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EFFECTS AND BENEFITS OF USING HIGH CONTENT OF FLY ASH IN CONCRETE

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ABSTRACT

The usage of fly ash products by the South African cement and construction industries has saved the country over 6 million tons of harmful greenhouse gas emissions. The recycling of it as cement extenders provides an immediate benefit for the environment while still improving the quality of concrete, and increasing the amount used in concrete can promote sustainable development. This study evaluated properties of 35MPa/9,5mm concrete with fly ash substituted at 30%, 40%, 50% and 60%.

Increasing the fly ash content can result in more workable and less permeable concrete. The compressive strength and durability index results showed that the fly ash content can be increased beyond 50% and still achieve the required strength and produce durable concrete.

Substituting high volumes of cement with fly ash in concrete can provide good quality concrete and a relief to the environment without compromising the quality and cost of concrete.

KEYWORDS: Compressive strength, concrete, cost, durability, environment, fly ash.

INTRODUCTION

South Africa has a large power generating industry and provides about 60% of the electric power generated on the African continent [1]. Eskom utilizes pulverized coal combustion to fire their boilers. This creates fly ash (FA), a fine powdery residue collected from electrostatic precipitators, prior to releasing the flue gases to the atmosphere [2]. Fly ash is widely used, in the building and construction industry, as a cement extender in blended cements. South Africa is the fourth largest producer of fly ash, at about 30 million tons per year [3].

More than 1.2 million tons of this fly ash is used for different purposes, with the cement and concrete industries remaining the largest consumer of fly ash, but significant amounts are also used by the polymer industry as filler [1]. It has been estimated that in the last decade, the use of fly ash products by the South African cement and construction industries has saved the country over 6 million tons of harmful greenhouse gas emissions [4]. For every ton used to replace cement, the release to the atmosphere of one ton of CO_2, a greenhouse gas, is avoided [2]. 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 4 % of the cement in concrete with fly ash [5].

Background

The specifications of fly ash content as an extender limits the use to about 30%. However, research has shown that concrete with fly ash can provide environmental and economic benefits. Fly ash concrete enhances the workability, compressive strength, flexural strength and durability. FA also reduces corrosion, alkali silica reaction, sulphate reaction shrinkage as it decreases concrete permeability and bleeding in concrete [6].

As fly ash is an industrial by-product that is normally consigned to landfills, the re-use of it as cement extenders provides an immediate benefit for the environment. To reduce the CO_2 emissions related to the cement production, the use of Portland cement should be reduced without compromising the performance of concrete structures [7]. Fly ash concrete has been known to be more durable than ordinary concrete. The compressive strength of the fly ash concrete is normally lower than that of ordinary concrete at early stages, but it gets higher in the long term. In the study done by [8], the laboratory test results showed that high volume fly ash concrete mixtures, containing 50 –

60% fly ash can be designed to fulfill the requirement of strength and workability suitable for concrete pavement construction.
Also, since fly ash is abundant and readily available, the cost associated with acquiring the product is fairly cheap, especially compared to the cost of buying cement, so the cost of making fly ash concrete is relatively cheaper than conventional concrete. This paper looks at the effects of increasing the content of fly ash to about 60% and what benefits it could have on structures and sustainable development. The compressive strength and durability tests are performed and a cost comparison is done to evaluate the performance of the high volume fly ash concrete.

SCOPE
Methodology
Four concrete mixtures of grade 35MPa were designed with FA partially substituting cement at four levels of 30% (control), 40%, 50% and 60%. Cube specimens of 100 x 100 x 100mm were made and tested at the Durban University of Technology (DUT) laboratory for compressive strength from 1 day to 1 year period as per [9]. Other test specimens, for the 35MPa mix were made at the Contest laboratory for the durability index testing in terms of Oxygen Permeability Index (OPI), Chloride Conductivity and Water Sorptivity as outlined in [10]. Slump tests were performed and other plastic properties were determined under laboratory conditions.

Materials Used
All the aggregates used in the experiment were locally available. The 9,5mm crushed tillite coarse aggregates were obtained from the local Lafarge quarry and the fine aggregates were purchased from the local hardware store. Tap water was used in the experiment. 52,5R OPC non-blended cement was used and the unclassified fly ash was obtained from Lafarge.
Fly ash and Portland cement have the same chemical elements but the major difference between these materials is the relative quantities of the different oxides.
The table below shows the comparison from [4], between the fly ash and the cement chemical properties.

Table 1. Typical chemical analysis comparison

Product	CaO	SiO2	Al2O	Fe2O3	MgO
Portland cement	66	21	5	2,5	1,5
Fly ash	4-7	47-55	30-34	3-4	1-2

Mixture proportions
For each mixture the aggregates and the total binder quantities remained the same with only the cement/ fly ash content changing, to control the effect on the concrete due to the fly ash content only. The mixture proportions for the mixes are shown in the Table 2.

Table 2. Concrete mixture proportions

Concrete Mix (MPa/FA%)	W/C	Water (litres/m3)	Total Binder (kg/m3)	Cement (kg/m3)	Fly Ash (kg/m3)	Stone (kg/m3)	Sand (kg/m3)
35/30	0,5	210	420	294	126	850	800
35/40	0,5	210	420	252	168	850	800
35/50	0,5	210	420	210	210	850	800
35/60	0,5	210	420	168	252	850	800

RESULTS AND DISCUSSION
Plastic properties
The slump tests were performed at the laboratory as per [11], and the results are shown in Table 3 which shows the plastic properties for the 35MPa mixtures.

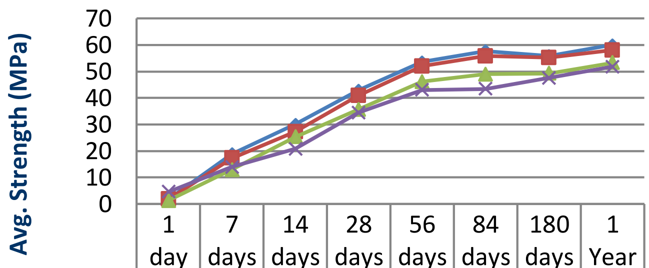
Table 3. Plastic properties of the 35MPa concrete mixtures

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^3)	2295	2295	2296	2282	2295

From the results obtained it is observed that with the increase of the fly ash volume can affect the plastic properties and the consistency of concrete. The increase in fly ash content resulted in concrete with slightly higher slump, especially compared to the concrete containing no fly ash. This increased slump shows that the concrete with higher fly ash content can result in more workable concrete with good consistency.

Compressive strength

The specimens for testing of compressive strength were made at the DUT laboratory and tested from 1 day to 1 year, in accordance with [9]. The compressive strength results are represented in Figure 1



	1 day	7 days	14 days	28 days	56 days	84 days	180 days	1 Year
35/9,5-30FA	1.7	18.9	30	42.9	53.6	57.7	55.9	60
35/9,5-40FA	1.8	17.3	27.2	40.9	52	55.8	55.2	58
35/9,5-50FA	1.3	12.9	25.3	35.7	46.1	49	49.3	53.3
35/9,5-60FA	4.6	13.9	20.8	34.5	43	43.4	47.5	51.8

Figure 1: Compressive strength results of 35MPa mixtures

From the results it is observed that the control mixture, with the 30% fly ash content, gained higher strength than the other fly ash mixtures. All the mixtures achieved acceptable compressive strength results, at 35MPa and beyond, after 28 days. The 56 day strength results improved considerably. It can be seen that over a period of a year, the mixtures continued gaining strength, with all the mixtures gaining more than 50MPa. The results show that the fly ash can partially substitute cement beyond 50% without compromising the compressive strength of structural elements.

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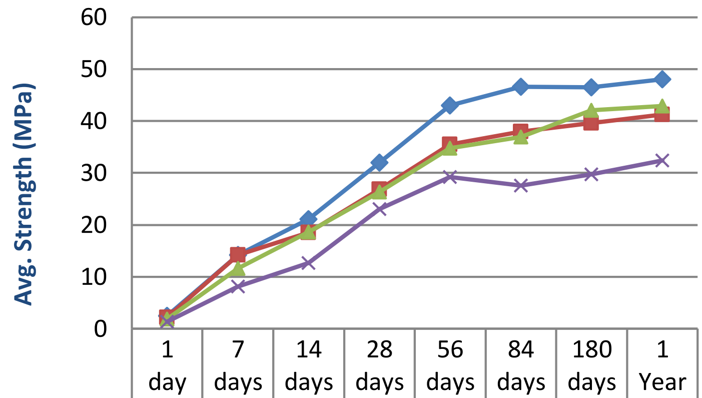

	1 day	7 days	14 days	28 days	56 days	84 days	180 days	1 Year
25/9,5-30FA	2.5	14.2	21.1	32	43	46.6	46.5	48
25/9,5-40FA	2.2	14.2	18.5	26.8	35.5	38	39.6	41.2
25/9,5-50FA	1.9	11.6	18.6	26.3	34.8	36.9	42.1	42.9
25/9,5-60FA	1.4	8.1	12.7	23	29.2	27.6	29.7	32.4

Figure 2. Compressive strength results for the 25MPa concrete mixtures

Durability

The three South African 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. Table 4 shows the acceptance criteria for durability indices in South Africa, obtained from [10].

Table 1. Acceptance criteria for Durability Index testing

Acceptance Criteria		**OPI (Log scale)**	**Sorptivity (mm/√h)**	**Cl Conductivity (mS/cm)**
Laboratory concrete		>10	<6	<0,75
As-built Structures	Full acceptance	>9,4	<9	<1.00
	Conditional acceptance	9,0 to 9,4	9 to 12	1,00 to 1,50
	Remedial measures	8,75 to 9,0	12 to 15	1,50 to 2,50
	Rejection	<8,75	>15	>2,50

Oxygen Permeability Test (OPI)

The testing for OPI was performed after 28 days of age and is graphically represented in Figure 2. It is observed that after 28 days curing period the lower fly ash mixture (30%) 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, 4.

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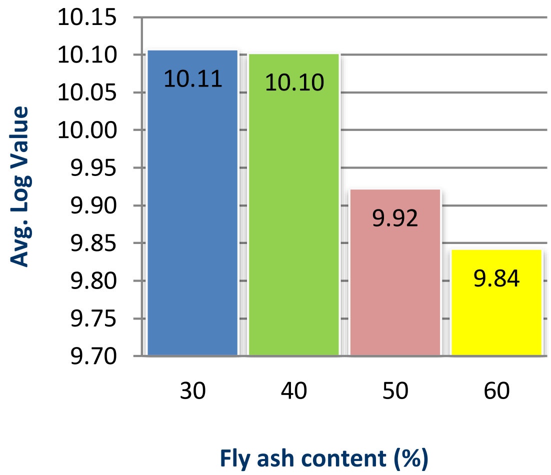

Figure 2. OPI test results for the 35MPa concrete mixtures after 28 days

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 3. The results show that the water sorptivity results are very close after 28 days, with the 30% fly ash mix having the lowest value. The lowest fly ash mix has the best sorptivity results overall, but all the mixes have good results after 28 days, averaging below 11mm/√h. It is expected that the results will improve with time due to the pozzolanic reaction.

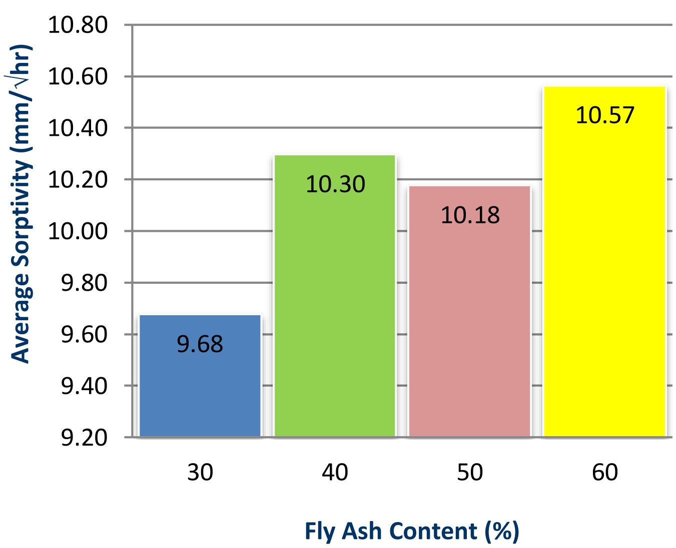

Figure 3. Water Sorptivity test results for the 35MPa concrete mixtures after 28 days

Chloride Conductivity Test

Figure 4 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.

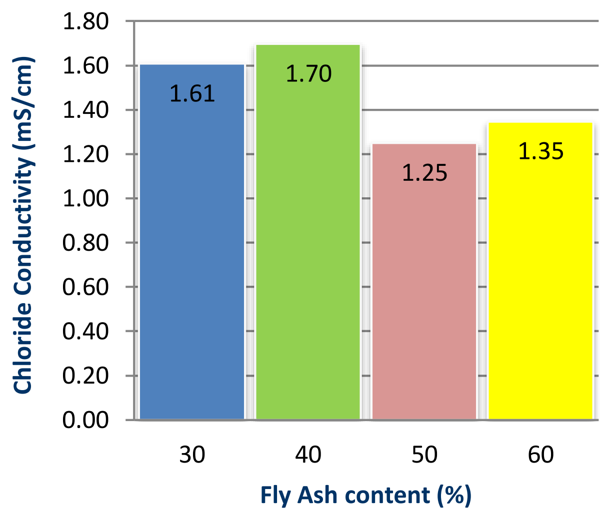

Figure 4. Chloride Conductivity test results for the 35MPa concrete mixtures after 28 days

Cost Comparison

When comparing the cost of the concrete mixes, the main differences are related to the total binder content. 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 [5];

$$C = B\,(1-0{,}8*FA/B) \qquad (1)$$

The cost analysis of concrete mixtures with unclassified fly ash was done and presented in Figure 5. Figure 5 shows that the concrete mixtures without fly ash as cement substitute would relatively cost more than a mixture with fly ash content as a partial cement substitute. The graph shows that 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 due to using fly ash as a partial substitute can range from about 26% to about 46% per cubic meter of concrete, depending on the substituted amount of cement. Where in lower W/C mixtures saving can range from 30% to 55% per cubic meter of concrete.

It is noted that the cost of 25MPa concrete without fly ash can cost higher than 35MPa concrete with fly ash at all levels of cement substitutions and more than the 50MPa with 50 and 60 per cent substitutions of cement.

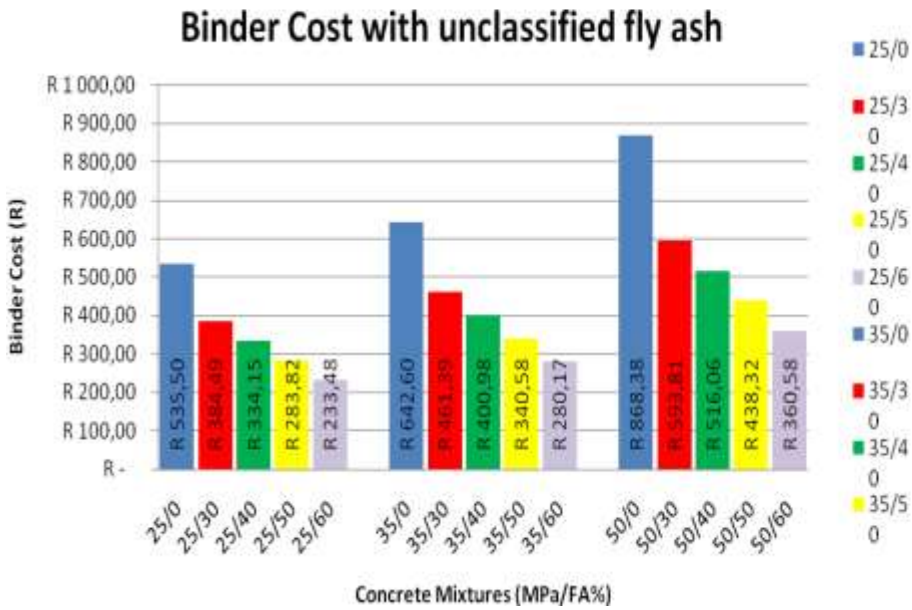

Figure 3: Cost comparison of mixtures with different FA volume

CONCLUSIONS

Based on the laboratory test results obtained, the following conclusions may be drawn:

1. Increasing the fly ash content affects the concrete plastic properties positively and it can provide better workability, with reduced water demand.
2. The compressive strength of concrete is not compromised with the increased fly ash content as all the mixtures obtained the required strength within 28 days. The required compressive strength can be obtained even if the cement content is less than of fly ash, as seen in the 50% and 60% fly ash mixes. The strength gain continues even after a year.
3. The durability index results 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.
4. The overall cost of concrete can be decreased by using more fly ash in concrete and still obtain high quality concrete.

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REFERENCES

[1] J. H. Potgieter, "Fly Ash Research at Technikon Pretoria, South Africa," *Energeia,* vol. 14, no. 1, pp. 1-3, 2003.

[2] South African Coal Ash Association, "South African Coal Ash Association," [Online]. Available: www.coalash.co.za. [Accessed 07 February 2014], 2010.

[3] E. Furter, "sheqafrica," [Online]. Available: http://www.sheqafrica.com, 2011.

[4] Ash Resources, [Online]. Available: http://www.ashresources.co.za. [Accessed 12 August 2009], 2009.

[5] L.K. Crouch, R. Hewitt and B. Byard , "High Volume Fly Ash Concrete," [Online]. Available: www.flyash.info/2007/2crouch.pdf. [Accessed 01 April 2009], 2007.

[6] Y. Shrivastava and K. Bajaj, "Performance of Fly Ash and High Volume Fly Ash Concrete in Pavement Design," in IACSIT Coimbatore Conferences, Singapore, 2012.

[7] A. Camoes, B. Aguiar and S. Jalali , "Durability of Low Cost High Performance Fly ash," [Online]. Available: www.flyash.info/2003/43cam.pdf. [Accessed 24 February 2009], 2003.

[8] B. Kumar, G.K. Tike, and P.K. Nanda,, "Evaluation of properties of high-volume fly-ash concrete for pavements," in JOURNAL OF SOUTH AFRICAN INSTITUTE OF CIVIL ENGINEERING, VOL. 45, NO. 1, pp. 906-911, 2007.

[9] SANS, "SANS 5863 - Concrete tests: Compressive strngth of hardened concrete," South African Bereau of Standards, Pretoria, 1994.

[10] Anonymous, "Durability Index Testing Procedure Manual," UCT, 2007. [Online]. Available: http://www.civil.uct.ac.za. [Accessed 27 10 2013], January 2007.

[11] SANS, "SANS 5862-1 Concrete tests: Consistence of freshly mixed concrete - Slump test," South African Bureau of Standards, Pretoria, 2006.

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