ENVIRONMENTAL EFFECTS OF ROAD PAVEMENTS STABILIZED WITH CLASS F FLY ASH

M.W. HEYNS[1] AND M.M. HASSAN[2]
SURT RESEARCH GROUP
[1]CIVIL TECHNOLOGIST, JODAN CONSTRUCTION
[2]CENTRAL UNIVERSITY OF TECHNOLOGY, FREE STATE

Abstract

Fly Ash is a residue generated by coal combustion and abundantly available, but due to potentially toxic elements found in Fly Ash, is considered harmful to the environment. The objective of this study is to evaluate the environmental effects of fly ash used as a stabilization agent in road pavement construction. Using laboratory-testing specimens of fly ashes namely, Kendal Dump Ash, Durapozz and Pozzfill, stabilized with classified G5 material and 1% AFRISAM and LAFARGE cement respectively and leach testing done to evaluate chemical leach properties over time and the harmful effects it has on the environment. Laboratory leaching sample results have indicated that Fly Ash constituents exhibit limited mobility. The study revealed that Fly Ash is an environmental option and has engineering advantages when used properly for soil stabilization techniques.

Keywords: Class F fly ash, Leach tests, Environmental Effects, Drinking Water, Soil Stabilization

1. INTRODUCTION

South Africa's electricity is mostly generated by pulverized coal-fired power stations, the country has large quantities of fly ash residues that traditionally would accumulate in landfill sites. The disposal of fly ash is of major concern due to possible release of contaminants to ground and surface water after disposal. Fly Ash is recognized as a suitable pozzolanic material and has been used in construction materials successfully on a large scale. Fly Ash utilization has significant environmental benefits:

1. Fly Ash concrete requires less energy and water in production and has lower greenhouse gas emissions.
2. Reduction of coal combustion products such as landfill sites.
3. Conservation of other natural materials and resources.

The chemical and physical properties of fly ash enable it to be utilized to limit environmental damage. In South Africa, it is necessary to use fly ash in conjunction with lime or cement to achieve alkalinity to reduce leach elements into the environment. Due to that fly ash is a pozzalanic material; it can be used in the stabilization of road pavements.

With concerns raised on harmful effects related to fly ash elements contaminating surface water, it is necessary to look at leach tests for fly ash when used as an stabilizing agent. The leach is done once material has been stabilized therefore comparisons can be analyzed between landfill sites and fly ash that has been entombed into soil with cement. Objective of this study is to provide a detailed insight into leaching of major elements to assess the continued use of South Africa fly ash as sustainable stabilization agent in road construction projects. Detailed comparison will be made to drinking water as this is a major life form, which, currently is under threat worldwide. This will need to be evaluated as to show the safe use of Fly Ash in Road stabilization projects.

2. LITERATURE REVIEW

This study relates to the effects of Fly Ash on the environment with the focus on leaching properties of Fly Ash when stabilized with cement and G5 classified material.

The chemical composition of Fly Ash is typically made of major elements 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). The chemical properties and composition provide greatest variability to Fly Ash. Studies have shown that Fly Ashes samples from various areas do vary in pH levels (Oppenshaw, 1992, Gitari, 2009).

In the United States, the Environmental Protection Agency (EPA) (EPA, 1999) issued numerous reports from 1970 to date on guidelines on Fly Ash and encourages its use as an environmental friendly material. In 1980, it was legislated that the beneficial use of Fly Ash is protected under the Bevill Amendment to the Resource Conservation and Recovery Act (RCRA) (RCRA, 1976). This legislation protects Fly Ash from classification as a hazardous waste. A study done by the American Road and Transportation Builders Association, Transportation Development Foundation (ARTB-TDF) (ARTB-TDF, 2011) have noted that over the years, Fly Ash has been used in transportation projects in Europe successfully. European countries design pavements with the focus on total lifespan of the pavement. An important key to this focus is the great attention to material and mixture properties. Fly Ash is regarded as an important component of most of the high performance designs in Europe (ARTB-TDF, 2011).

In South Africa, the public has not yet been convinced that Fly Ash is environmentally safe, due to European and American countries completed research on Class C Fly Ash and South Africa only produces Class F. 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 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).

Organizations, like Electric Power Research Institute, have encouraged the use of Fly Ash. Most of the research to date are to encourage the use of Fly Ash in construction mainly concerning strength analysis and to save cost. Using Fly Ash is the solution to provide a viable alternative to non-renewable primary aggregates. Fly Ash products are recognized worldwide as an environmentally friendly alternative to the construction industry. Each ton of Fly Ash used in South Africa saves approximately one ton of CO2 emissions (National Inventory, 2001). It has been estimated that the use of Fly Ash in cement for concrete has saved in excess of 6 million tons of harmful greenhouse gas emissions in South Africa (Ash Resources, 2012). South Africa produces millions of tons of Fly Ash per annum and only about six (6) percent are utilized (National Inventory, 2001). Fly Ash landfill sites are an environmental concern due to that the release of contaminants to the ground and surface water after disposal, but, when used for stabilization, chemical reactions take place, binding the Fly Ash particles and thus the chances of pollution is minor (Heebink, 2001).

Hasset completed a study (Hasset, 2001), to evaluate coal Fly Ash in typical soil stabilization applications. The study involved three types of investigations:

1. Laboratory evaluations of Coal Fly Ash composition.
2. Evaluation of the runoff quality
3. Leaching of full scale soil stabilization projects

The studies revealed the following:

1. Fly Ash – soil leachants do not exceed limits of concern by regulatory communities for drinking water and groundwater.
2. Concentrations of the elements in long-term leachants have decreased.

One of the main environmental benefits by using Fly Ash to replace ordinary

Portland cement:

1. Recycling of Fly Ash.
2. Reduces emissions and energy required to produce cement.
3. Reduces amount of water required in concrete mixing process.

Laboratory leaching and field run-off sample results have indicated that Fly Ash constituents exhibit limited mobility.

The study revealed that Fly Ash is an environmental option and has engineering advantages when used properly for soil stabilization techniques (Heebink, 2001) Key potential hydrological impact is the collection of contaminants by water as it percolates through or over a material. Leachant tests are conducted to analyze the solubility of Fly Ash (Oppenshaw, 1992; Solc, 1995). Studies shown that leachate is highly variable depending on the type of coal and plant process. Roy et al (1981) have shown that leachability of certain elements decreased as the material aged. The pH levels of Fly Ash encourages leaching of trace metals although it has been found that high pH levels favors leaching of arsenic (Solc, 1995; Gitari, 2009; Moolman, 2011).

3. MATERIALS AND METHODOLOGY

Materials used in the study are materials used in basic road construction. The material in question is a G5 Granite material normally specified for sub base construction. Cementing agent chosen for this study were two types of cement developed by two different suppliers specially developed for stabilization purposes namely; LAFARGE CEM II 32,5 VA(S-V) and AFRISAM CEM II 32,5 B-M(S-V). These cement types are commonly used in South African road construction works. The cement is more effective for soils of low clay content and to gain early strengths. Fly Ash has a low early strength gain but continues to gain strength slowly over a longer period. Both cement types have an improved durability and is effective across a wide range of materials.

Three (3) Fly Ashes were chosen for this study namely: Kendal Dump Ash, Durrapozz and Pozzfill. Kendal Dump Ash was sampled directly from the dumpsites while Durapozz and Pozzfill 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. Both Durapozz and Pozzfill are successfully utilized for cement production in South Africa.

For the purpose of this study, Leach Testing was conducted on classified G5 material stabilized with Cement and Fly Ash with the following Fly Ash mixtures:

1. 1% LAFARGE mixed with 16% Dump Ash
2. 1% LAFARGE mixed with 16% POZZFILL
3. 1% LAFARGE mixed with 16% DURAPOZZ
4. 1% AFRISAM mixed with 18% Dump Ash
5. 1% AFRISAM mixed with 18% POZZFILL
6. 1% AFRISAM mixed with 18% DURAPOZZ
7. G5 + 1% AFRISAM
8. G5 + 1% LAFARGE

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 thus 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.

4. FINDINGS AND DISCUSSION

The elements found in common South African Class F Fly Ash conducted under an X-Ray spectrometry test, as seen in Table 1. In order to understand some of these elements, another comparison must be conducted to show the impact of these elements 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, 1993). Table 2 show 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 dumps without any treatment, therefore, it is critical that leach tests are conducted for potential hazards to be red flagged for the use of Fly Ash in any destined road construction project. The 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. The possible effect is reflected in Table 2. Arsenic (As) however, is low and does not create a concern if leached into the groundwater.

Table 1: X-Ray spectrometry tests on typical Class F Fly Ash

Parameter	Range (ppb)
As	20
Ba	150
Bi	3.8
Br	<2
Ce	235
Co	16
Cs	7.8
Cu	49
Cr	190
Pb	54
Se	2.8
Zn	49
Zr	476

Table 2: Maximum allowable inorganics accepted in drinking water

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

Table 3: Leach results for comparing to Table 2

	Leachate (parts per million)						
	Cr	Cu	Zn	As	Se	Ba	Pb
Description	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1% OPC AFRISAM	8.18	15.91	< 60	5.32	< 0.4	< 4	< 6
1% OPC LAFARGE	8.56	18.89	< 60	5.36	< 0.4	< 4	< 6
1% OPC + 16% D.POZZ LAFARGE	46.35	14.24	< 60	15.30	< 0.4	< 4	< 6
1% OPC + 16 POZZ FILL LAFARGE	58.11	14.88	< 60	13.65	1.56	< 4	< 6
1% OPC + 16% D.ASH LAFARGE	23.97	16.39	< 60	7.59	< 0.4	< 4	< 6
1% OPC + 18% DURA POZZ AFRISAM	50.29	14.20	< 60	19.41	2.33	< 4	< 6
1% OPC + 18% POZZ FILL AFRISAM	59.14	17.14	< 60	15.04	< 0.4	< 4	< 6
1% OPC +18% D.ASH AFRISAM	8.89	17.11	< 60	8.19	< 0.4	< 4	< 6

Table 2, as stated, shows the leach elements of the Fly Ash when compared to maximum allowable inorganics in accepted drinking water. High levels of Ba and Cr are found in the results therefore it can be said that Fly Ash left in dumps can be harmful once elements are leached and once the elements find their way into the ground water system. When Fly Ash is stabilized, fly ash mixtures are leached to show elements of concern as compared in Table 2. The results are shown in Table 3. The result conclusively proves that the leach elements have limited mobility when stabilized.

Table 4 (Leach Testing Results compared to Typical Class F Fly Ash) is a comparison to the typical class F analysis as shown in Table 1 (X-Ray Spectrometry test on typical Class F Fly Ash) and leach tests done as per indicated Fly Ash mixtures. One must keep in mind that the results in table 4 are shown as Parts per Million (ppm) and not as in table 1, Parts Per billion (ppb). The results in Table 4 show a tremendous reduction in leach elements when the samples are stabilized which is due to the reaction-taking place between cement, Fly Ash and soil.

Table 4: Leach testing results compared to Typical Class F Fly Ash

Description	Leachate (ppm)								
	As	Ba	Bi	Co	Cr	Cu	Pb	Se	Zn
Typical Class F Fly Ash (ppb)	20	1502	3.8	16	190	49	54	2.8	49
1% LAFARGE + 16% DURAPOZZ	15.30	< 4	1.76	< 0.2	46.35	14.24	< 6	< 0.4	< 60
1% LAFARGE +16 POZZFILL	13.65	< 4	1.72	< 0.2	58.11	14.88	< 6	1.56	< 60
1% LAFARGE + 16% DUMP ASH	7.59	< 4	1.70	< 0.2	23.97	16.39	< 6	< 0.4	< 60
1% AFRISAM + 18% DURAPOZZ	19.41	< 4	1.68	< 0.2	50.29	14.20	< 6	2.33	< 60
1% AFRISAM + 18% POZZFILL	15.04	< 4	1.76	< 0.2	59.14	17.14	< 6	< 0.4	< 60
1% AFRISAM +18% DUMP ASH	8.19	< 4	1.67	< 0.2	8.89	17.11	< 6	< 0.4	< 60
1% AFRISAM	5.32	< 4	1.70	0.44	8.18	15.91	< 6	< 0.4	< 60
1% LAFARGE	5.36	< 4	1.70	0.29	8.56	18.89	< 6	< 0.4	< 60

Microorganisms are able to degrade pollutants in soil leading to in-situ rehabilitation of pollutant soils (Surridge, 2009). Fly Ash consists of fine, powdery particles that are spherical in shape and is mostly glassy (amorphous) in nature. Bituminous coal Fly Ash is silica, alumina, iron oxide and calcium with various amounts of carbon. Fly Ash is alkaline a product of fossil fuel power generated stations. It has a pH of approximately 11.5 when fresh and due to weathering, pH reduces and stabilizes to pH value of about 8.5 (Surridge, 2009; Ayanda, 2012). Table 5 shows the pH value of the stabilized material, which shows that material stays an alkaline product.

Table 5: pH values of stabilized material with Class F Fly Ash and Cement

Description	Leachate		
	pH	Alkalinity mg/L CaCO3	Acidity mg/L CaCO3
1% OPC AFRISAM	10.56	51.47	0
1% OPC LAFARGE	10.54	51.47	0
1% OPC + 16% D.POZZ LAFARGE	10.77	66.49	0
1% OPC +16 POZZFILL LAFARGE	10.82	71.92	0
1% OPC + 16% D.ASH LAFARGE	10.57	60.2	0
1% OPC + 18% DURAPOZZ AFRISAM	10.77	60.05	0
1% OPC + 18% POZZ FILL AFRISAM	10.65	60.05	0
1% OPC +18% D.ASH AFRISAM	10.29	42.89	0

5. CONCLUSION

Fly Ash is utilized worldwide and substation documents are in place for environmental protection namely: RCRA and the EPA. Fly Ash is constantly evaluated and studied to produce reports namely:

1. Coal Fly Ash composition
2. Leaching to facilitate field performances
3. Concentrations of Fly Ash elements in long term leachants
4. Advantages of using of recycled Fly Ash
5. Report on emissions and energy produced including the reduction of landfill sites

These reports are constantly updated and are readily available for further and future studies.

A number of studies have addressed the leaching of Fly Ash residue and what impact it has on the environment. The studies have revealed that when Fly Ash is used in concrete, there is a minimal risk of leaching. Fly Ash, as shown in this study, when used in road stabilization projects, has been proved to leach only trace amounts of elements and is not harmful to the environment.

Laboratory leaching sample results have indicated that Fly Ash constituents exhibit limited mobility. The study revealed that Fly Ash is an environmental option and has engineering advantages when used properly for soil stabilization techniques.

Elements in Fly Ash vary from different classes. As shown, common Class F Fly Ash in South Africa have some potential hazardous material compared with water's maximum inorganic allowable when not stabilized as indicated in the study, a full comparison must be conducted at the design stage of an intended project, to compare what hazardous materials are leached and at what toxic level it represents.

The pH values of the stabilized material varied between 10.29 and 10.82 which shows that the material is alkaline. This will ensure continuous reactions and the leach ability of certain elements will be decreased over a period. The pH values are also not high and this will reduce the leaching of arsenic over time.

Critical variables include the sample size and particles size distribution, leachant volume and 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 repro ducibility of the results.

The Leach results have shown that the material was “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 stabilization 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.

6. ACKNOWLEDGEMENT

The authors are indebted to Ash Resources for the supply of the Fly ash samples and to Geoscience Laboratory for the undertaking of the experimental work and for Central University of Technology for funding the project.

7. REFERENCES

Ash Resources, (2003); “Dura-Pozz”, Data-Sheet, www.ashresources.co.za

Ash Resources, (2007); “Pozz-Fill”, Data-Sheet, www.ashresources.co.za

Ash Resources; (2007), “Technical Information Bulletin, Users' Guide to Handling of Fly Ash Products”, Issue 1 No 1, www.ashresources.co.za

Ash Resources; (2012), “Material Safety Data Sheet (MSDS) for Fly Ash Products and Furnace Bottom Ash”, version: (2012/1), www.ashresources.co.za
American Coal Ash Association, (2003): “Fly Ash Facts for Highway Engineers”, Technical Report No. FHWA – IF – 03 – 019.

Ayanda, OS; Fataki, OS; Adekola, FA and Ximba, BJ; (2012), “Characterization of Fly Ash Generated from Matla Power Station in Mpumalanga, South Africa”, ISSN: 0973-4945; Coden Echjhao, E-Journal of chemistry, 9(4), 1788-1795

Bicki, TJ and Hirschi, MC; (1993), “Safe Drinking Water” Land and Water Number 17, Conserving Natural Resources in Illinois, University of Illinois at Urabana – Champaign, College of Agriculture, Cooperative Extension Service

Electric Power Research Institute (EPRI), (1998); “Environmental Focus – Coal Ash: Its Origin, Disposal, Use and Potential Health Issues”

Fly ash Facts for Highway Engineers, (2003), Technical Report Document, Report No: FHWA-IF-03-019.

Gitari, M.W; Fatabo, OO; Nyamihinura, A; Petrik, LF; Vadapalli, VRK; Nel, J; Dlamini, L; Gericke, G; Mahlaba, JS; (2009), “Chemical Weathering in Dry Ash Dump: An Insight from Physicochemical and Mineralogical Analysis of Drilled Cores”, World of Coal Ash (WOCA) conference – May 4-7, (2009) in Lexington, KY, USA

Hassett, DJ and Heebink, LV; (2001), “JV Task 13 – Environmental Evaluation for Utilization of Ash in Soil Stabilization”, Final Report No: DE-FC26-98FT40321; UND Fund 4715.

Heebink, LV; Hassett, DJ; (2001), “Coal Fly Ash Trace Element Mobility in Soil Stabilization”, International Ash Utilization Symposium, Center for Applied Energy Research, University of Kentucky, Paper ♯64, http://www.flyash.info.

Moolman, D; (2011), 'Baseline Study of Kendal Power Station”, Thesis published for Magister Scientae Degree, In the Faculty of Natural and Agricultural Sciences, Institute for Groundwater Studies, University of the Free State.

Ojo F, (2010), “Chemical interactions and mobility of species in fly ash-brine co-disposal systems” Thesis published for Doctoral in Chemistry, Department of Chemistry, University of Western Cape.

Oppenshaw, SC; (1992), “Utilization of Coal Fly Ash” Thesis published for Master Degree in Engineering, University of Florida.

Resource Conservation and Recovery Act as amended, (1998), Public Law 94-580, United States Congress, Washington, D.C, October 21, 1976 National Inventory, 2001, “Discard and Duff Coal”, Summary report.

Solc, J; Foster, HJ and Butler, RD; (1995), “Environmental impact of Fly Ash disposal of Colorado, Illinois and Ohio test sites – hydrogeological approach”, Ground water quality: Remediation and Protection, Proceedings of the Prague Conference, IAHS Publ. no. 225.

Surridge, AKJ; Van der Merwe, A; Kruger,R; (2009),” Preliminary microbial studies on the impact of plants and South African fly ash on amelioration of crude oil polluted acid soils” World of Coal Ash (WOCA) conference – May 4-7.