Interim report on Fly Ash concretes for ECOSMART

By David Cooney
Development Manager
UNIBETON

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Testing phase 1

- Routine optimization work on Portland cement pumpable concretes carried out in July 2007 (work unconnected with ECOSMART project)
- Mixes designed for pumpable consistency, target slump 150mm (see chart)
- 5 designs, 200-500kg/m³ binder content chosen for comparison using various supplementary cement types, replacement levels
- Phase 1 trials to gather information by substituting cement whilst maintaining general proportions, water addition varied for target consistency

Mix proportions used in phase 1 trials

Pumpable designs July '07	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Portland cement	200	275	350	425	500
20mm	728	730	733	738	746
10mm	364	365	367	369	372
5mm	378	375	370	351	315
Dune Sand	538	484	432	378	319
Water	190	176	175	170	180
Type G Admixture	All mixes at 1.2% BWC				
W/C	0.95	0.64	0.5	0.4	0.36

Material sources - phase 1 trial series

Portland cement ex. Fujeirah Cement Industries

Blast Furnace slag ex. Sharjah Cement

Type F Fly Ash, ex. India

20mm, 10mm and 5mm limestone aggregates ex. Ras Al Khaima

Dune Sand ex. Al Ain

Type G admixture

Parameter/property	tested	Method of test & comments
trial water demand	√	gradual addition to required target slump
slump	√	British/universal standard
plastic density & finalized mix proportions	√	British/universal standard
slump retention	√	British/universal standard - slump tested at 15 minute intervals for 1 hour
setting time	√	ASTM C403
heat of hydration	√	Insulated samples tested via data logger and proprietary software
bleeding, finishability, pumpability	√	not tested in a quantitative/qualitative test - evaluated by visual assessment
plastic shrinkage and settlement	*	not tested in a quantitative/qualitative test
compression	√	British/universal standard
initial surface absorption	√	BS 1881 part 206
water absorption	√	BS 1881 part 122
rapid chloride permeability	√	ASTM C1202-97

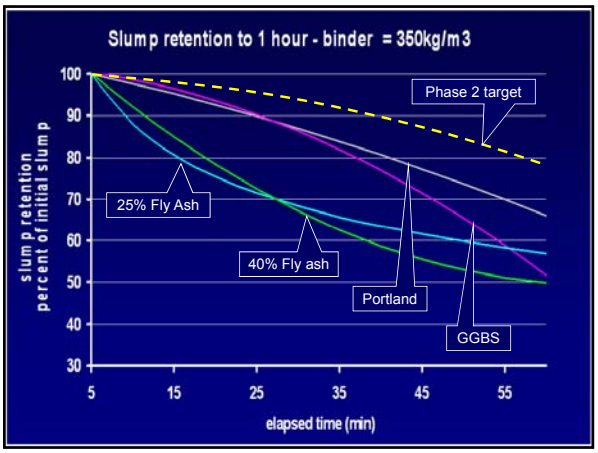
Comparative mix proportions Portland and alternative mixes

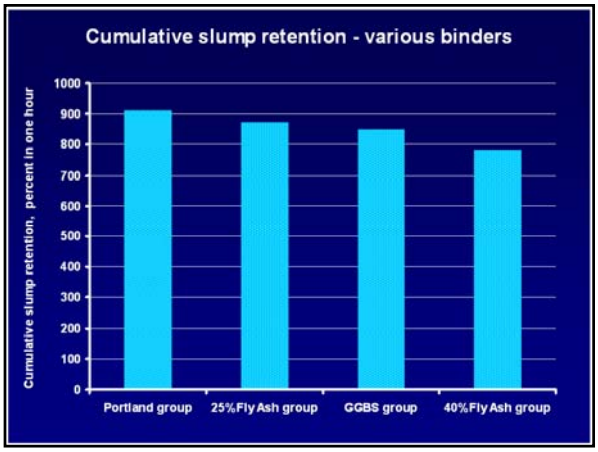
≈ 350kg test group	Portland cement	Supplementary cement	C. AGG	F. AGG	Admix	Water	Density	WC ratio
Portland	344	0	1085	777	4	170	2380	0.49
GGBS (65%)	120	226	1088	775	4	170	2382	0.49
Fly Ash (25%)	256	85	1071	764	4	165	2345	0.48
Fly Ash (40%)	206	137	1080	773	4	158	2358	0.46
Fly Ash (55%)	155	189	1086	776	4	147	2357	0.42

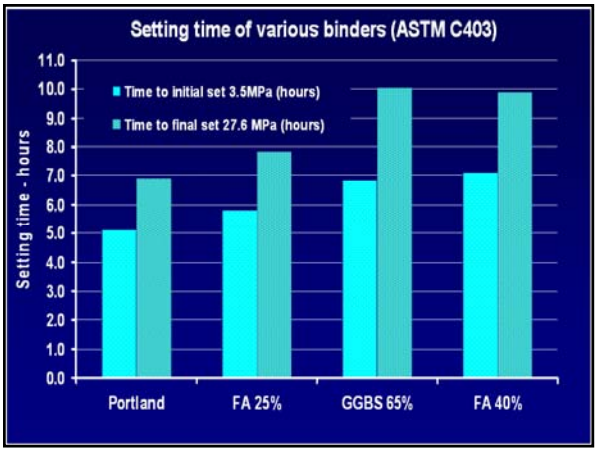
Comparative mix proportions for Portland and alternative mixes - Phase 1 trials

Observations

- Water demand of Portland, GGBS and control concretes nominally the same - about 17% of concrete volume - GGBS concretes less workable
- Effect of 25% Fly Ash - water demand reduced approx. 3% in 25% trial series (16% of concrete volume)
- Effect of 40 and 55% Fly Ash - water demand reduced approx 7 and 13.5% (<16 and 15% of concrete volume)
- At 55% Fly Ash, extreme workability prevents accurate slump determination
- About 1% density reduction after yield correction





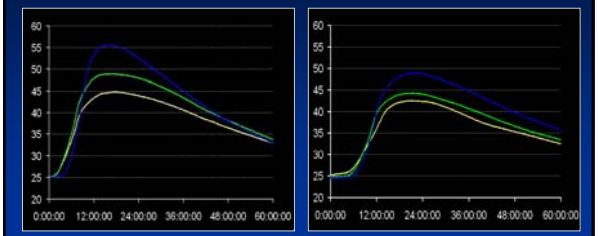


Heat of Hydration tests on various binders

Binder/s and binder content kg/m³		Peak °C	Rise °C	Group temp. rise °C/100 Kg	Average time to Peak temperature	Cumulative °C 5min. intervals 60 hours (%)	Total °C (group)
100% OPC	350	45	20	5.8	17 hours	91	91490
	425	49	24			97	
	500	56	31			100	
25% FLY ASH	350	43	18	4.8	22 hours	85	85201
	425	44	19			88	
	500	49	24			94	
40% FLY ASH	350	37	12	3.5	22 hours	79	79029
	425	40	15			81	
	500	44	19			89	
65% GGBS	350	39	14	3.9	32 hours	80	78652
	425	41	16			83	
	500	44	19			85	
55% FLY ASH	350	33	8	2.6	31 hours	70	71733
	425	36	11			76	
	500	39	14			79	

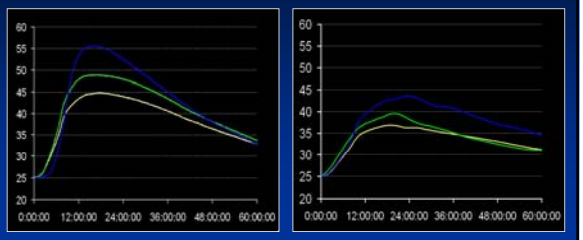
Heat of Hydration tests on various binders

(350kg, 425kg and 500kg)



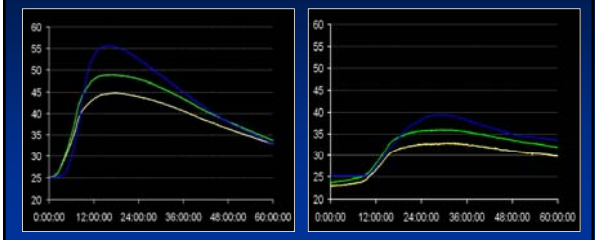
Portland group | Fly Ash group 25%

Heat of Hydration tests on various binders
(350kg, 425kg and 500kg)



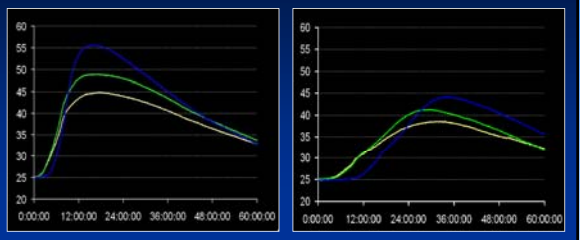
Portland group | Fly Ash group 40%

Heat of Hydration tests on various binders
(350kg, 425kg and 500kg)



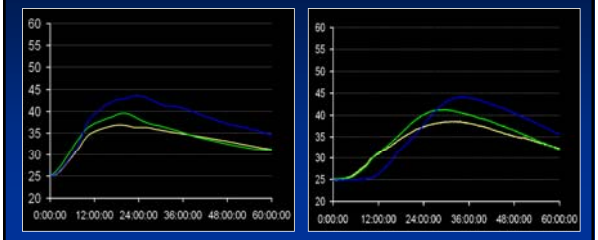
Portland group | Fly Ash group 55%

Heat of Hydration tests on various binders
(350kg, 425kg and 500kg)



Portland group | GGBS group 65%

Heat of Hydration tests on various binders
(350kg, 425kg and 500kg)



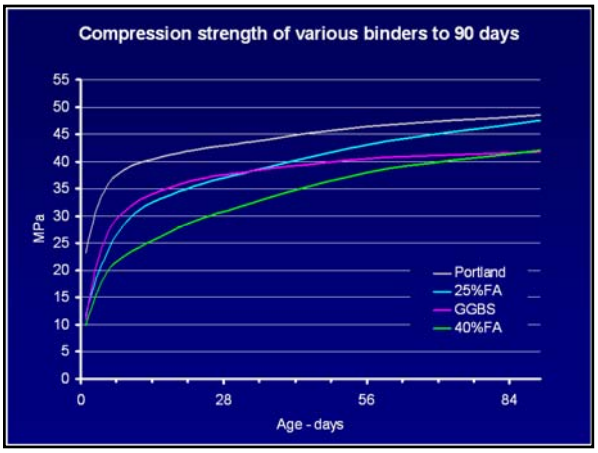
Fly Ash group 40% | GGBS group 65%

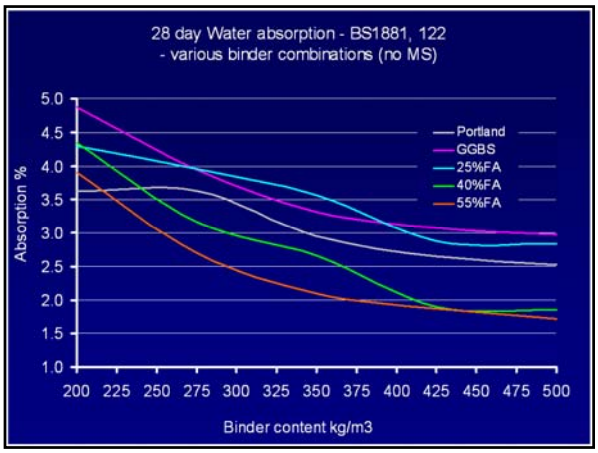
Compression strength of various binders to 90 days

Group	Compression strength vs. age - days after casting									
	1 day	3 days	5	7 days	10	14	21	28 days	56 days	90 days
Portland	23	31	35	37	39	40	42	43	46	49
25%FA	12	19	23	27	30	33	35	37	43	48
65%GGBS	11	21	26	29	32	34	36	38	41	42
40%FA	10	16	20	22	24	26	29	31	38	42

- Portland cement strength gain 7-28, 6MPa, 28-56, 3MPa, 28-90, 6MPa
- 25% Fly Ash, strength gain 7-28, 10MPa, 28-56, 6MPa, 28-90, 11MPa
- 65% GGBS strength gain 7-28, 9MPa, 28-56, 3MPa, 28-90, 4MPa
- 40% Fly Ash, strength gain 7-28, 9MPa, 28-56, 7MPa, 28-90, 11MPa

Compression strength of various binders to 90 days





Outcomes from phase 1 trials

Fresh properties

- Water demand at all fly ash replacement levels satisfactory vs. Portland and GGBS reference concretes
- Lower density and modest net yield advantage after adjustment for lower water demand
- Fly Ash and GGBS concretes - minor slump retention disadvantage probably due to paste volume and choice of admixture, compared to Portland concretes
- 25% Fly Ash final setting time + 1 hour compared to Portland
- 40% Fly Ash setting time comparable to GGBS, both + 3 hours compared to Portland
- Superior Low Heat properties, 40 and 55% Fly Ash concretes compared to 65% GGBS

Outcomes from phase 1 trials

Hardened properties

25% Fly Ash

- 25% Fly Ash strength nominally equal to Portland cement at 90 days with significant strength gain after 28 days
- Superior strength and significant strength gain vs. GGBS at 90 days, comparable strength at 28 and 56 days

40% Fly Ash

- 40% Fly Ash early strength low vs. GGBS to 56 days but achieves parity at 90 days
- Absorption values (BS1881-122) for 40 and 55% Fly Ash concretes significantly lower than GGBS and Portland concretes at >400kg

Phase 2 trial plan (in progress)

- Design commercial high strength piling and pumpable concretes at
- 25, 32.5 and 40% Fly Ash replacement levels, using stock admixtures (WC ratios ≈ 0.3)
- Reduce water demand vs. phase 1 trials with target slump >225mm
- Improve slump retention - 80% of initial slump at 1 hour
- Measure low heat properties for mass concrete applications
- 1 day strength >12MPa at 24 hours
- 7 day strength >50MPa at 7 days, 28 day strength >60MPa at 28 days
- Select concretes from these trials for similar applications incorporating MS to meet/exceed common UAE specification durability parameters (RCP<1000 at 56, initial surface and water absorption <2% at 56)

Material sources - phase 2 trial series

Portland cement ex. Fujeira Cement Industries

Type F Fly Ash ex. India

Microsilica

20mm, 10mm and 5mm limestone aggregates ex. Ras Al Khaima

Dune Sand ex. Al Ain

Type D type F admixtures

Phase 2 trials - initial results

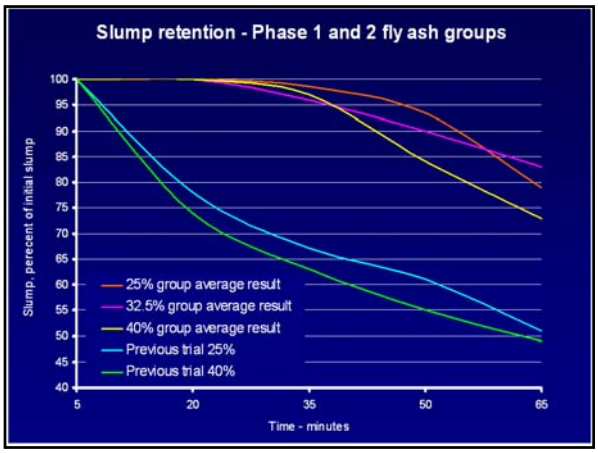
Water demand

- Water reduced in all Fly Ash groups to 13-15% of concrete volume, with ≈0.3 WC ratio for slump >225mm

Slump retention

Fly ash trial group *	Slump, percent of initial slump minutes after completion of mixing				
	5 mins.	20	35	50	65
25% group average result	100	100	98	93	79
32.5% group average result	100	100	96	90	83
40% group average result	100	100	97	84	73

* 25, 32.5 and 40% Fly Ash groups tested at 440, 460, 480 and 500 kg/m³ binder content and results reviewed against Phase 2 parameters



Phase 2 trials - initial results

Compression strength MPa				
Age	**1 day**	**3**	**7**	**28**
25% group average result	**21**	**48**	**63**	**85**
32.5% group average result	**13**	**43**	**59**	**78**
40% group average result	**8**	**39**	**54**	**75**

Durability group compression strength MPa (MICROSILICA)				
Age	**1 day**	**3**	**7**	**28**
25% Fly Ash, 520kg, 6% MS	**20**	**52**	**75**	**114**
40% Fly Ash, 500kg, 6% MS	**16**	**44**	**65**	**97**

With exception of 24 hour strength, (40% group) all groups meet Phase 2 age-strength criteria

Phase 2 trials - preliminary conclusions

Results demonstrate that fly ash concrete can produce results equivalent or superior to high performance Portland and blended GGBS high performance concrete (at similar cost)

Use a quality-assured source of Fly Ash

Admixture methodology important when maximizing performance however normal type D and type F admixtures can produce excellent results

28 day interpretations of performance may be waived in circumstances where later age testing permits users to take advantage of the superior strength gain

Supplementary cement concretes set more slowly and good curing is essential to maximize benefits

Thank you!