmental Assessment

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## ABSTRACT

Using fly ash as alterative material in place of conventional materials is continually gaining interest over decades. This results from its international recognition as non-hazardous construction material. However, fly ash composition varies and thus it cannot be generalized that every fly ash is non-hazardous. In South Africa, fly ash is produced in large quantity, yet its utilization on annual basis remains at 6 percent which is majorly utilized in cement and concrete production. Thus, this study focuses on investigating leaching of major elements in South Africa Class F fly ash when used as a stabilizer in road construction. Three different specimens of fly ashes, namely; Kendal Dump Ash, Durapozz and Pozzfill enhanced with different cements were used as stabilizer for G5 soil use in road construction. Using an X-Ray spectrometry analyser the samples were tested for any possible leach elements. Leach tests results show that fly ash enhanced with cement as soil stabilizer in road construction is not harmful as the fly ash constituents' exhibit limited mobility. However, results also indicated that fly ash left in dump sites can be harmful, if some of the leached elements find their way to the ground water. Thus, utilization of fly ash for road construction is an environmental sustainable option and has engineering advantages when properly used for soil stabilization.

**Keywords:** Class F fly ash, drinking water, leach tests, pavement materials, and soil stabilization

## INTRODUCTION

### Material Shift

Material selection for pavement design is based on a combination of suitable materials, environmental consideration, construction methods, economics and previous experience (Bureau for Industrial Cooperation, 2012). Previously, road construction had depended mainly on the virgin materials from the nearest borrow pit, but in situations where the available soil lacks some geotechnical properties or need some improvement for a particular work such soil needs to be stabilized. Soil stabilization aimed at increasing or maintaining the stability of soil mass through mechanical or chemical means (Takhelmayum, Savitha & Krishna, 2013). However, stabilizing soil using lime, cement, chemicals, plastics, rice husk ash, millet husk ash, corn cob ash, coconut shell ash, foundry sand, cement kiln dust, granular blastfurnace slag (GBS), or fly ash increases the soil's resistance, strength and permeability (Marto, Latifi & Sohaei, 2013). Furthermore, results and experience show that lime as a stabilizer yields better results than others, but its use will make pavement structure uneconomical, which in turn makes fly ash an alternative stabilizer.

### South Africa: Fly Ash Producer

South Africa is the fourth largest producer of fly ash at 30 mega ton per year after the likes of China, USA and India. This results from the fact that coal plays an important role in its economy and it serves as the primary energy source for electricity generation (National Inventory, 2001; Furter, 2011). Thus, the disposal of fly ash is increasingly becoming a major concern due to possible environmental disaster. Yet, this ash has recognition as a suitable pozzolanic material and successfully used as construction materials, even on large scale. Globally, fly ash is being used for various purposes such as; raw material for cement and concrete production, soil and asphalt stabilizer, embankment works, flow-able fill, and waste stabilizer, all owning to its cement-like property (Li, Benson, Edil & Hatipoglu, 2008; Torii, Hashimoto, Kubo, & Sannoh, 2013). Withal, South Africa only utilizes 6 percent of the

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annual production. However, one of the major factors contributing to its low utilization is the concern of contamination of the surface and ground water during leaching process. Therefore, this study focuses on investigating leaching of major elements in South Africa fly ash when used as a stabilizer in road construction.

## LITERATURE REVIEW

### Chemistry of Fly Ash

Fly ash, a finely divided residue that results from the combustion of pulverized coal, an amorphous ferroaluminium silicate with a matrix very similar to soil and its elemental composition varies with types and source of coal (Comberato, Vance & Someshwar, 1997). These ash particles are transported from the combustion chamber by exhaust gases as a result of their light weight and collected in control devices such as filter bags and electrostatic precipitators. They are spherical in shape and range in size from 0.5 micron to 100 micron. Its chemical and physical properties depend greatly on several factors such as production type, raw feed and the handling method. This in turn gives the two classes of fly ash based on the chemical composition. Class C ashes are from sub-bituminous and lignite coals and may contain more than 20 percent CaO with 1 percent to 3 percent free lime, while Class F ashes are generally obtained from bituminous and anthracite coal and contain less than 20 percent CaO with no free lime ASTM C618 (ASTM-C618, 2011).

In addition, fly ash is a heterogeneous material, which consists of major element such as; Silicon (Si), Calcium (Ca), Aluminium (Al), Magnesium (Mg), Iron (Fe), Sodium (Na) and Potassium (K) (Oppenshaw, 1992). Various trace elements also contained in Fly Ash are Cobalt (Co), Cadmium (Cd), Arsenic (As), Selenium (Se), Zinc (Zn), Molybdenum (Mo), Manganese (Mn), Lead (Pb), Boron (B), Copper (Cu), and Nickel (Ni) (Ojo, 2010; Snellings, Mertens, & Elsen, 2012). These chemical compositions give it variability in properties (Gitari, 2009). In the United States, the Environmental Protection Agency issued reports on the environmental friendliness of fly ash and protected legislatively as non-hazardous waste. In like manners, it was successfully used in transportation projects and thus, regarded as an important component of the high performance designs in Europe (American Road and Transportation Builders Association, Transportation Development Foundation (ARTB-TDF) (ARTB-TDF, 2014)).

### Fly Ash as Stabilizer

Various studies have been conducted on fly ash utilization as soil stabilizer and as an alternative to the use of virgin materials. Senol, Bin-Shafique, Edil & Benson, (2002) carried out a study on the use of self-cementing class C fly ash for the stabilization of soft sub-grade. In this study, the optimum mix design and stabilized layer thickness were estimated by strength and modulus-based approaches. The results obtained showed that the engineering properties such as unconfined compressive strength (UCS), California bearing ratio (CBR) and resilient modulus increase substantially after fly ash utilization. Also, in 2002, Pandian and Krishna conducted laboratory CBR tests on the stabilized fly ash-soil mixtures and observed that fly ash is an effective admixture for improving the soil quality. In addition, Brooks (2009) reported the soil stabilization with rice husk ash and fly ash mixed together with natural soil, the study showed improvement in CBR values and UCS. Also, researchers have proven that mixtures of fly ash with inert materials reach 50 percent to 70 percent of the strength of the corresponding cement-inactive materials (Eskioglou & Oikonomou, 2008).

According to literatures, it was noted that the use of Class C is more dominant especially in road construction while Class F is only finding usage in concrete works; this however, results from Class C self-cementing properties and its endorsement as non-hazardous material from international bodies. Generally, fly ash landfill sites are an environmental concern due to possible release of contaminants to the ground and surface water, however according to Heebink and Hassett (2001) when fly ash is used as stabilizer; chemical reaction takes place, which binds the particles of fly ash and consequently, reduce the chances to pollution. Furthermore, Heebink and Hassett conducted laboratory leaching and field run-off sample; results indicated that fly ash constituent's exhibit limited mobility. Consequently, fly ash Class C is an environmental option and of engineering advantages when used properly for soil stabilization. In essence, leachate test should be conducted on fly ash to analyse its solubility (Oppenshaw, 1992; Solc, Foster, & Butler, 1995). However, studies show that leachate of fly ash is highly variable as it's depends on the type of coal and plant in question, and also decreases with age (Moolman, 2011).

However, in South Africa, the public has not yet been convinced that fly ash is environmentally safe, due to the fact that European and American countries completed research on Class C Fly Ash and South Africa only produces Class F. Nevertheless, for a Class F to use as stabilizer, a reaction starter such as lime and cement is needed because it is low calcium (American Coal Ash Association, 1995). Yet, there are only limited studies on the environmental friendliness of Class F produced in South Africa. Considering its production per year in South Africa, the government is at the stage where it is strategically finding ways to reduce fly ash through treatment, re-use and beneficiation. Overall, the use of fly ash in road construction provides viable alternative to non-renewable primary aggregates, yet the question remains; what is the environmental impact of using Class F fly ash as soil stabilizer in road construction?

## MATERIALS AND METHODOLOGY

In this study, basic construction materials for road construction are used. A G5 granite material specified for sub-base construction and this material will be stabilized using three different Class F fly ash which are; Kendal dump ash, Durapozz and Pozzfill. Kendal dump ash was sampled directly from the dumpsite while other samples were sourced from processed fly ash suppliers. Durapozz is the highest quality processed ash in South Africa that conforms to international standards while Pozzfill only conforms to certain international standards. However, both Durapozz and Pozzfill are successfully utilized for cement production in South Africa.

As early mentioned, cement would be use to start-up the reaction process, cementing agent such as; LAFARGE CEM II 32,5 VA(S-V) and AFRISAM CEM II 32,5 B-M(S-V). The justification for the selection of these cements is because they are specially developed for stabilization purpose and commonly used for road works here in South Africa. In addition, these cements are more effective for low clay content and gain strengths early, and both cement types have an improved durability and is effective across a wide range of materials.

Based on the scope of this study, leach testing was conducted on classified G5 material stabilized with cement and fly ash with the following mixtures:

- 1% LAFARGE
- 1% AFRISAM
- 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 Ash
- 1% AFRISAM mixed with 18% Pozzfill
- 1% AFRISAM mixed with 18% Durapozz

The above mixtures were subjected to leach testing and compared to maximum allowed trace elements in water. Stabilization with fly ash and cement is not only to gain strength and meet required specifications but it can also be used to "entomb" the harmful elements that can enter and contaminate the ground water system. Once these elements are shown to be less than the maximum allowed elements found in drinking water, then it can be concluded that the use of fly ash in road stabilization can be used and that the risk of harmful elements being released to the environment will be negligible.

**FINDINGS AND DISCUSSIONS**

Using an X-Ray spectrometry analyser, elements similar to those found in other fly ash around the world were noticed in typical Class F fly ash. Some of the elements with their range in part per billion (ppb) are; Bi (3.8), Br (<2), Ce (235), Co (16), Cs (7.8), Zr (476), and those listed in Table 1 were found in this South Africa Class F fly ash. However, in order to environmentally assess this ash and understand these elements, a comparison analysis must be conducted to show the impact of their on the environment, if any. Water is the main source for human and environmental survival; therefore, elements are compared to the maximum allowed concentrations in water fit for human consumption (Bicki & Hirschi, 1993). Table 1 further showed the comparisons of required maximum allowed elements also found in fly ash with possible health effects. It must be noted that these results are from ash found in dump sites without any treatment; therefore, it is critical that leach tests are conducted for potential hazards before considering the use of fly ash in any destined road construction project. Fly ash with no treatment shows that leached elements namely: Barium (Ba), Chromium (Cr) and Lead (Pb), are of a concern once the elements have leached into the groundwater and the possible effect is also reflected in Table 1. Arsenic (As) however, is low and does not create a concern if leached into the groundwater.

Furthermore, table 1 shows higher levels of Ba and Cr in fly ash, thus this implies that fly ash left in dump sites can be harmful once leached elements find their way into the ground water. However, when samples enhanced with cement as stabilizer for G5 soil were tested, results show that the leach elements have limited mobility (Table 2) when compared with those of table 1. In addition, comparing table 1 and 2, one must keep in mind that the results in table 2 are shown as ppm while those in table 1 are shown as ppb. Considering this, the cement enhanced fly ash can be said to have experience a tremendous reduction in leach element as a result of the entombed reaction that takes place between the soil, fly ash and cement. Also, it is worthy to note that G5 soil stabilized with only cement did produced these leach elements yet, the results are all below the maximum allowable in drinking water.

*Table 1 Some elements in typical Class F Fly Ash and maximum allowable in drinking water*

| Element | Class F Fly Ash (ppb) | Maximum Acceptable Level (ppb) | Possible Effects of Higher Levels |
|---|---|---|---|
| As | 20 | 50 | Lung Cancer, kidney damage |
| Ba | 1502 | 1000 | Heart damage |
| Cr | 190 | 50 | Liver, kidney damage |
| Cu | 49 | 49 | Metallic taste, blue-green stains on fixtures |
| Pb | 54 | 50 | Brain damage |
| Se | 2.8 | 10 | Growth inhibition |
| Zn | 49 | N/A | Metallic taste |

Conclusively, fly ash at fresh stage has an approximate pH of 11.5; this pH tends to reduce to about 8.5 due to weathering process as a result of being left on dump sites (Surridge, van der Merwe & Kruger, 2009; Ayanda, Fatoki, Adekola & Ximba, 2012). However, considering the results presented in table 3, the pH of the G5 soil stabilized with cement enhanced fly ash, shows that the material maintain an alkalinity pH position. This implies that when Class F fly ash is enhanced with cement, it can perform as a stabilizer without affecting the environment negatively.

*Table 2 Leach results of G5 soil stabilized with cement enhanced fly ash*

| | Leachate (parts per million (ppm)) | | | | | | |
|---|---|---|---|---|---|---|---|
| | As | Ba | Cr | Cu | Pb | Se | Zn |
| G5 + 1% LAFARGE | 5.36 | < 4 | 8.56 | 18.89 | < 6 | < 0.4 | < 60 |
| G5 + 1% AFRISAM | 5.32 | < 4 | 8.18 | 15.91 | < 6 | < 0.4 | < 60 |
| G5 + 1% LAFARGE + 16% Dump Ash | 7.59 | < 4 | 23.97 | 16.39 | < 6 | < 0.4 | < 60 |
| G5 + 1% LAFARGE + 16% Pozzfill | 13.65 | < 4 | 58.11 | 14.88 | < 6 | 1.56 | < 60 |
| G5 + 1% LAFARGE + 16% Durapozz | 15.30 | < 4 | 46.35 | 14.24 | < 6 | < 0.4 | < 60 |
| G5 + 1% AFRISAM + 18% Dump Ash | 8.19 | < 4 | 8.89 | 17.11 | < 6 | < 0.4 | < 60 |
| G5 + 1% AFRISAM + 18% Pozzfill | 15.04 | < 4 | 59.14 | 17.14 | < 6 | < 0.4 | < 60 |
| G5 + 1% AFRISAM + 18% Durapozz | 19.41 | < 4 | 50.29 | 14.20 | < 6 | 2.33 | < 60 |

*Table 3 pH values of G5 soil stabilized with cement enhanced fly ash*

| Description | Leachate | | |
|---|---|---|---|
| | **pH** | **Alkalinity mg/L CaCO3** | **Acidity mg/L CaCO3** |
| G5 + 1% LAFARGE | 10.54 | 51.47 | 0 |
| G5 + 1% AFRISAM | 10.56 | 51.47 | 0 |
| G5 + 1% LAFARGE + 16% Dump Ash | 10.57 | 60.2 | 0 |
| G5 + 1% LAFARGE + 16% Pozzfill | 10.82 | 71.92 | 0 |
| G5 + 1% LAFARGE + 16% Durapozz | 10.77 | 66.49 | 0 |
| G5 + 1% AFRISAM + 18% Dump Ash | 10.29 | 42.89 | 0 |
| G5 + 1% AFRISAM + 18% Pozzfill | 10.65 | 60.05 | 0 |
| G5 + 1% AFRISAM + 18% Durapozz | 10.77 | 60.05 | 0 |

## CONCLUSION

Using fly ash as alterative material in place of conventional materials is continually gaining interest over decade. This results from its international recognition as non-hazardous construction material. However, it must be noted that fly ash composition varies and thus it cannot be generalized that every fly ash is non-hazardous. Although, fly ash is produced in large quantity in South Africa, yet it utilization on annual basis remains at 6 percent which is majorly utilized in cement and concrete production. Thus, this study investigated the environmental effect of Class C fly ash when used as a soil stabilizer for road construction.

The results of this study showed that trace amounts of elements which might be leached to the ground water when fly ash is used in road project is not harmful. This is based on the laboratory leach test results which indicated that fly ash constituents when used as soil stabilizer exhibited limited mobility, thus it can serve as an alternative stabilizer in road construction when used properly and environmental sustainable. Results also show that elements in fly ash vary from different classes and if South Africa Class F fly ash is left on dumps sites without utilization; potential hazardous elements can be release into the ground water and thus, before utilization for any project a full comprehensive test must be conducted at the design stage.

Furthermore, critical variables which include the sample size and particles size distribution, leachant volume, pH, and duration of leachant test. The project objective, type of material and type of data desired will determine the most appropriate method. It must be kept in mind that when tests are performed with some methods, extraneous variables, such as analytical sensitivity and sample inhomogeneity may influence the reproducibility of the results. The leach results have shown that the elements in the ash were "entombed" and the possibility of leachant releasing agents of a dangerous nature are to a minimal. The results have shown a tremendous reduction in leach agents and have shown that it is even safe if the minor leach agents do enter the drinking water tables. The leach tests in this study have shown that the fly ash enhanced with cement as stabilizer is environmental friendly. It also shows that the fly ash particles that are normally released are bound within the soil due to chemical reactions and continue to be bound as long as reactions take place.

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