Compiled Test Analysis

Construction projects in the United Arab Emirates (UAE) face many challenges due to the harsh environment of the Gulf region. Hot weather and high humidity are common in the Emirates and high concentrations of corrosive salts are prevalent in many buildings locations and materials. The hot weather in particular is a concern for the construction industry as fresh concrete gives off heat while it is hardening and this can lead to crack formation. The current practice used to address this in the UAE is by mixing ice with the mixing water in concrete to keep it from heating up too much, but with daytime temperatures easily reaching 40^{o}C large amounts of ice must be consumed - adding to project costs. Additionally, as water is supplied from a desalination plant and consequently frozen, the use of large amounts of ice leads to additional greenhouse gas (GHG) emissions.

Many of the issues faced by the construction industry in the UAE can be addressed through the use of EcoSmart concrete – concretes with the highest practical level of cement replacement. Research and demonstration projects of EcoSmart Concretes have been thoroughly documented in Canada and the benefits of using fly ash as a cement replacement are becoming increasingly well known. The use of EcoSmart concrete in the context of the Gulf construction environment, however, is still new and the technical foundation for its use in the hot and harsh conditions in the UAE are still undocumented and untested. Therefore to demonstrate viability and to ensure buy-in from potential users in the Emirates a testing program was devised as a proof of concept for EcoSmart concrete.

To demonstrate the benefits of EcoSmart concrete, the EcoSmart Foundation commissioned four organizations (two government and two private) to test samples of concrete for various properties and characteristics. Dubai Central Laboratory (DCL) and UniBeton Ready Mix conducted tests in the UAE while the Canadian Materials Technology Lab (CANMET) and SIMCO Technologies Inc. conducted tests in Canada using material from the UAE.

Tests Performed

A range of fresh and hardened concrete properties were investigated throughout the testing series. A focus was placed on strength and durability data however other tests such as length change, water reduction and the effects of varying curing regimes were also investigated.

The key tests that were:

- Ultimate Strength and Strength development – to see how strong the concrete gets and how long until it gets there
- Chloride Penetration – to see how corrosive environments affect concrete
- Heat of Hydration – to see how much heat the concrete generates while it's hardening
- Water demand – to see how much water is required for each concrete mix

A table of all tests compiled by different testing bodies is outlined in the Appendix.

Mix Designs

Mix designs varied according to testing body and goals of the testing series. A table of mix all designs is provided in the Appendix but below is a brief summary of mix designs used and reasons for designing mixes.

DCL and SIMCO: mix designs used were identical as all samples were created in the UAE by DCL. Mix designs were chosen based on the range of concrete types used in the UAE with two samples of low, medium and high strength concretes undergoing testing.

CANMET: Mixes were designed according to a specific project; as such, all mixes were designed with one target strength in mind and fly ash volumes were varied accordingly.

UniBeton: A large number of mix designs were created for Phase 1 and Phase 2 of the testing series. Phase 1 of testing required six key mixtures representing low, medium and high strength, pumpable concretes while Phase 2 took knowledge gained in Phase 1 to design high strength concretes specifically designed for a UniBeton project with a number of performance parameters.

Testing Report Summaries

UniBeton

UniBeton has conducted two sets of tests on trial mixes of high volume fly ash (HVFA) concretes for use in the Emirates. The report shows EcoSmart Concrete mixes compare quite favourably to many physical and mechanical properties of other concrete mixtures, namely Ordinary Portland Cement (OPC) concretes and samples mixed with high volumes of Ground Granulated Blast Furnace slag (GGBS).

The goal of the first phase of testing was to introduce a range of commercially viable fly ash mixtures to the UAE market. Six designs were chosen for comparative purposes, covering the range of low, medium and high performance concretes.

During the first phase, tests were conducted on absorption, bleeding, early and late age strength gain, heat of hydration, setting time, slump retention, and water demand. Water demand and heat of hydration of EcoSmart Concretes outperformed the other mixes. Early age strength gain of EcoSmart concretes was lower than the OPC and GGBS samples but approached or exceeded gains of OPC and GGBS concretes after seven days.

A second phase of tests was to validate high performance concrete specifications and improve upon the mix designs used in the first phase. Phase two requirements were based on the specifications of UniBeton's Landmark project where an 80 MPa compressive strength at 28 days and pumping heights of 360 meters were required. Additionally, UniBeton added the further criteria:

1) Concrete designs shall meet all specification requirements including strict durability parameters
2) Mass concrete temperature requirements (peak < 70^{o}, differential < 20^{o}) require a low heat concrete with high fly ash as 80 MPa column dimensions are self insulating.

3) Slump of > 200 mm, with retention of 80%, in 1 hr. preferably using stock admixtures rather than Polycarboxylates.
4) 1 day strength of 12 MPa to permit early stripping of falsework
5) Compression strength from laboratory trials to exceed characteristic strength by 3 x Standard deviations, or at least + 15 MPa
6) Fly ash level to be 25-40% based on outcomes from phase 1 trials.

Tests completed in this phase showed significant improvements in results when compared with Phase 1 data, due to the increased familiarity with fly ash concretes by UniBeton. Significant water reductions were achieved, all mixes passed slump tests and significant improvements in compressive strength were achieved when compared to similar mix designs used in Phase 1. However early age strength for the 40% fly ash group and the 28 day strength for all groups failed to meet the specifications but were within one standard deviation of the target strength (± 5 MPa). While this is unfortunate high early age strength and 28 day strengths were achieved and show that mixes similar to these may find application in other elements.

Following this, further trials with 6% silica fume and 25% and 45% fly ash were carried out and all criteria and specifications were easily met. This is encouraging as it is common practice in the UAE to include some amount of silica fume in concrete mixes to meet high performance and durability requirements.

Dubai Central Laboratory

Dubai Central Laboratory (DCL) carried out one batch of test of high performance fly ash mixtures. Fly ash replacement levels of 25% and 45% were compared based on depth of water penetration, permeability, rapid chloride penetration tests, slump retention and strength tests. Low, medium and high performance concretes were tested with differing cementitious contents and water to cement ratios which makes direct comparison quite difficult. However, it was found that at the low and medium strength (40 and 60 MPa target 28 days) mixes comprised of 25% or 41% concrete performed to satisfaction. For the high performance mix, the 28 day strength was not reached as targeted and this may be due to improper mix designs, admixture contents or other factors. The high performance mix with 25% fly ash replacement and 6% silica fume did reach the targeted 28 day strength but only after a 56 day period. It was also found that the 60 MPa sample with 40% fly ash replacement had higher ultimate strength and greater late-age strength development than the 80 MPa sample with 40% fly ash and 6% micro silica replacement levels.

Tests on chloride penetration, water absorption and depth of water penetration revealed good durability performance results. Chloride penetration tests revealed very low chloride penetration for all specimens, with high volume fly ash samples tending to a pass lower charge. Depth of water penetration and absorption were slightly lower with higher fly ash contents but were overall very comparable.

SIMCO Technologies

Modelling done by SIMCO Technologies focused on durability characteristics of fly ash concretes. Samples tested were cast in the UAE and sent to Canada wrapped in wet burlap. These samples were prepared by DCL and therefore had the same cementitious contents and cement replacement levels. The purpose of sending these samples to SIMCO was to evaluate the porosity and ionic transport properties for the purposes of modelling using STADIUM software which DCL was unable to do.

Samples were allowed to cure of a period of 70 and 100 days before transport properties were evaluated. Porosity values were found to be good in all cases, particularly for five mixes (EMD-02 to EMD-06). The first mix had uncharacteristically high water to cementitious content which may explain its higher porosity. Ionic diffusion and moisture diffusion contents were also found to be good and in line with the porosity findings.

Modelling using STADIUM software revealed corrosion times ranging from 14 – 39 years for fully submerged elements with 75 mm cover and 24 – 50+ years for elements with 100 mm cover. Within the tidal zone the onset of corrosion was found to range from 28 – 50+ years for 75 mm cover and 49 – 50+ years for 100 mm cover. Subjected to exposure to groundwater, which is much more aggressive, none of the samples were able to resist corrosion for more than 50 years. It was noted in the report that despite reaching the threshold level for chloride concentrations, in some scenarios a lack of oxygen would have prevented corrosion from occurring.

CANMET

CANMET investigated the effects of different curing regimes on the fresh and hardened properties of EcoSmart concrete (mechanical properties and durability characteristics). Mimicking Gulf temperature cycles, CANMET performed a wide range of tests on four samples with cement replacement levels of 0% (for the control concrete), 30% and 45% with fly ash.

Fly ash concretes, having a total cementitious material content less than that of the control concrete were found to achieve the specified 28 day strength requirements and also out performed the control concrete in heat generations, resistance to chloride ion penetration and drying shrinkage.

It was observed that the fly ash concrete benefited from the higher curing temperature which led to acceleration of the pozzolanic reaction and this compensated, at least in part, for shorter moist curing periods. All fly ash concretes showed increased resistance to chloride ion penetration at both 28 day and 56 day testing when compared to control concretes for all curing scenarios.

Volume of permeable voids and absorption decreased with an increasing moist curing period however it was noted that fly ash concretes were more susceptible to changes in results for varying curing scenarios when compared to the control sample.

Conclusion

Given the high volumes of cement consumed in the UAE there is a large opportunity for increasing fly ash usage and the results of these reports demonstrate the technical merits doing so. Increased building lifespan (as illustrated by DCL and SIMCO testing), applicability to the UAE's climate (CANMET), and applicability of a variety of designs including high strength mixes (UniBeton).

Overall the test series showed great potential for high volume fly ash concretes in the UAE. All durability testing results were extremely positive and indicated that superior performance can be achieved with the use of fly ash concretes when compared to regular OPC concretes. Challenges with strength gain can be overcome using properly designed and cured mixtures or with the addition of silica fume in the extreme cases (such as where very high strengths are required at an early age).

Appendix

Tests Completed

Tests were carried out as follows:

Test	DCL	SIMCO	CANMET	UniBeton	
				Phase 1	Phase 2
Absorption & Volume of Permeable Voids	X	X	X	X	
Bleeding, Finishability and Pumpability				X	
Compressive Strength	X		X	X	X
Depth of water penetration	X				
Drying Shrinkage			X		
Heat of Hydration			X	X	
Modeling of Ionic Diffusion Coefficients		X			
Rapid Chloride Penetration Test (RCPT)	X	X	X	X	X
Setting time			X	X	
Slump	X			X	
Tensile Strength	X				
Time to Corrosion		X			
Water Demand				X	X

Mix Designs

Test Group	Sample	Binder Content (kg/m3)	% OPC	% FA	% GGBS	% SF	Water (l/m3)	Water/Binder ratio
DCL & SIMCO	EMD-01	340	75%	25%	0%	0%	166	0.49
	EMD-02	435	75%	25%	0%	0%	148	0.34
	EMD-03	515	70%	24%	0%	6%	153	0.30
	EMD-04	415	60%	40%	0%	0%	152	0.37
	EMD-05	455	59%	41%	0%	0%	138	0.30
	EMD-06	495	57%	37%	0%	6%	146	0.29
CANMET	1	381	100%	0%	0%	0%	165	0.43
	2	358	70%	30%	0%	0%	155	0.43
	3	353	55%	45%	0%	0%	152	0.43
	4	353	55%	45%	0%	0%	142	0.4
UniBeton Phase 1	P1	200	100%	0%	0%	0%	172	0.86
	P2	300	100%	0%	0%	0%	171	0.57
	P3	350	100%	0%	0%	0%	175	0.5

	P4	425	100%	0%	0%	0%	174	0.41
	P5	500	100%	0%	0%	0%	175	0.35
	PG 1	197	35%	0%	65%	0%	171	0.87
	PG 2	272	35%	0%	65%	0%	169	0.62
	PG 3	386	31%	0%	69%	0%	189	0.49
	PG 4	416	35%	0%	65%	0%	171	0.41
	PG 5	501	34%	0%	66%	0%	170	0.34
	PGSF 1	200	35%	0%	60%	5%	172	0.86
	PGSF 2	300	37%	0%	60%	3%	159	0.53
	PGSF 3	350	37%	0%	60%	3%	168	0.48
	PGSF 4	425	38%	0%	60%	2%	174	0.41
	PGSF 5	500	38%	0%	60%	2%	175	0.35
	PFA 1.1	200	75%	25%	0%	0%	168	0.84
	PFA 1.2	300	75%	25%	0%	0%	168	0.56
	PFA 1.3	350	75%	25%	0%	0%	168	0.48
	PFA 1.4	425	75%	25%	0%	0%	170	0.4
	PFA 1.5	500	75%	25%	0%	0%	175	0.35
	PFA 2.1	200	60%	40%	0%	0%	162	0.81
	PFA 2.2	300	60%	40%	0%	0%	159	0.53
	PFA 2.3	350	60%	40%	0%	0%	161	0.46
	PFA 2.4	425	60%	40%	0%	0%	157	0.37
	PFA 2.5	500	60%	40%	0%	0%	160	0.32
	PFA 3.1	200	45%	55%	0%	0%	154	0.77
	PFA 3.2	300	45%	55%	0%	0%	144	0.48
	PFA 3.3	350	45%	55%	0%	0%	147	0.42
	PFA 3.4	425	45%	55%	0%	0%	140	0.33
	PFA 3.5	500	45%	55%	0%	0%	155	0.31
UniBeton Phase 2	25% group average	440	75%	25%	0%	0%	-	-
		460	75%	25%	0%	0%	-	-
		480	75%	25%	0%	0%	-	-
		500	75%	25%	0%	0%	-	-
	32.5% group average	440	68%	33%	0%	0%	-	-
		460	68%	33%	0%	0%	-	-
		480	68%	33%	0%	0%	-	-
		500	68%	33%	0%	0%	-	-
	40% group average	440	60%	40%	0%	0%	-	-
		460	60%	40%	0%	0%	-	-
		480	60%	40%	0%	0%	-	-
		500	60%	40%	0%	0%	-	-

	31% FA MS Blend	520	69%	25%	0%	6%	-	-
	46% FA MS Blend	500	54%	40%	0%	6%	-	-