APPENDIX Biv

CRE LINER FLUE PROJECT
– TEST COUPON PROGRAMME

CRE FLUE LINER PROJECT - TEST COUPON PROGRAMME

Preparation of Test Coupons

Test coupons measuring 4 x 4 x l6cms were prepared for 5 different mixes (see attached tables a) to e)).

These specimens were stored in standard curing room conditions (2O°C; 100% Relative Humidity) for 3 days then despatched to CRE for inclusion in chimney flue tests. During the period of despatch and until installed the test specimens were wrapped in wet cloth and polythene to maintain moist curing conditions. Three of each type of specimen were made, two were used in the flue tests and one retained as a control specimen in the curing room.

Composition of Test Coupons

The logic behind the mixes chosen was as follows:

I. Basic Mixes

a) Portland Cement with washed pit sand (quartz).
e) High Alumina Cement with kiln burnt aggregate.

II. To examine the effect of replacing part of the sand with a kiln bumt aggregate.

b) Portland Cement with sand/Lytag aggregates.
The exact mix proportions for this mix were taken from the Geomaterials Research Services Ltd., report, Ref. 4484 table 4-4404/1

Ill. To examine the effect of replacing part of the Portland Cement with High Alumina Cement.

c) Portland Cement/High Alumina Cement (90:10) with sand
d) As c with part of the sand replaced by Lytag in same proportions as b.

Series Ill was included, since it is believed that concretes using a proportion of High Alumina Cement with Portland Cement have been manufactured in the past. The exact proportion of HAC was unknown, hence a 10% addition was assumed, as a higher addition rate would tend towards flash setting.

Whilst every effort was made to ensure that these materials were representative of current practice, it was not possible to obtain exactly the same aggregates, particularly concerning the sand, as those reported in the report by Geomaterials Research Services Ltd.,

The proportions for all mixes were calculated on a volume basis to give approximately the same ratio of cement to aggregate as mix B.

These proportions were not necessarily optimised from the point of view of good mix design, but were not believed to be unrepresentative of concretes currently in use.

Treatment of Test Coupons.

One coupon of each type of mix was suspended inside the flues tested by CRE. For simplicity these have been designated, Aa to Ae for Chimney A and Ba to Be for Chimney B. The results of examination of these test coupons are given in the attached table.

Discussion of Results

Density

The densities of the five control specimens reflect the aggregate type and proportions used. Thus the specimens made with sand only (a and c) are densest followed by (b and d) which comprise sand/Lytag in proportions (53%/47%) and finally the least dense, mix a, which is solely Lytag aggregate.

The replacement of part of the Portland Cement with High Alumina Cement would not be expected to affect the density, since these cements and their hydrates have very similar densities.

Unfortunately the densities of the ten test specimens could not be measured after testing, since their size and shape had been modified during preparation (notches and holes were cut) and due to the presence of a jubilee clip, which could not easily be removed with the risk of damage to the specimens.

“Ring”

The sound made when an object is struck, can tell us something about the microstructure and elasticity of an object (e.g. train wheels, pottery). When struck with a short metal rod, the sounds made by the test specimens were as given on the table. “Good represents a sharp ring, indicating a higher elastic modulus, “Dead’ represents no ring at all, indicating a low elastic modulus.

The control samples, except “e” (HAC/Lytag) gave a good ring. They were not however, all the same. Samples “a” and “c” were “sharper” than “b’ and “d”, this again reflects the type of aggregate used and therefore the density. Sample “e” gave a noticeably duller note, as would be expected, since the aggregate was all Lytag i.e. much less dense.

After testing, there was no discernible difference between the ”ring” of the coupons from Chimney A or B.

Samples “a” and “b” had a “good” ring, “c” was slightly dull and “d” was dead. This seems to indicate that the addition of HAG to Portland Cement in some way reduced the elasticity of the concrete. The addition of MAC to Portland Cement is known to accelerate the setting and hardening, however, it tends to reduce the ultimate strength.

The combination of HAG/OPC with sand/Lytag appears to seriously effect the “soundness” of the concrete (this concrete also appears to have the highest positive linear change — see below). Why this should be is not understood, however, it is worth noting that this combination of materials is or has been used by manufacturers of flue liners.

The “ring” of the HAC/Lytag specimens remained essentially unchanged by the treatment i.e. slightly dull.

Linear Change After Treatment

The HAC/Lytag specimens Ae and Be show approximately 0.5% shrinkage. This value is consistent with the behaviour of a typical low range refractory/insulating concrete on firing.

Normally some shrinkage of any concrete (HAG or OPC) would be expected, due to drying and partial dehydration of the cement matrix. However, all other samples showed an expansion after treatment. This expansion is likely to be due in part to the expansion of siliceous sand and may also be due to some dehydration/rehydration reactions of the $Ca(OH)_2$ in the Portland Cement. Lytag - being a kiln burnt aggregate will not show any linear change at the temperatures of these tests. Further work would be needed to clarify this observation.

The total positive movement of these specimens is likely to be of the order of +0.5 to 1% if the normal drying shrinkage is added to the expansion.

Compressive Strengths

The compressive strengths of the control specimens a - d were all of the same magnitude i.e. 25-3OMPa, typical of “28 day” strengths of low grade Portland Cement concretes.

Concrete “d” (HAC/OPC – sand/Lytag combination) showed slightly higher strengths than a, b and c. Why this should be is not clear, although the combination of acceleration due to HAC and Pozzolanic action (see below) could explain this.

Concrete “e” (HAC/Lytag) has the lowest compressive strength. This may be explained by the very high water/cement ratio (1:22) necessary when using absorbent, lightweight aggregates. However, in comparison with the water/cement ratios of concretes “b” and “d” (0.98 and 0.92 respectively) it could be argued that some enhancement of the strength of the specimens containing Portland Cement and Lytag was due to Pozzolanic action. HAC concretes are not subject to pozzolanic action, and hence the strength has remained at a constant level.

After treatment the strengths of all concretes (with the possible exception of S a.) decreased compared to the control coupons. This would be as expected since a certain degree of dehydration of the cement matrix would be normal at these temperatures.

Two of the concretes are worth particular note:

- Test Coupon “d” (OPC/HAC - Sand/Lytag) which gave the highest control strength (3OMPa) showed the same low strength (I4MPa) as the group of concretes containing Portland Cement

- Test Coupon “e” (HAC/Lytag) although maintaining position as the lowest strength concrete, has shown the smallest decrease in strength (11.SMPa to 7MPa).

If the change in strength reflects a decrease in the overall properties of the concretes then concrete “d” has suffered more than concrete “a”. This again reflects what would be expected from a low range refractory concrete such as “d”. The effects of repeated firing have had little effect when compared to the OPC concretes.

The “dead” sound of concrete “d’ after treatment together with the high loss of strength seems to indicate that this particular mix suffered most from the treatment.

CRE Flue liner project – Results of Examination of Test Coupons

Controls	Coupon	Date		Weight g	Density Kg/m3	“Ring”	Liner Change %	Comp.Strength MPa	
		Cast	Tested						
	a	15.06.99	23.07.99	548	2108	Good	-	26.5	24.6
	b	16.06.99	“	496	1908	Good	-	27.4	26.6
	c	15.06.99	“	545	2096	Good	-	22.6	25.6
	d	16.06.99	“	495	1904	Good	-	29.6	30.6
	e	15.06.99	“	399	1535	Sl. Dull	-	11.4	11.5

Chimney A	Coupon	Date tested	Weight g	Density Kg/m3	“Ring”	Liner Change %	Comp.Strength MPa	
	a	23.07.99	-	-	Good	0.06	17.8	20.0
	b	“	-	-	Good	0.20	13.5	14.1
	c	“	-	-	Sl.	0.19	14.7	12.7
	d	“	-	-	Dull	0.32	9.6	8.8
	e	“	-	-	Dead Sl.Dull	-0.59	6.9	7.2

Chimney B	Coupon	Date tested	Weight g	Density Kg/m3	“Ring”	Liner Change %	Comp.Strength MPa	
	a	23.07.99	-	-	Good	*	24.7	*
	b	“	-	-	Good	0.31	13.6	13.3
	c	“	-	-	Sl. Dull	0.29	13.5	9.0**
	d	“	-	-	Dead	0.32	15.0	11.2**
	e	“	-	-	Sl.Dull	-0.43	7.8	7.6

*part of sample was broken when received
**low result due to notches is sample

Test Coupons for Flue Liner Test Programme

- Date of casting: 15.06.99
- Designation: a
- Mix: Portland Cement/Sharp Sand[(1)]

Proportions by Weight

Portland Cement	300g
Sharp Sand (wet)[(2)]	1655g
Water from aggregates	58g
Mixing water	124 g
Total water	182
Aggregate/Cement Ratio	5.33
Total Water/Cement Ratio	0.61

COMMENTS:

(1) Washed Thames Valley pit sand 0 - 5mm
(2) Moisture in sand 3.6% by weight.

Test Coupons for Flue Liner Test Programme

- Date of casting: 16.06.99
- Designation: b
- Mix: Portland Cement/Sharp Sand[(1)]/Lytag

Proportions by Weight[(2)]

Portland Cement	229 g
Sharp Sand (wet)[(3)]	*741* g
Lytag 0—2 mm (wet)[(4)]	642 g
Water from aggregates	128 g
Mixing water	96 g
Total water	224
Aggregate/Cement Ratio	5.5
Total water/Cement Ratio	0.98

COMMENTS:

(1) Washed Thames Valley pit sand 0-5 mm
(2) From Geomaterials report Ref 4484 table 4-4484/1
(3) Moisture in Sand 3.6% by weight.
(4) Moisture in Lytag 16% by weight
(5) Mix was slightly too wet.

Test Coupons for Flue Liner Test Programme

- Date of Casting: 15.06.99
- Designation: (c)
- Mix: Portland Cement/High Alumina Cement/Sharp Sand[1]

Proportions by Weight[2]

Portland Cement	270 g
High Alumina Cement	30 g
Sharp Sand (wet)[3]	1658 g
Water from aggregates	58 g
Mixing water	124 g
Total water	182 g
Aggregate/cement ratio	5.33
Total water/cement ratio	0.61

COMMENTS:

(1) Washed Thames Valley pit sand 0-5 mm
(2) As ‘A’ with 10% of Portland Cement replaced by High Alumina Cement
(3) Moisture in sand 3.6% by weight.

Test Coupons for Flue Liner Test Programme

- Date of casting; 16.06.99
- Designation (d)
- Mix: Portland Cement/High Alumina Cement/Sharp Sand(1)/Lytag

Proportions by Weight(2)

Portland Cement	206g
High Alumina Cement	23g
Sharp Sand (wet)(3)	741g
Lytag 0 – 2 mm (wet)(4)	642g
Water from aggregates	128g
Mixing water(5)	83g
Total water	211
Aggregate/Cement Ration	5.5
Total water/Cement Ration	0.92

COMMENTS:-

(1) Washed Thames Valley pit sand 0 – 5 mm
(2) 10% of Portland Cement replaced by High Alumina Cement
(3) Moisture in Sand 3.6% by weight
(4) Moisture in Lytag 16% by weight

Test Coupons for Flue Liner Test Programme

- Date of casting; 15.06.99
- Designation (e)
- Mix: High Alumina Cement/Lytag

Proportions by Weight[1]

High Alumina Cement	229g
Lytag 0 – 2 mm (wet)[2]	1069g
Water from aggregates	171g
Mixing water[5]	109g
Total water	208g
Aggregate/Cement Ration	3.9
Total water/Cement Ration	1.222

COMMENTS:-

(1) As ‘A’ calculated by volume and converted to weight
(2) Moisture in Lytag 16% by weight