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Influence of high content fly ash on concrete durability

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Abstract* - 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. 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 while still improving the quality of concrete. Fly ash blended cements in concrete perform better than pure cement in providing better concrete properties. Current specifications limit the use of fly ash in concrete to 30%, although an increase of this amount can be very beneficial in concrete structures, economically and environmentally. In South Africa the durability index of concrete is commonly determined by performing the Oxygen Permeability test, Water Sorptivity test and Chloride Conductivity test, developed by the Universities of Cape Town and the Witwatersrand. Performing these tests in this study, the results obtained showed that concrete mixes with fly ash content that is higher than the specification limit can result in concrete with acceptable good durability qualities, and with age, the durability qualities are improved due to pozzolanic reactions. Substituting high volumes of cement with fly ash in concrete can provide high quality concrete and a relief in the environment without compromising the quality of concrete.

Index terms -**Concrete, durability, environment, fly ash.**

I. INTRODUCTION

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 [1]. Also 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 [2].The specifications of fly ash content as an extender limits the use to 30%. However, research has been done with results showing that the use of fly ash as a partial cement extender or substitute in concrete mixes improves the concrete properties. Also the use of fly ash in concrete provides a great relief to the environment in terms of cement production and recycling of the by-product. 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_2 emitted during the production of Portland [3].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 [4]. With the compressive strength of concrete being the most common performance measure used by engineers in designing structures, the durability of concrete is vital to ensure that structures can withstand most environmental and chemical attacks for a prolonged period. Durability is the ability to maintain integrity and strength over time [3]. Two concrete specimens with equal strengths can vary widely in their permeability, resistance to chemical attack, resistance to cracking and general deterioration over time, all of which are important to durability. In ordinary concrete, lime remains intact and over time it would be susceptible to the effects of weathering and loss of strength and durability [5]. Fly ash reacts with lime to create more calcium-silicate hydrate (CSH) produced during hydration of cement and water, thereby closing the capillaries that allow the movement of moisture through the concrete, resulting in a less permeable concrete [2]. By decreasing permeability, the corrosion - caused by ingress of moisture corrosive chemicals and oxygen - protection is improved.

II. DISCUSSION

A. Background

Durability of concrete can be defined as its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration, and hence to retain its original shape, dimension, quality and serviceability. The use of fly ash as a partial cement substitute in concrete has proven to produce concrete that is more durable. The increase in the fly ash content could prove not only to be beneficial environmentally but also economically as more durable structures cost less to repair. The durability of concrete depends, to a large extent, on permeability and diffusivity. Permeability is defined as the property that governs the rate of flow of a fluid into a porous material under a hydraulic gradient. Diffusivity is defined by Fick's law, and it is the rate of moisture migration under a concentration gradient at the equilibrium diffusion condition. Since both the permeability and diffusivity are related to the pore structure of concrete, concrete with low permeability will also possess low diffusivity. Means to reduce permeability and diffusivity (e.g. use lower w/c ratio to reduce capillary porosity, specification of cement content high enough to ensure sufficient consistency and hence proper compaction, proper curing to reduce surface cracks) are generally helpful to concrete durability. The incorporation of fly ash can result in considerable pore refinement (Joshi and Lohtia, 1997) cited by [6]. The transformation of large pores to fine pores, as a result of the pozzolanic reaction between

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Portland cement paste and fly ash, substantially reduces permeability in cementitious systems [7]. The reduced permeability of fly ash concrete can decrease the rate of ingress of water, corrosive chemicals, and oxygen [8]. This leads to enhanced durability because aggressive agents cannot attack the concrete nor the reinforcing steel embedded in it. After 28 days of curing, at which time little pozzolanic activity would have occurred, fly ash concretes are more permeable than ordinary Portland cement concretes. However, after 6 months of curing, fly ash concretes are much less permeable than ordinary Portland cement concretes due to the slow pozzolanic reaction of fly ash (Davis, 1954; Berry and Malhotra, 1986; Joshi and Lohtia, 1997) cited by [6].

B . Factors affecting concrete durability

1) Carbonation

Corrosion of reinforcement is a major cause of the deterioration of concrete structures and carbonation is widely recognised as a significant factor in this corrosion process. Carbonation of concrete is a process by which carbon dioxide from the air penetrates the concrete and reacts with the hydroxides, such as calcium hydroxide, to form carbonates. In the reaction with calcium hydroxide, calcium carbonate is formed. Carbonation lowers the alkalinity of concrete. High alkalinity is needed to protect embedded steel from corrosion. Carbonation leads to a reduction in porosity of the exposed concrete surface because the volume of the reaction product (CaC03) exceeds that of the original reactants [9]. The amount of carbonation is significantly increased in concretes with a high water-cementing materials ratio, low cement content, short curing period, and low strength. With fly ash concrete there is a low water/cement ratio as fly ash promotes workability of concrete and resulting in less porous concrete.

2) Permeability and Absorption

Permeability is the most important aspect of concrete durability. To be durable, concrete must be relatively impervious (Berry and Malhotra, 1986) cited by [6]. The strength and curing of concrete are the main factors affecting the impermeability index of concrete. For example, the impermeability index of the high strength, water-cured specimens would be greater than that for the lower strength water-cured specimens. With adequate curing, fly ash and natural pozzolans generally increase the long term strength of concrete and reduce the permeability and absorption of concrete. Tests have shown that the permeability of concrete decreases as the quantity of hydrated cementing materials increases and the water-cementitious materials ratio decreases. The absorption of fly-ash concrete is about the same as concrete without ash, although some ashes can reduce absorption by 20% or more. With the reduced levels of permeability in fly ash concrete, also the chemical attack on concrete is usually reduced. Fly ash can reduce steel corrosion by significantly reducing the permeability of properly cured concrete, to water, air, and chloride ion ingress. With proper proportioning and material selection, fly ash could improve the resistance of concrete to sulphate or seawater attack.

3) Alkali Aggregate Reactivity

Alkali Aggregate Reaction (AAR) also referred to as Alkali Silica Reaction (ASR), can be defined as the disruptive expansion and cracking can usually occur in concrete due to the reaction between the alkalis and the aggregates. The introduction of certain supplementary cementitious materials such as ground granulated blastfurnace slag (GGBS) and fly ash can reduce the risk of AAR significantly regardless of the type of aggregates used in concrete.

III. SCOPE

In this study, we looked at how the durability of concrete is affected by the increased amount of fly ash in the same concrete mixture. This work is part of a dissertation undertaken at Durban University of Technology (DUT) and was done by the author at Contest Laboratory in Pinetown, Durban, South Africa A 35MPa/9,5mm concrete mix was designed, with fly ash as cement substitute at four levels, i.e. 30%, 40%, 50%, and 60%. All the other constituents remained the same and the total binder content remained the same for all mixing proportions. This was done to examine the durability properties of the same mix with different fly ash content. Table I (see Apendices) shows the mixing proportions for the 35MPa concrete test specimen. The goal of this study is to produce a fly ash mixture with properties that were comparable to or better than a 30% fly ash mixture in terms of durability.

IV. RESULTS

A. Compressive Strength

The concrete compressive strength measures the ability of concrete to withstand loads and also the quality of concrete. This test is performed in accordance with SANS 5863:1994 [10]. The compressive strength testing for a 35MPa concrete mixture, of the mixing proportions shown in Table 1, was done at the laboratory at the Durban University of Technology. Fig. 1 shows the graphical representation of the compressive strength results from 1day to 28 days of curing in water. The results obtained show that the 30% and 40% FA concrete mixtures gained higher strength by the 28th day than the 50% and 60% FA concrete mixtures. Although the lesser cement substituted mixtures gained higher strengths, the higher FA content mixtures still obtained acceptable compressive strength results in terms of strength specifications.

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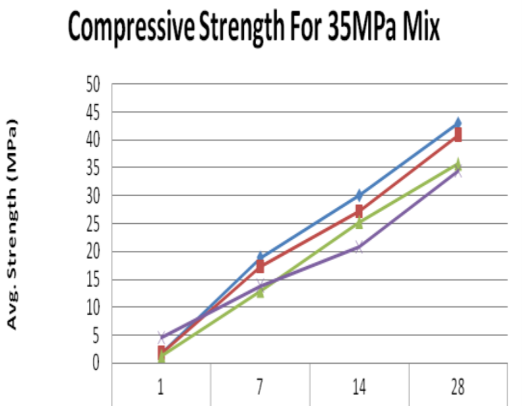

	1	7	14	28
35/9,5-30FA	1,7	18,9	30	42,9
35/9,5-40FA	1,8	17,3	27,2	40,9
35/9,5-50FA	1,3	12,9	25,3	35,7
35/9,5-60FA	4,6	13,9	20,8	34,5

Fig 1: Compressive Strength results for the 35MPa concrete mixture

A. Durability

In South Africa the durability index of concrete is commonly determined by performing the Oxygen Permeability Index (OPI) test, Water Sorptivity test and Chloride Conductivity test [11]. Durability index tests were developed by the Universities of the Witwatersrand and Cape Town and are being implemented into practice in the South African construction industry. The tests give a relative indication of the resistance of the cover concrete to the ingress of chlorides and/or carbon dioxide. In critical structures such as bridges or in severely corrosive environments such as the marine splash zone, an engineer might specify that these properties be measured and controlled during construction. In other less critical structures or less corrosive environments, the strength requirements of the concrete will most likely take precedence and limiting material type and content should suffice in achieving an adequate level of durability. The durability specifications currently used in South Africa are shown in Table II (Raath B. 2001) cited by [11].

(a) Oxygen Permeability Index (OPI) test

The South African oxygen permeability index (OPI) test method comprises measuring the pressure decay of oxygen passed through a concrete disk (typically 70 mm diameter by 25 mm thick) placed in a falling head permeameter. A pressure gradient is applied across the test specimen and subsequently the pressure decay in the pressure cell is monitored over time [11]. The test is suitable for the evaluation of materials and mix proportions for design purposes, and for research and development. The test can also be used for quality control of concrete on site. Fig. 2 shows a schematic drawing of the oxygen permeability test cell arrangement.

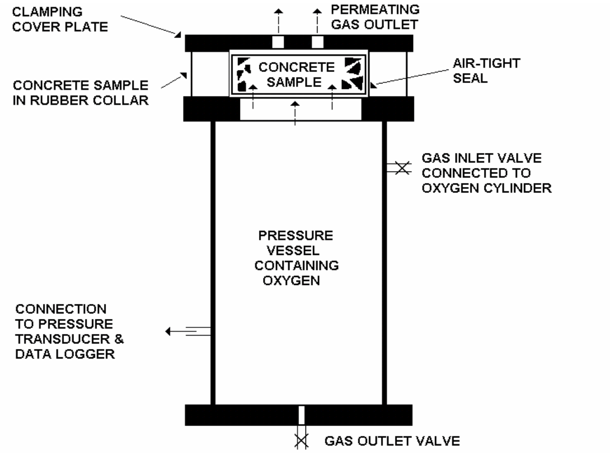

Fig 2: Schematic drawing for the permeability cell arrangement

Oxygen permeability indexes are logarithmic values and range generally from 8 to 11, i.e. three orders of magnitude; the higher the index, the less permeable the concrete.

Fig. 3 shows the representation of the results of the OPI for the 35MPa/9,5mm concrete mix with fly ash partially replacing cement at 30%, 40%, 50%, and 60%. The testing was done after 7 days and after 28 days of specimens curing.

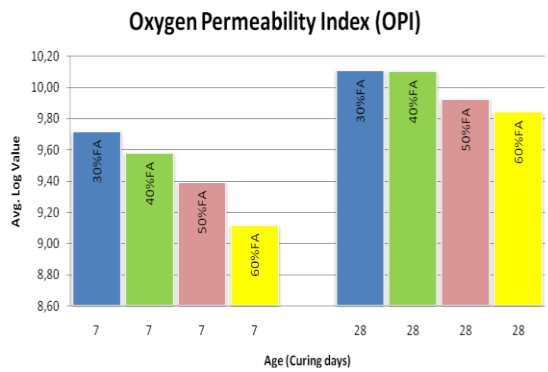

Fig 3: Representation of OPI for different FA content in 35MPa/9,5mm mixes.

From Fig. 3 above is it observed that after 7 days of curing in water for the specimens, the 35MPa/ 30%FA mix has the highest OPI value and the 35MPa/ 60%FA mix has the lowest value. This shows that the lower the fly ash content, the lower is the permeability of concrete, thus providing a more durable concrete. After 28 days curing period the trend continues but the margin between the mixes in narrowing the 30% fly ash mix having the highest value and the 40% getting similar results. All the mixes obtain very good results as the OPI values are way above 9, 5.

(b) Water Sorptivity test

Sorptivity can be defined as the rate of movement of a wetting front through a porous material. The water sorptivity test involves the uni-directional absorption of water into one face of a pre-conditioned concrete disc sample [12]. After conditioning concrete slices from cores or cylinders in a specified low humidity environment, the rate of absorption of

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water into one face of the disc is measured. Generally, sorptivity will decrease with lower w/cm and increased maturity of the concrete.The lower the water sorptivity index, the better is the potential durability of the concrete. Sorptivity values typically vary from approximately 5 mm/√h, for well-cured concrete, to 15 – 20 mm/√h for poorly cured concrete. The water sorptivity test results for the 35MPa/9,5mm mixes with different fly ash percentage after 7 and 28 days of water curing are represented in Fig .4.

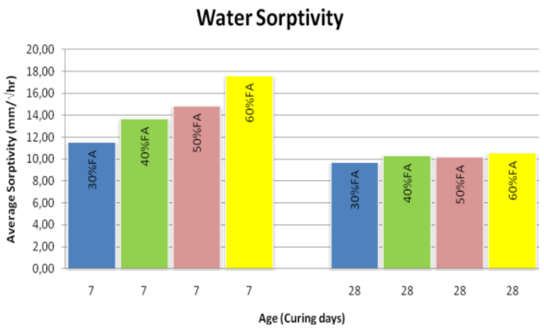

Fig 4: Water Sorptivity comparison for the 35MPa/9,5mm mixes.

Fig. 4 illustrates that the water sorptivity of the concrete mixtures are very different at early days (7 days) and they seem to be very close after 28 days, with the 30% fly ash mix having the lowest value with a slight margin. It can be seen from the graph that after 7 days of specimens curing, the higher the fly ash content, the higher the sorptivity of the concrete mixture. The results show that 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 around 10mm/√h. Due to the continuing pozzolanic reaction of fly ash in concrete, it can be expected that the results can change as time goes by.

(c) Chloride Conductivity test

The South African chloride test involves the measurement of a sample's electric conductivity [12]. Four test specimens are required per test. The test specimen shall consist of a 70 ± 2 mm diameter concrete disc with a thickness of 25 ± 2 mm cored and cut in accordance with Concrete Durability Index Testing, the concrete specimens are dried in an oven and vacuum pre-saturated with a 5 M NaCl solution. A schematic representation of the test is show in Fig. 5.

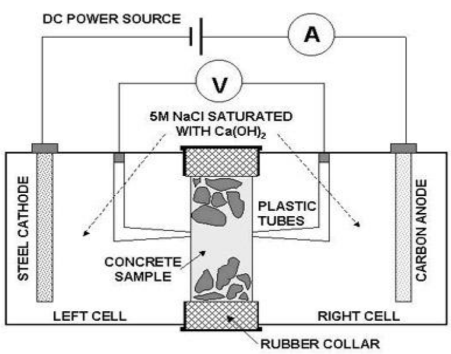

Fig 5: Schematic drawing of Chloride conductivity test apparatus

Typical chloride conductivity index values range from > 3 mS/cm for M20 – M30 OPC concretes, to < 0.75 mS/cm for M40 – M50 slag or fly ash concretes. The lower the index, the better is the potential durability of the concrete. Fig. 6 shows a representation of the chloride penetration results of the different fly ash content in the 35MPa/9,5mm concrete mixtures after 7 and 28 days of curing. Figure 6 shows that at early days (7 days), the chloride conductivity results are higher than 28 days results. At 7 days the 40% fly ash mix has the lowest index while the 60% fly ash mix has the highest index. This trend changes at 28 days with the 50% and 60% fly ash mixtures obtaining the lowest and good results between 1,0 and 1,5mS/cm while both the 30% and 40% fly ash mixtures obtained poor results, above 1,5mS/cm.

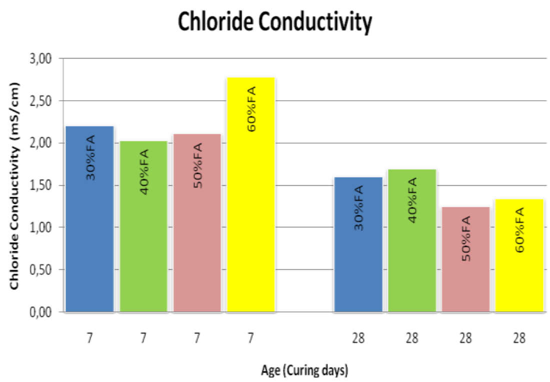

Fig 6: Chloride conductivity comparison for 35MPa/9,5mm mixes

V. CONCLUSION

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

1. The increase of fly ash content can still result in concrete mixtures with acceptable compressive strength.
2. The study shows that by increasing the fly ash in the concrete mixtures can result in equally durable concrete as the standard 30% fly ash concrete without compromising the quality of the concrete, as demonstrated in the Oxygen Permeability Index, Sorptivity and Chloride Penetration durability tests.

VI. RECOMMENDATION

More work needs to be done in South Africa with regard to specifying concrete with fly ash for durability to enable all role players in the concrete industry to be familiar with the fly ash benefits and expel certain myths that create skepticism on using fly ash in concrete.

VII. ACKNOWLEDGMENT

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REFERENCES

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

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

[3] Bold K.K., 2005. Headwaters Resources. [Online] Available at http://www.flyash.com [Accessed 24 February 2009].

[4] 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 [Accessed 24 February 2009].

[5] 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].

[6] Burden, D., 2003. [Online] Available at: http://dspace.hil.unb.ca [Accessed 27 October 2013].

[7] Manmohan, D. & Mehta, P., 1981. Influence of Pozzolanic, Slag, and Chemical Admixtures on Pore Size Distribution and Permeability of Hardened Cement Pastes. [Online] Available at: http://www.astm.org [Accessed 08 May 2013].

[8] ACI Committee 232, 2003. ACI-232.2R-03 - Use of Fly Ash in Concrete. [Online] Available at http://www.scribd.co [Accessed 12 May 2013].

[9] Peter A. Claisse, Hanaa I. Elsayad and Ibrahim G. Shaaban, 2000. Permeability and pore volume of carbonated concrete. [Online] Available at: http://www.claisse.info/publish.htm [Accessed 07 May 2013].

[10] Holcim, 2006. Materials Handbook of Holcim South Africa. Johnson Haydenbry Afrika.

[11] The Concrete Portal, n.d. Performance Based Design for Durabilityl. [Online] Available at: http://www.theconcreteportal [Accessed 27 October 2013].

[12] Anon., 2007. Durability Index Testing Procedure Manual. [Online] Available at: http://www.civil.uct.ac.za [Accessed 27 October 2013].

AUTHOR'S PROFILE

Sabelo Zulu is a student at Durban University of Technology, in Durban South Africa, doing an M-Tech Degree in the Civil Engineering Department. The Author attained his National Diploma qualification in 2004 and has a B-Tech Degree in Civil Engineering, Structures, attained form the DUT in 2008. He is currently working as a Engineer Representative for a Consulting Company called Royal Haskoning DHV in South Africa and has over 10 years of industrial experience. This paper is the first work prepared by the Author for publication and is a part of the M-Tech Dissertation work which is ongoing. Sabelo Zulu is a registered Candidate Technologist with Engineering Council of South Africa (ECSA) and is a full member of Concrete Society South Africa (CSSA).

Prof Dhiren Allopi is the Associate Professor/Director in the Department of Civil Engineering and Surveying at the Durban University of Technology. He has five qualifications from four different tertiary institutions including a Doctorate Degree in Civil Engineering. Prof Allopi has over 35 years of combined industrial and academic experience mainly in the field of geotechnical, traffic and transportation engineering. Dhiren has over 80 conference proceedings and journal papers to his credit. He is professionally registered with the Engineering Council of South Africa and is a fellow member of the South African Institute of Civil Engineering.

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APPENDICES

Table I: Mix proportions for the 35MPa concrete mixture

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

Table II: Acceptance limits for durability indexes

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