

# **OPTIMISING THE USAGE OF FLY ASH IN CONCRETE IN THE CONSTRUCTION OF ROADWORKS**

**S Zulu and D Allopi\***

Royal Haskoning DHV House, 6 Payne Street, Pinetown, 3610

Tel: 031 719-5500; Email: [sabelo.zulu@rhdhv.com](mailto:sabelo.zulu@rhdhv.com)

\*Durban University of Technology, P O Box 1334, Durban, 4000

Tel 031 373-2310; Email: [allopid@dut.ac.za](mailto:allopid@dut.ac.za)

## **ABSTRACT**

The use of recycled materials in road construction has been around for many years and with the environment getting severely affected by the daily use of natural resources used in construction, every bit of intervention that can provide a relief to the environment is greatly welcomed. This study looked at one of the ways the industry can play a big role in promoting recycling of by-products such as fly ash, on a larger scale, in the cement and concrete industry, by utilizing the fly ash to the optimum. Concrete mixtures of 35MPa with fly ash partially substituting the cement at four levels, 30%, 40%, 50% and 60%, were produced and numerous tests were performed to determine an optimum amount of fly ash that can be used and still obtain better or comparable concrete to ordinary concrete. Performing concrete tests such as compressive strength, durability, slump and setting was done at the Durban University of Technology and Contest laboratories over a period of one year. Also a cost comparison between the ordinary concrete and fly ash concrete was done.

The results obtained during compressive testing showed that although the lowest fly ash content (30%) mixture resulted in higher strength over a year, other mixtures also obtained acceptable and very good strength. The durability index testing showed that utilizing higher fly ash content can also result in concrete with good durability qualities. Using higher fly ash content resulted in very workable concrete with good consistency. Also the cost of producing and working the concrete can be greatly reduced when the amount of fly ash is increased. The fly ash content in concrete can be used up to 50% with positive results in concrete structures and the environment. The transport sector can play a big role in promoting sustainable development by incorporating larger scale use of fly ash in construction.

**Keywords:** Fly ash, concrete, durability, cement, compressive strength, workability, environment.

## **1. INTRODUCTION**

The use of recycled materials in road construction has been around for many years and with the environment getting severely affected by the daily use of natural resources used in construction, every bit of intervention that can provide a relief to the environment is greatly welcomed. Transportation is amongst high contributors with regard to the carbon footprint and more environmentally friendly construction practices need to be implemented and promoted to help reduce the carbon emissions. It has been estimated that in the last decade, the use of fly ash (FA) products by the South African cement and construction industries has saved the country over 6 million tons of harmful greenhouse gas emissions (Ash Resources, 2009). In the USA, Leadership in Energy and Environmental Design (LEED) points, which are points awarded based on environmental performance, are available for any mixture that replaces up to 40 percent of the cement in concrete with fly ash (Crouch, Hewitt and Byard, 2007).

### **1.1 Background**

The National Building Research Institute (NBRI) of the Council for Scientific and Industrial Research (CSIR) did the first investigation into the use of South African fly ash as a cement extender in 1955 and research into fly ash and its use is still ongoing (Kearsley and Wainwright, 2003). Although there has been a usage of fly ash concrete with more than 30% cement replacement, In general practice the 30% fly ash replacing cement in concrete is considered suitable for durable concrete, and the specifications limit the fly ash usage to 30%.

Fly ash is an industrial by-product that is normally consigned to landfills and the re-use of it as cement extenders provides an immediate benefit for the environment. Each ton of fly ash used in cement, or blended into the concrete mix, saves approximately one ton of CO<sub>2</sub> emitted during the production of Portland (Bold, 2005). It is well documented around the world that the fly ash concretes perform better than pure cement in providing workability and durability of concrete. A lot of road construction projects nowadays involve using large quantities of concrete, from pavements to bridges and culverts. Many Engineers tend to stay away from specifying fly ash concrete in the road projects due to uncertainty and sometimes lack of information. Employing a fly ash blended concrete in such projects would play a huge role in promoting responsible and sustainable development.

An increase of the standard 30% fly ash amount can result in better performing concrete and consequently more relief on the environment. In some areas of construction, fly ash is used extensively with positive results. Some projects have used an increased amount of fly ash in concrete to more than 60%.

#### **1.1.1 Case studies**

Fly ash is considered a pozzolan material. It is a siliceous/aluminous material which, and in itself, possesses little or no cementitious value, but when mixed with lime (Calcium Hydroxide) and water, form cementitious compounds. The usage of pozzolanic materials dates back to the Roman times in structures such as the Pantheon and Pont du Gard and they are still standing today (Wikipedia, 2009).



**Figure 1. Pont du Gard in Gard, France.**

In recent history in the US state of Florida, a housing project in Gainesville, Madeira employed the usage of high volume fly ash successfully to promote resource-efficient construction. Approximately 33 yards of 60% Class F fly ash concrete mix was used in the construction of exterior walls and approximately 18 tons of fly ash was used to replace cement, which reduced CO<sub>2</sub> emissions into the atmosphere by approximately 18 tons (Headwaters Resources, n.d.).

Recently in Rustenburg, South Africa, in a Bus Rapid Transit (BRT) project, the Engineers opted to replace 60% of cement with fly ash from Eskom's coal-fired power plants. The project was hailed as a great success and it played a big role in mitigating climate change.

In a project at the Van Reenen's Pass, engineers were commissioned by the N3 Consultants Consortium (N3CC) to evaluate the probability of failure of an embankment, and in their designs for the concrete piles, to ensure the durability of concrete and reinforcement, they opted to blend cement with the pozzolan "Dura-Pozz", from Ash Resources. This was due to the density and impermeability being improved and the heat of hydration is low for mass pours, and also the off-shutter finish is excellent, even if small cracks develop, there is a benefit of autogenous healing where fine cracks tend to seal themselves over time in the presence of "Dura-Pozz".

## **1.2 Effects of fly ash on concrete properties**

The compressive strength is the most common performance measure used by engineers in designing structures. The use of fly ash as a partial replacement in concrete has been proven to reduce the early strength up to 28 days, but improves the ultimate strength (after more than a year) due to the pozzolanic reaction. In their study, Kumar, Tike and Nanda (2007) found that the high volume fly ash (HVFA) concrete mixtures containing 50-60% fly ash can be designed to fulfil the requirement of strength and workability suitable for concrete pavement construction.

The spherical shape of fly ash particles and their extreme fineness have a beneficial effect on the workability and durability of concrete. The greater the percentage of FA in the concrete paste, the better the lubrication of aggregates and the better the flow of concrete due to "ball bearing effect" of FA particles. The use of FA has been proven to reduce the amount of water needed to produce a given slump. The cement/water ratio could be reduced by 2% to 10% (Bold, 2005).

In concrete, lime remains intact and over time it would be susceptible to the effects of weathering and loss of strength and durability (Obla, Lobo and Lemay, 2006). Fly ash reacts with lime to create more Calcium Silicate Hydrate (CSH), produced during hydration of cement and water, resulting in a less permeable concrete. By decreasing permeability, the corrosion - caused by ingress of moisture corrosive chemicals and oxygen - protection is improved and resulting in a more durable concrete, which can be very beneficial to concrete pavements and bridges.

This study was undertaken to determine the optimum amount of fly ash that could partially replace cement in concrete without compromising the integrity of the concrete and achieve acceptable results in terms of concrete specifications. This paper contains a summary of results from the dissertation research work, where the effects of fly ash on concrete properties such as workability, compressive strength, durability and cost are evaluated.

## **2. SCOPE**

### **2.1 Methodology**

Four concrete mixtures with water/cement ratio of 0,5 (grade 35MPa) with fly ash partially replacing cement at four levels of 30%, 40%, 50% and 60% were designed and made at the DUT laboratory. 100 x 100 x 100mm concrete cube specimens were made from the mixtures in accordance to SANS 5861-3 and tested for the compressive strength of the concrete from 1 day to 1 year period as per SANS 5863. Also other specimens were made at the Contest laboratory for the durability testing in terms of Oxygen Permeability Index (OPI), Chloride Conductivity and Water Sorptivity. Slump tests were performed on these mixtures for the determination of workability in terms of consistency. The setting time of concrete was also determined under laboratory conditions.

### **2.2 Materials**

The materials used were sourced locally, although the cement and fly ash were originally from the Gauteng region. The unclassified fly ash was obtained from Lafarge and 52,5N Ordinary Portland Cement (OPC) was bought from a supplier outside from Cato Ridge. The 9,5mm stones used were sourced from the local Larfarge quarry and the fine aggregates (river sand) were sourced from a local hardware store. Sample preparation was according to TMH1 (1979). Ordinary tap water was used for mixing. No admixtures such as plasticisers or retarders were used in the experiment.

### 3. RESULTS AND DISCUSSION

The mix proportions for the 35Mpa mixture produced at the laboratory are shown in Table 1 below.

**Table 1 Mix proportions for the 35MPa concrete mixtures**

Materials (kg)	35Mpa/0FA	35Mpa/30FA	35Mpa/40FA	35Mpa/50FA	35Mpa/60FA
Cement	380	266	228	190	152
Fly ash	0,00	114	152	190	228
Stone	850	850	850	850	850
River sand	860	860	860	860	860
Water	190	190	190	190	190

#### 3.1 Workability

The most frequently used test for fresh concrete is the slump test. It determines the ease of which the concrete may be placed, compacted and moulded. The slump tests were performed on the 35MPa concrete mixtures and the results are shown in Table 2 below.

**Table 2 Plastic properties for the 35Mpa concrete mixtures**

Description	35Mpa/0FA	35Mpa/30FA	35Mpa/40FA	35Mpa/50FA	35Mpa/60FA
Fly ash (%)	0	30	40	50	60
Slump (mm)	55	70	85	85	75
Air content (%)	0,5	2,1	2,2	2,0	1,3
Density (kg/m <sup>3</sup> )	2295	2295	2296	2282	2295

From the results it is observed that with the increase of the fly ash volume, the plastic properties, especially the slump, get affected. The increase in fly ash content resulted in concrete with slightly higher slump, especially compared to the concrete containing no fly ash. As mentioned, this may be attributed to the spherical shape of the fly ash particles which promotes cohesion in the concrete. This increased slump means that the concrete with higher fly ash content can result in more workable concrete with good consistency.

#### 3.2 Time of set

The determination of setting time for a 35Mpa concrete mixture with fly ash content of 0%, 30%, 40%, 50% and 60% was done at Contest laboratory and yielded the results shown in Table 3. The setting time results show us that by increasing the fly ash content, the concrete takes longer to set. The ordinary concrete took the least time to set than the fly ash mixtures. This is consistent with the literature as the heat of hydration is lowered when the cement content is decreased, thus making the concrete set slower than ordinary.

**Table 3 Setting time for the 35MPa mixtures at a laboratory**

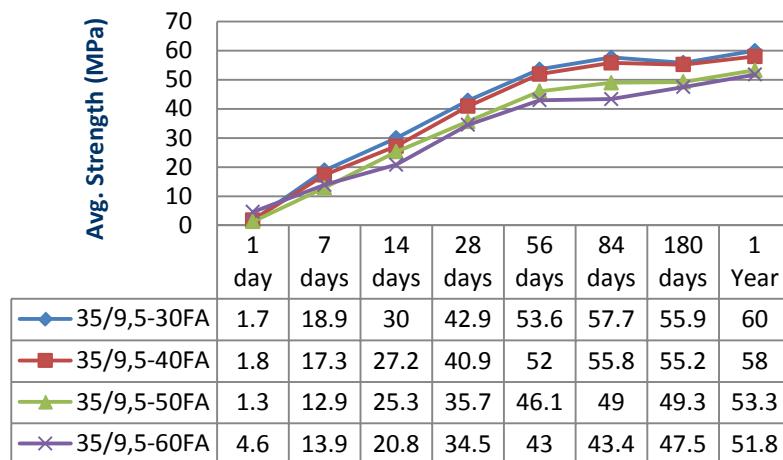
Mix Description	Lab. Reference	Initial Setting (Hrs:min)	Final Setting (Hrs:min)
35/9,5-0%FA	CT1148	7	8:45
35/9,5-30%FA	CT1032	8:40	12:24
35/9,5-40%FA	CT1039	-	13:47
35/9,5-50%FA	CT1048	10:40	13:28
35/9,5-60%FA	CT1054	11:24	14:38

### 3.3 Compressive strength

The specimens made from the DUT laboratory were tested for compressive strength from 1 day to 1 year of age, with the average of three cube specimens taken as the final results in accordance with SANS 5863. The compressive strength results of the specimens are shown in Table 4.

**Table 4 Compressive strength tests results**

Mix Description	Cast Date	Average Compressive Strength (MPa)							
		1 day	7 days	14 days	28 days	56 days	84 days	6 months	1 year
35/9,5-30FA	12/09/2013	1,7	18,9	30	42,9	53,6	57,7	55,9	60
35/9,5-40FA	23/09/2013	1,8	17,3	27,2	40,9	52	55,8	55,2	58
35/9,5-50FA	04/10/2013	1,3	12,9	25,3	35,7	46,1	49	49,3	53,3
35/9,5-60FA	10/10/2013	4,6	13,9	20,8	34,5	43	43,4	47,5	51,8

**Figure 2 Compressive strength results for the 35MPa concrete mixtures**

The compressive strength test results shown in Table 4 were represented in Figure 2. From the results it is apparent that the mixture with the lowest, 30%, fly ash content gained higher strength than the other fly ash mixtures. All the mixtures achieved acceptable compressive strength results after 28 days. It can be seen that over a period of a year, all the mixtures continued gaining strength to more than 50MPa, which is very remarkable. The results show that the fly ash can partially substitute cement beyond 50% without compromising the compressive strength of structural elements.

### 3.4 Durability

The three concrete durability index tests, namely, Oxygen Permeability Index (OPI), Water Sorptivity and the Chloride Conductivity, were performed on the grade 35MPa mixtures at the Contest laboratory. These tests give a relative indication of the resistance of the cover concrete to the ingress of chlorides and/or carbon dioxide.

#### 3.4.1 Oxygen Permeability Test (OPI)

The testing for OPI was performed after 28 days of age and is graphically represented in Figure 3. From Figure 3 it is observed that after 28 days curing period the lower fly ash mixture obtained best results, but the margin between the mixes is very small, with the 40% fly ash mix obtaining almost similar results. All the mixtures obtained very good results as the OPI values are way above 9, 5.

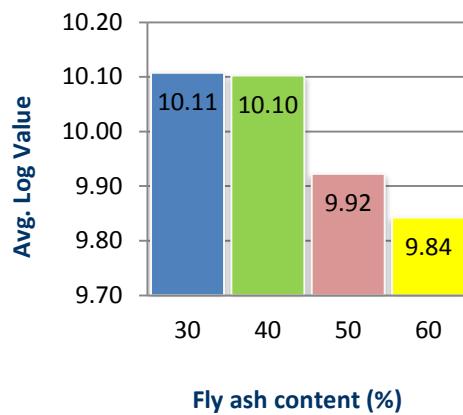


Figure 3 OPI 28-day test analysis

#### 3.4.2 Water Sorptivity Test

The water sorptivity test results for the 35MPa/9.5mm mixes with different fly ash percentage after 28 days of water curing are represented in Figure 4. The results show that the water sorptivity results are very close after 28 days as illustrated in Figure 4, with the 30% fly ash mix having the lowest value with a slight margin. The lowest fly ash mix has the best sorptivity results overall, but all the mixes have fairly good results after 28 days as they average below 11mm/ $\sqrt{\text{hr}}$ . Due to the continuous pozzolanic reaction of fly ash in concrete, it is expected that the results will improve with age.

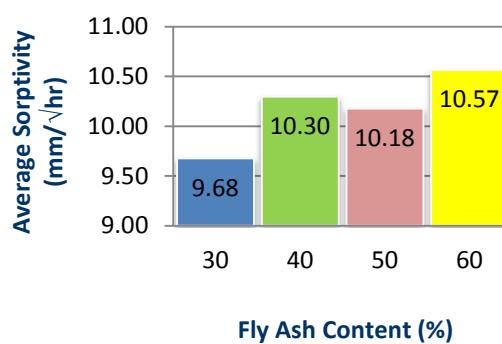
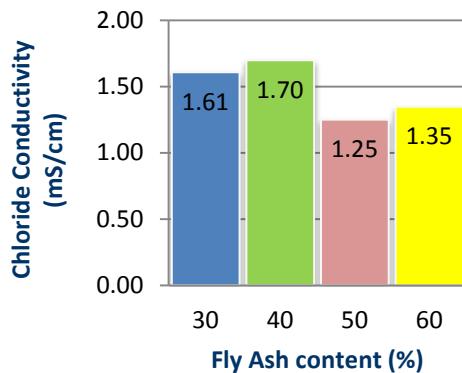


Figure 4 Water Sorptivity 28-day test analysis

### **3.4.3 Chloride Conductivity Test**

Figure 5 shows a representation of the chloride conductivity results of the different fly ash content in the 35MPa/9,5mm concrete mixtures after 28 days of curing. The figure shows that with the increase of fly ash content (the 50% and 60% fly ash mixtures) the chloride conductivity improves, with the higher fly ash mixtures obtaining results between 1,0 and 1,5mS/cm while both the 30% and 40% fly ash mixtures obtained poor but acceptable results, above 1,5mS/cm.



**Figure 5 Chloride Penetration 28-day test analysis**

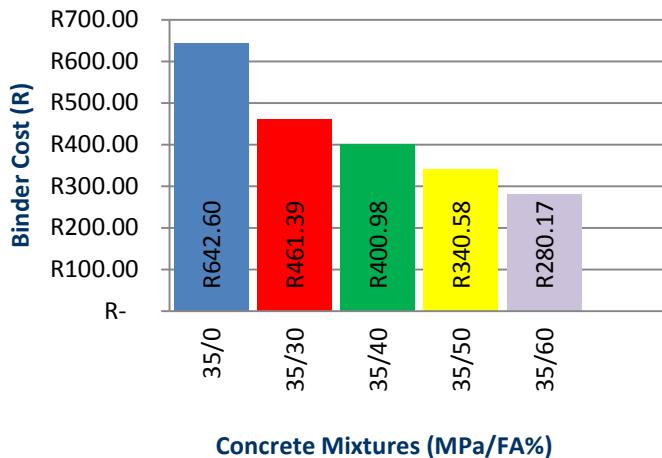
The overall durability index results obtained show that the concrete with high fly ash content can get better and acceptable durability results as illustrated in the OPI and Chloride Conductivity tests. The higher fly ash mixtures (50% and 60%) obtained better Chloride Conductivity results than the lower, 30% and 40%, which is very beneficial for structures exposed to constant harsh conditions such as pavements and bridges.

### **3.5 Cost comparison between ordinary and fly ash concrete**

For each grade on concrete mixture the cost variation is relatively proportional to the amount of cement substitution by fly ash. From the materials used in this study the cost of fly ash ranges between 6 – 12% of the cost of OPC, excluding logistical costs. The cost of the binder can therefore be evaluated according to the price of equivalent cement content by using the following formula derived by Camoes, Aguiar and Jalali (2003);

$$C = B(1-0,8*FA/B) \quad (1)$$

Figure 6 shows the cost comparisons between all the concrete mixtures at different levels of cement substitutions. The increase in the fly ash content decreases the total cost of the mixture per cubic meter, in terms of the binder. In higher W/C mixtures, the savings range from 26 - 46% per m<sup>3</sup>, where in lower W/C mixtures saving can range from 30 - 55% per m<sup>3</sup>. Although the decision of choosing the type of concrete depends on other requirements and properties, the cost of concrete does play a big role in choosing what type of concrete to use.



**Figure 6 Cost comparisons for mixtures with unclassified fly ash**

#### 4. CONCLUSIONS

Based on the results obtained from the study, the following conclusions may be drawn:

- 1) Fly ash improved the plastic properties of concrete providing better workability.
- 2) The compressive strength results show that the concrete can gain acceptable compressive strength even if the cement content is less than of fly ash.
- 3) Increasing the fly ash in the concrete mixtures can result in equally or more durable and less permeable concrete as the standard 30% fly ash concrete which is good for concrete pavements.
- 4) Due to the fact that fly ash is relatively more than 80% cheaper than cement, the substitution of cement with fly ash reduces the materials cost of the concrete.

#### 5. RECOMMENDATIONS

This study has enlightened us about how fly ash affects the concrete properties. Although the results obtained in the research were positive, continuous researches should be encouraged due to many factors. Therefore, after this study the following recommendations can be made;

- 1) The utilization of higher fly ash content in concrete should be endorsed by designers and engineers to increase the awareness and usage in the road construction.
- 2) The incorporation of fly ash in the non-structural concrete works should be exercised to promote sustainable development and responsible construction practices.

## 6. REFERENCES

- Ash Resources, 2009. [Online] Ash Resources Available at: <http://www.ashresources.co.za> [Accessed 12 August 2009].
- Bold, KK, 2005. Headwaters Resources. [Online] Available at: <http://www.flyash.com> [Accessed 24 February 2009].
- Camoes, A, Aguiar, B, and Jalali, S, 2003. Durability of Low Cost High Performance Fly ash. [Online] Available at: [www.flyash.info/2003/43cam.pdf](http://www.flyash.info/2003/43cam.pdf) [Accessed 24 February 2009].
- Crouch, LK, Hewitt, R, and Byard, B, 2007. High Volume Fly Ash Concrete. [Online] Available at: [www.flyash.info/2007/2crouch.pdf](http://www.flyash.info/2007/2crouch.pdf) [Accessed 01 APRIL 2009].
- Headwaters Resources, n.d. HVFA in the Madera Project: A Green & Profitable Residential Community Development. [Online] Headwaters Resources Available at: [www.flyash.com](http://www.flyash.com). [Accessed 29 September 2013].
- Kearsley, EP, and Wainwright, PJ, 2003. The effects of fly ash properties on concrete strength. Journal of South African Institute of Civil Engineering, 45(1), pp.19 - 24.
- Kumar, B, Tike, GK, and Nanda, PK, 2007. Evaluation of properties of high-volume fly-ash concrete for pavements. Journal of Materials in Civil Engineering, 19(10), pp.906-11.
- Obla, K, Lobo, C, and Lemay, L, 2006. Specifying Concrete for Durability. [Online] National Readymix Concrete Association Available at: <http://www.nrmca.org> [Accessed 24 February 2009].
- SANS, 1994. SANS 5863 - Concrete tests: Compressive strength of hardened concrete. Pretoria: South African Bureau of Standards.
- SANS, 2006. SANS 5862-1 Concrete tests: Consistence of freshly mixed concrete - Slump test. Pretoria: South African Bureau of Standards.
- TMH 1,1979. Standard test methods for road building materials. Published by the CSIR, Pretoria, South Africa
- Wikipedia, 2009. Fly Ash. [Online] Available at: [http://en.wikipedia.org/wiki/fly\\_ash](http://en.wikipedia.org/wiki/fly_ash) [Accessed 05 August 2009].