32nd Cement and Concrete Science Conference **Paper Number XX**
17-18 September 2012
Queen's University Belfast

Concrete made with incinerator fly ash

Asma Y. Shebani
Department of Engineering and Computing, Coventry University

Peter Claisse
Department of Engineering and Computing, Coventry University

ABSTRACT

This paper reports on recent results from a programme of testing of concrete which includes fly ash from a domestic waste incinerator as a partial replacement for the cement. The incinerator fly ash was won locally from the domestic waste incinerator at Coventry. The other materials used in the mixes included ggbs, silicafume and bypass dust, which was used as an activator and was also won locally from the Rugby cement plant.

Mix designs were developed to optimise the compressive strength results. The optimised mixes were then tested for slump, viscosity, freeze and thaw, permeability, chloride migration and expansion.

In the testing reported in this paper concrete mixes were used and the results were compared with those for mortar mixes which had been tested previously during the mix development. Using concrete has considerably improved the results for the majority of the tests. However, better permeability results were observed with mortar mixes rather than concrete mixes.

Promising results were finally achieved for strength results, where a fly-ash mix recorded over 40 MPA for compressive strength at 28 days.

1. INTRODUCTION

The main theme of this research has been to investigate the durability aspects of concrete made with waste materials, in the form of cement replacements.

The mechanical, physical and chemical properties of concrete made predominantly with incinerator fly ash as a partial cement replacement have been studied. The incinerator fly ash used was won locally from the local domestic waste incinerator in Coventry. The other secondary materials which were used in the mixes were Ground Granulated Blastfurnace Slag (GGBS) Silica Fume (SF) and cement kiln bypass dust (BPD). The BPD was used as an activator and was also obtained locally from the Cemex cement plant in Rugby.

2. PREVIOUS WORK

2.1 RESEARCH FINDINGS FROM PREVIOUS YEARS

The development of the mixes used in this work has been reported (Shebani 2010 and 2011)

3 EXPERIMENTAL METHOD

3.1 MIX PREPARATION

Designs are in Table 1.

Mixes 2011

Cast Date	Mix	Proportions	W/B Ratio	Type of curing
06/05/11	Mix 1	10% SF, 32.5% IFA, 2.5% SP, 15% BPD, 10% GGBS, 30% OPC	0.5	Dry
06/05/11	Mix 2	10% SF, 32.5% IFA, 2.5% SP, 15% BPD, 10% GGBS, 30% OPC	0.5	Wet
20/05/11	Mix 3	100% OPC	0.5	Dry
20/05/11	Mix 4	100% OPC	0.5	Wet
03/06/11	Mix 5	100% OPC	0.6	Dry
03/06/11	Mix 6	100% OPC	0.6	Wet
17/06/11	Mix 7	10% SF, 32.5% IFA, 2.5% SP, 15% BPD, 10%	0.6	Dry

		GGBS, 30% OPC		
17/06/11	Mix 8	10% SF, 32.5% IFA, 2.5% SP, 15% BPD, 10% GGBS, 30% OPC	0.6	Wet

A mixer with a maximum capacity of 80 litres was used to prepare the mixes. The mix designs are shown in Table 1.

3.2 CURING THE SAMPLES

Both wet and dry curing was applied, as shown in Table 1. Wet curing was carried out in a tank at 20 ^{o}C and dry curing was in laboratory air at the same temperature. The samples were cured for 90 days, measuring compressive strength at 7, 28 and 90 days. Samples from eight various mixes were cured and tested as listed in Table 1.0

3.3 WORKABILITY MEASUREMENTS

Workability was measured with slump test to EN12350 and also with an ICAR rheometer (Germann Instruments 2007). The device was linked to a desk top computer, recording all results. Also, the computer contained the system/operating software for the machine. Results were also calculated for Torque and Viscosity

3.4 STRENGTH MEASUREMENT

Compressive strength was measured to EN12390.

3.5 CHLORIDE MIGRATION MEASUREMENT
Chloride migration was measured to ASTM C1202. Cylindrical samples were used, 50mm thick and 100mm dia. The concrete samples were initially de-aerated for 18 hours to remove all air from the concrete pores. They were then placed in cells with Potassium chloride aqueous solution in one side and sodium hydroxide base solution on the other side. 60 volt D.C was then applied across them. Current readings were taken hourly for six hours throughout the test.

3.6 FREEZE-THAW TESTING

Samples were placed in an environmental chamber and subjected to freezing and thawing. The temperature rises as high as 4.4 C and drops as low as -17.8 C in a cyclic fashion, totaling 300 cycles, each cycle lasting for 5 hours, giving a total duration of 60 days for the test.
The Chamber is connected that computer that has an operating software performing the test to ASTM C666.

3.7 EXPANSION

Mortar were tested for expansion/shrinkage effects using an expansion frame with a digital displacement gauge.

The samples were thin Beams 15 x 15 x 200mm in length, that were cast and cured for 28 days taking measurement of their expansion/shrinkage at 3 days, 7 days, 14 days, and 28 days, during curing.

3.8 PERMEABILITY RESULTS

Permeability was both measured in 2010 and 2011. Results of 2010 were published in last year's conference (Shebani 2011). In 2010, it was measured using mortar samples, however, in 2011 it was measured using concrete samples. A Coventry University developed apparatus was used for carrying out the experiment that gave correlated results with what is expected in research and industry.

4 RESULTS

4.1 WORKABILITY

4.1.1 Slump

Generally, high slump values were achieved however, they did not have a detrimental effects on compressive strength results. They are shown in figure 1.

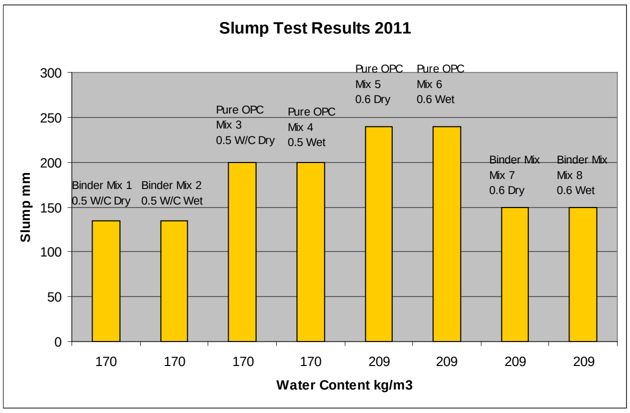

Figure 1. Slump values.

4.1.2 Viscosity.

The results are shown in figure 2. Each of the tests, where Binder Mixes showed high viscosity as opposed to pure OPC mixes. This is because, mixes with high quantities of IFA generally require more moisture content for the ash being more water absorbent, thus having higher viscosity readings.

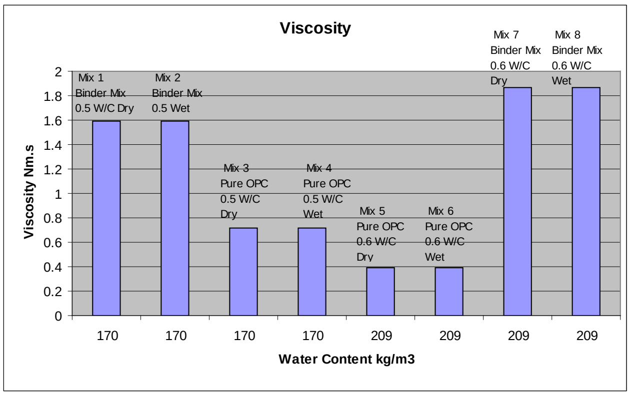

Figure 2. Viscosity results.

The comparison of slump and viscosity is shown in figure 3 showering that mixes with higher slump test values have lower viscosity readings

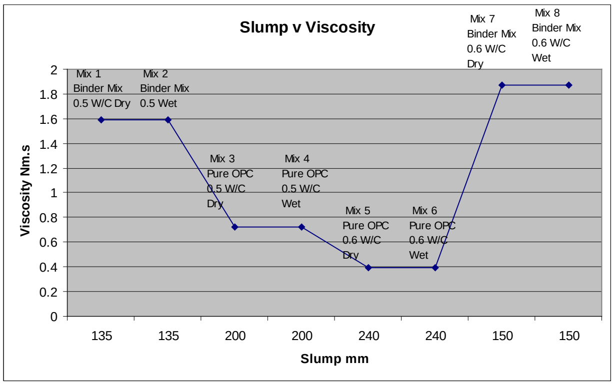

Figure 3. Slump vs viscosity.

4.2 STRENGTH

Figure 1 shows the Compressive Strength results

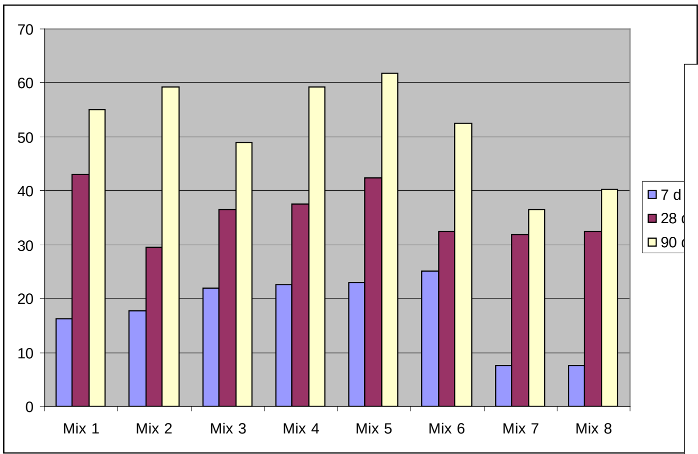

Figure 4. Compressive strength of 100mm cubes

The results achieved for the compressive strength (figure 4), both for the control samples and the binder mix samples. Results as high as 43 MPA at 28 days were achieved for the binder mix..

4.3 CHLORIDE MIGRATION

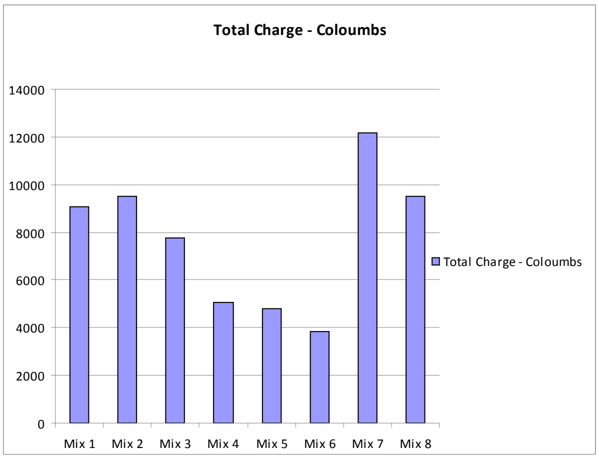

Figure 5. Chloride migration results.

The chloride migration results are in figure 5. It may be seen that the samples with incinerator ash (mixes 3-6) had generally lower charge passing.

4.4 FREEZE THAW RESULTS

All samples tested for Freeze Thaw underwent a degree of shrinkage (figure 6). However, one binder sample of mix 8, having 0.6 Water/Binder Ratio and wet cured failed completely and collapsed, as can be seen from figure 6.0. On the other hand all other remaining samples remained intact after being through all the cyclic events of freeze and thaw at extreme temperatures as high as 160 C and as low as -80 C. ASTM International C666 (1997)

The Weight Loss is shown in Figure 7.0

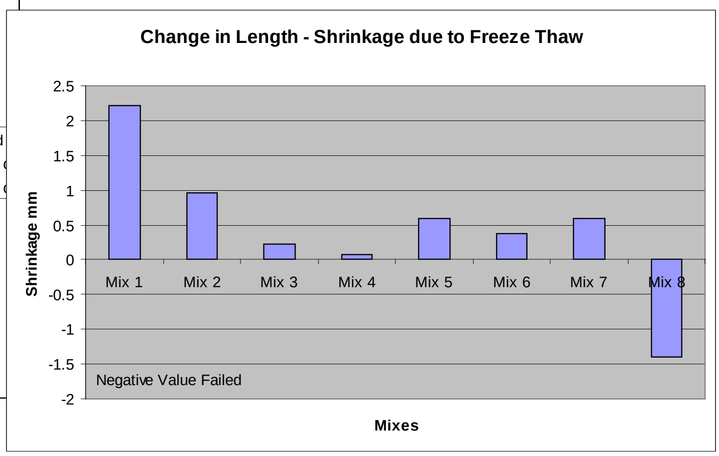

Figure 6. Freeze-Thaw results.

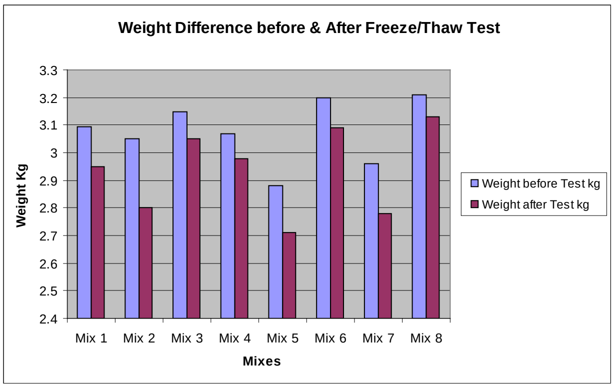

Figure 7. Weight Difference before and after Freeze/Thaw

4.5 PERMEABILITY TEST

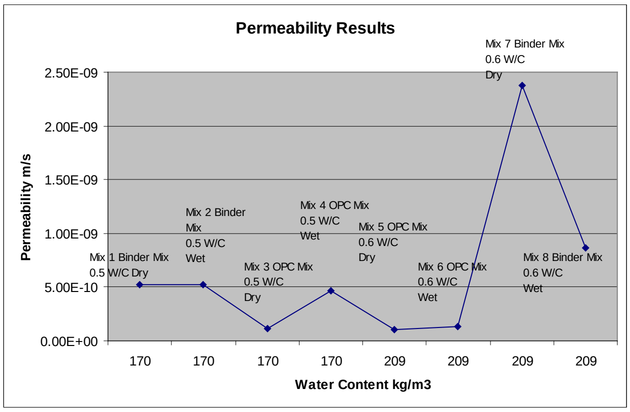

Figure 8. Permeability Results

4.6 EXPANSION RESULTS

All samples that were tested failed and underwent severe forms of shrinkage causing the samples to crack and break. Some sort of shrinkage of binder mixes was expected due to the natural behaviour of IFA, as it is very water sequestering. However, what was surprising was the intense shrinkage of the OPC mixes. This can only justified by the high strength of the OPC, making the samples quickly hydrate gain strength and shrink. ASTM International C151(2005), ASTM International C490 (2004)

5 DISCUSSION

The reason why the author did not experiment with concrete before and only concentrated on mortar mixes, was because the main theme of the research in the initial years was to emphasis on improving the compressive strength results. This needed the mix to be improved and tested both in binary and ternary mixes using mortar only. However, as soon as promising results were achieved, it became more apparent to test this material even further, studying some of its mechanical and physical properties using concrete and mortar.

5.1 SLUMP TESTS

The slump results indicate that the mixes could be used in construction. Even though, they were slightly higher than what would be expected in the field, if considering similar concrete for building use or bridges substructure and foundation slumps. Usually a slump of S3 (90-170) is expected for bridge's substructures and foundations **(**Neville 1996). On the other hand, the slump test results reported here were typical of S4 which has a range of 150 to 230 indicating, that the mixes were slightly wetter than expected. Having said that, some types of CFA (Continuous Flyous Auger) Piling necessitates the use of S4 concrete.

Even though the mixes were slightly wetter than expected, the concrete continued to hydrate and give an impressive results of compressive strength. Some of the binder mixes, containing IFA (Incinerator Fly Ash) gave results higher than 40 MPA at 28 days. Again, this sort of strength is what would be expected for concrete bridges substructure and foundations.

5.2 VISCOSITY TESTING

All Viscosity results were correlating to what was expected from the slump tests, the binder mixes in general were more viscous than the Pure OPC mixes, which gave better correlation with the slump results, where mixes with higher slump were less viscous as would be expected.

5.3 CHLORIDE MIGRATION

All samples resisted penetration of current and recorded a low charge in the initial hours, however as the experiment continued, less resistance to the current penetration was record for the binder mixes as opposed to the pure OPC mixes. However, what made the difference between the results of the pure OPC and the binder mixes was the reading of the initial 3 hours primarily.

Some of the samples during the course of experiment displayed vigorous and heat emitting reactions with greenish boiling bubbles. This was because, potassium hydroxide was used instead of sodium hydroxide. and as an alkaline, it is well known as part of its chemical characteristics that potassium hydroxide is much more reactive than sodium hydroxide. All samples giving such reaction were OPC samples, again this is because OPC is much more active than the binder mix samples.

5.4 PERMEABILITY TESTING

Concrete made with binder mixes was much more permeable than concrete made with Pure OPC. However, the interesting observation that was recorded, by the author was that Mortar mixes gave better operability results than concrete mixes, even though the compressive strength was higher in the concrete mixes, for both binder and pure OPC samples.

5.5 FREEZE-THAW

The ASTM C666 (1961) test method includes two different procedures: procedure A, Rapid Freezing and Thawing and Procedure B Rapid Freezing in Air and Thawing in Water. The procedure carried out by the Author is Procedure A. Both procedures are considered to be more severe than field conditions. Primarily, due to the rapid freezing rates in the test of roughly 5 to 15C/hr as compared to a common field rates of less than 3C/hr. As with all laboratory freeze thaw test methods, the test is not intended to simulate field conditions, but instead it produces an indication of relative freeze thaw resistance between different specimens. Terje Finnerup Rønning (2001)

5.6 EXPANSION

All samples failed and underwent severe forms of shrinkage causing the samples to crack and break. Some sort of shrinkage of binder mixes was expected due to the natural behaviour of IFA, as it is very water sequestering. However, what was surprising was the intense shrinkage of the OPC mixes. This can only justified by the high strength of the OPC, making the samples quickly hydrate gain strength and shrink

6.0 Site Trial

The Author is planning to carry out a site trial of the concrete binder mix in one of the building site of Warwickshire County Council.

In the initial process of preparation for the site trial, there has been continuous consultation with the Environment Agency to help establish an acceptance criteria for the trial mix and to ensure that producing concrete of such nature in huge quantities will not have any detrimental effects on the environment nor the ground water quality..

7.0 CONCLUSION

Promising results were achieved in all types of experiments which were mainly, testing compressive strength, slump, migration, viscosity, permeability, freeze and thaw and expansion.
The author, will be further testing corrosion effects on concrete made with IFA and Carbonation effects on concrete both controlled pure OPC and IFA.

REFERENCES

Asma Y Shebani and Peter Claisse. Strength optimisation in concrete mortars made with incinerator fly ash. Cement and Concrete Science 30. University of Birmingham 14-15 September 2010. ISBN 978-0-70442-797-6

Asma Shebani and Peter Claisse. Permeability and expansion on concrete mortars made with incinerator fly ash. Proc. 31st Cement and Concrete Science Conference. 12-13 September 2011, Imperial College London. ISBN 978-0-9570152

AASHTO T259 (1980) "Resistance of Concrete to Chloride Ion Penetration."

AASHTO T277, "Standard Method of Test for Rapid Determination of the Chloride Permeability of Concrete"

ASTM International. 2004. C490-04. Standard practice for use of apparatus for the determination of length. ASTM International, West Conshohocken (PA).

ASTM C1202 (1997) Standard test method for electrical indication of concrete's ability to resist chloride ion penetration

ASTM International. 2005. C151-05. Standard test method for autoclave expansion of hydraulic cement.

ASTM International C 666 Standard Test Method for Resistance of Concrete to Rapid Freezing and Thawing (1997)

Dale P. Bentz (2007) A virtual rapid chloride permeability test

GERMANN INSTRUMENTS (2007), ICAR Rheometer Manual