Advanced Multi-Product Coal Utilization By-Product Processing Plant

Technical Progress Report for the Period : 1 January 2006 to 31 March 2006

Principal Authors: John Groppo, Thomas Robl and Robert Rathbone

June 2006

U. S. Department of Energy Cooperative Agreement No. DE-FC26-03NT410781

Center for Applied Energy Research
2540 Research Park Drive
University of Kentucky
Lexington, KY 40511

DISCLAIMER

ABSTRACT

The objective of the project is to build a multi-product ash beneficiation plant at Kentucky Utilities 2,200-MW Ghent Generating Station, located in Carroll County, Kentucky. This part of the study includes an investigation of the secondary classification characteristics of the ash feedstock excavated from the lower ash pond at Ghent Station.

The secondary classification testing was concluded using a continuous demonstration-scale lamella classifier that was operated at a feed rate of 0.3 to 1.5 tons/hr. Feed to the secondary classifier was generated by operating the primary classifier at the conditions shown to be effective previously. Samples were taken while the secondary classifier was operated under a variety of conditions in order to determine the range of conditions where the unit could be efficiently operated.

Secondary classification was effective for producing an ultra-fine ash (UFA) product. Inclined lamella plates provided an effective settling surface for coarser ash particles and plate spacing was shown to be an important variable. Results showed that the closer the plate spacing, the finer the size distribution of the UFA product. Flotation of the secondary classifier feed provided a lower LOI UFA product 2.5% LOI vs. 4.5% LOI) and a dispersant dosage of 2 to 2.5 g/kg was adequate to provide UFA grade (3.8 to 4.4 μm) and recovery (53 to 68% 5μm recovery). The UFA yield without flotation was ~33% and lower (~20%) with flotation.

Demonstration plant product evaluations showed that water requirements in mortar were reduced and 100% of control strength was achieved in 28 days for the coarser products followed by further strength gain of up to 130% in 56 days. The highest strengths of 110% of control in 7 days and 140% in 56 days were achieved with the finer products. Mortar air requirements for processed products were essentially the same as those for standard mortar, suggesting that the unburned carbon remaining does not have an affinity for air entraining admixture (AEA), a consideration that is a significant benefit.

In concrete, substitution of 20% showed that the UFA product outperformed a typical ash by achieving 105 to 107% of control strength after 28 days and 109.5 to 112% after 56 days. Higher substitution levels were shown to delay early strength development, but surpass control strength after 28 days while lower substitution levels provide both early and longer term strength.

One of the most significant benefits provided by using UFA in concrete mix designs is the improved resistance to chloride permeability while some improvements is flexural strength were realized and tensile strength was essentially unchanged. Potentially significant benefits may also be offered by using UFA as a process addition in the manufacture of cement clinker

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The project area is located in Carroll County, Kentucky, approximately one mile northeast of Ghent, Kentucky. The lower ash pond is situated immediately adjacent to U.S. Highway 42 on the southwest corner of the Ghent power plant site. Disposal of ash into the 120-acre pond began when the Ghent power plant became operational in 1973 and continued over a period of 20 years until the upper ash pond became operational in 1993. The Ghent power plant has four separate generating units. Units 1 and 2 burn a high sulfur coal and an Appalachian low sulfur compliance coal. Units 3 and 4 have multi-fuel burners and are fueled by a mixture of low sulfur subbituminous and bituminous coal. The coals burned within these units were subjected to major and trace elemental analyses, mercury analysis, and loss-on-ignition (LOI) tests.

Secondary classification testing was concluded using inclined lamella plates as settling surfaces for coarser ash particles. Evaluations included using primary classification overflow as feed with and without flotation to produce UFA. While flotation did provide a lower grade UFA by removing fine carbon, some of the carbon reduction was attributed to changes in stockpile feed grade. A dispersant dosage of 2 to 2.5 g/kg was adequate to provide UFA grade (3.8 to 4.4 μm) and recovery (53 to 68% 5μm recovery). The UFA yield without incorporating flotation was ~33% and lower (~20%) when incorporating flotation. Flotation also reduced the amount of unburned carbon in the UFA product from 4.5% to 2.5% LOI.

Demonstration plant product evaluations showed that water requirements in mortar were reduced, with finer products providing better water reduction. Coarser products (EP and FP) achieved 100% of control strength in 28 days followed by further strength gain of up to 130% in 56 days. The highest strengths of 110% of control in 7 days and 140% in 56 days were obtained with the finer products (UFA and FUFA). A particularly advantage for these products was that mortar air requirements were essentially the same as those for the standard mortar, suggesting that the unburned carbon remaining did not increase the amount of air entraining admixture (AEA) required to achieve constant mortar air.

Concrete testing at a substitution rate of 20% showed that the UFA product outperformed a typical ash by achieving 105 to 107% of control strength after 28 days and 109.5 to 112% after 56 days. Higher substitution levels were shown to delay early strength development, but surpass control strength after 28 days while lower substitution levels provide both early and longer term strength.

One of the most significant benefits provided by using UFA in concrete mix designs is the improved resistance to chloride permeability while some improvements in flexural strength were realized and tensile strength was essentially unchanged.

The use of UFA to inter-grind with OPC cement clinker may also be feasible.

INTRODUCTION

This project will complete the final design and construction of an ash beneficiation plant that will produce a variety of high quality products including pozzolan, mineral filler, fill sand, and carbon. All of the products from the plant are expected to have value and be marketable. The ash beneficiation process uses a combination of hydraulic classification, spiral concentration and separation, and froth flotation. The advanced coal ash beneficiation processing plant will be built at Kentucky Utility's 2,200 MW Ghent Power Plant in Carrollton, Kentucky. The technology was developed at the University of Kentucky Center for Applied Energy Research (CAER) and is being commercialized by CEMEX Inc. with support from LG&E Energy, Inc., the UK CAER, and the U.S.DoE.

This technical report includes research that was conducted during the first quarter of 2006. The focus of the effort was to complete testing on secondary classification to produce an ultra-fine ash (UFA) product. The feed to the secondary classifier was the overflow from the primary classifier, with and without froth flotation to remove fine carbon. Operating conditions to the secondary classifier were along with the physical configuration of the classifier, in order to generate pertinent scale-up data.

Bulk products produced from demonstration plant testing were also evaluated for use in mortar and concrete, as well as process addition in the manufacture of cement clinker.

FIELD DEMONSTRATION TESTING

Secondary Classification

The winter weather prevented extensive pilot test work during the quarter; however warm spells in January and February allow two test series to be completed. The flowsheet used during testing on January 10, 2006 was primary classification followed by secondary classification to produce UFA product. Testing conducted on February 24, 2006 used a configuration where the primary classification overflow (-100 mesh) reported to froth flotation to remove fine carbon. Flotation tailings were then fed into secondary classification to again produce a UFA product.

The tests parameters for these two tests are presented in Tables 1 and 2. The lamellae plate spacing was 3.0 cm, the same as for tests 83, 84 and 85. The dispersant, (Disal), was added on line in a 1:1 dilution with water (20% solids). The overall feed varied about 30% during the tests, with retention times ranging from 25 to 35 minutes. The test strategy was to duplicate the feed rate of January 10 during the February tests. However, due to a calibration issue with the ultrasonic flow meter used, the feed for the second test was somewhat low.

Table 1. Test parameters for secondary classifier.						
Date	Test	Feed Rate	Retention Time	Sv	Yield	Rec 5μm
	No.	GPM	min	cm/min	wt%	wt%
1/10/2006	86	14.0	26.22	9.31	32.2%	52.7%
1/10/2006	87	14.8	24.76	9.86	34.3%	56.3%
1/10/2006	88	14.5	25.32	9.64	33.6%	55.1%
2/24/2006	89	11.2	35.33	6.95	19.2%	60.5%
2/24/2006	90	11.2	33.82	7.23	20.9%	63.8%
2/24/2006	91	12.8	29.40	8.31	21.1%	67.8%

The overall product yield of 34% of Test 87 was the highest of the test program as was the <5 μm recovery of 68% of test 91. The overall product yield was found to be a function of the feed rate, as illustrated in Figure 1. Recovery is a function of weight percent of <5 μm material in the product as compared to that in the feed. The feed material differed greatly during these tests, with the feed for January tests being much finer, with an average particle diameter (d_{50}) averaging ~10 μm, with 33% of the ash less than 5 μm (Tests 86, 87, 88, Table 2) than the February tests, which had a feed d_{50} averaging ~25 μm with 19% smaller than 5 μm (89, 90, 91, Table 2).

Table 2. Test parameter for secondary classifier					
Test	Feed Solids	Feed Grade	Product Grade	Disal	LOI
No.	wt%	d_{50} μm	d_{50} μm	g/kg	wt%
86	17.5	10.0	4.3	2.71	4.4%
87	17.4	10.1	4.4	2.25	4.6%
88	16.9	10.0	4.4	2.35	4.6%
89	14.2	25.6	3.8	3.94	2.7%
90	13.8	25.7	3.9	3.47	2.5%
91	16.3	26.0	3.8	3.14	1.7%

The product recovery rates for both tests were good. The efficiency of recovering the <5 μm was better in the February tests even though the yield was less. This may be due to these tests having both lower feed rate and lower solids content. Total solids feed rate was between 7 to 8 kg/min during the February tests versus ~10 kg/min for the January tests.

The dispersant dosages varied from 2.2 to almost 4 g/kg. While the target dosage was 2.0 and 2.5 g/kg, higher values were due to errors in on-line flow measurement.

Dosages above the target did not adversely affect either yield or grade, nor did they provide performance improvements.

This variation in feed size is a reflection of the nature of the ponded ash. It was found during the resource assessment coring of pond that the ash was deposited in layers, some of which were coarse and some very fine in nature. The layers or strata of the finest materials were sticky, with a "pudding-like" consistency and proved to be difficult to blend as they tended to ball up. Although considerable effort was put forward to homogenize the feedstock for the tests, achieving homogeneity was difficult. Before each test series, the stockpile was blended with a loader to ensure consistency, but there was simply no way to maintain feed consistency on a month to month basis. While changing feed conditions make comparison of data more challenging, it does present more realistic operating conditions to what would likely be encountered during commercial production. In that light we found that large variations in feed resulted in very small variations in product.

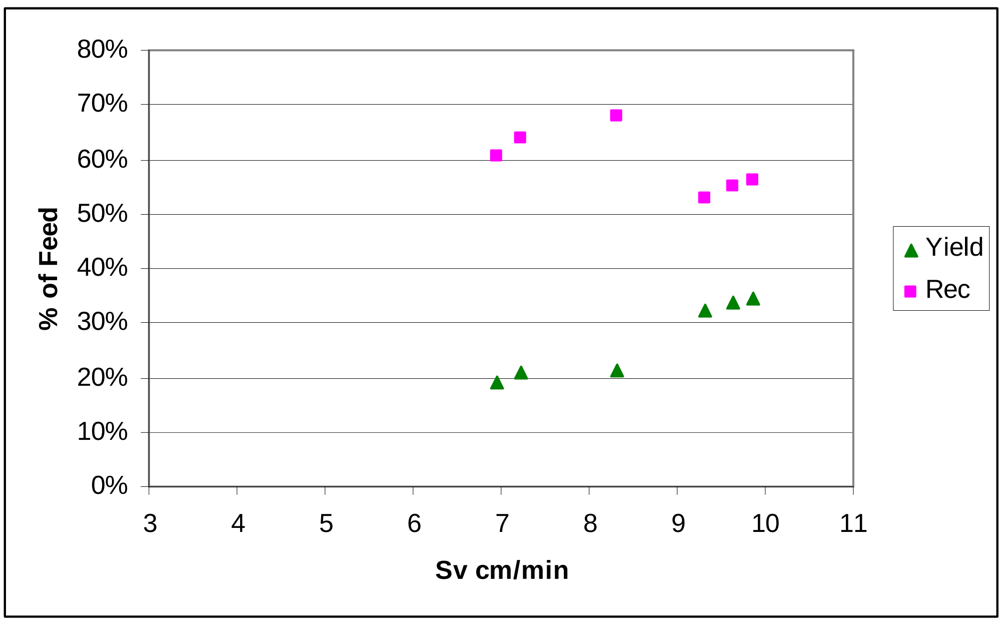

Figure 1. Effect of superficial velocity versus yield and recovery for test series.

The variation in loss on ignition (LOI) between the tests was also due to changes in the feed, with the second tests being conducted with secondary classifier feed from the tailings of the froth circuit. As mentioned previously LOI is not a direct measure of carbon for the ponded ash. A plot of carbon versus LOI for the study samples is presented in Figure 2. The carbon is generally found to be ~1% lower than the LOI. Test of the materials on the CAER's TGA-Mass Spec. indicates the other LOI components to be small amounts CO_2, OH and SO_2 in approximately equal proportions. These constituents are most likely from small amounts of carbonates, tightly bound H_2O and the sulfates, along with a small amount (probably ~ 0.2%) of residual surfactant.

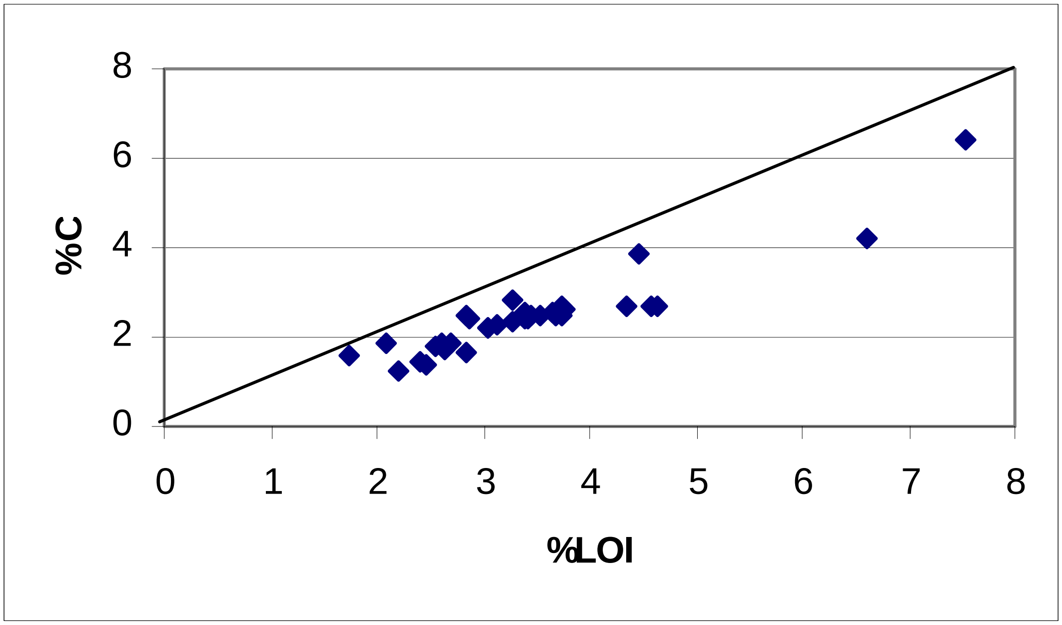

Figure 2. Plot of carbon versus LOI for study samples.

Product Evaluations

Product evaluations were conducted on bulk composite products produced during demonstration plant operation at the Ghent site. These products were produced after the desired operating conditions for each of the unit processes were determined. The unit processes were configured in the desired arrangement and operated at a feed rate of 2 tph for several hours and sampled at regular time intervals. Once steady state operating conditions were achieved, the primary cementitous products were collected, thickened and dewatered for several hours to produce a bulk product of approximately 500 lbs to 1000 lbs. The bulk products were transported to CAER, thoroughly characterized and used for a variety of product evaluations.

A total of four process flowsheet configurations were evaluated and are summarized in Table 3. Flowsheet 1 was the simplest, incorporating only primary classification and spiral concentration and produced pozzolan and coarse carbon products. In Flowsheet 2, froth flotation was added and thus produced an additional fine carbon product. Flowsheet 3 included primary classification, spiral concentration and secondary classification and the resulting products were ultrafine ash (UFA) and coarse carbon. The most complex circuit evaluated was Flowsheet 4 which used primary and secondary classification, spiral concentration as well as froth flotation. With this configuration, three prodects were generated; UFA, coarse carbon and fine carbon. An additional pozzolan product could potentially be recovered with this flowsheet, but was not considered in this evaluation.

Product Evaluations in Mortar

A summary of product evaluations in mortar are also shown in Table 3. To simplify notation, the products obtained by the various flowsheet configurations are denoted by abbreviations; product EP is an Econosizer product recovered with only primary classification, product FP is a flotation product recovered by primary classification and flotation, product UFA an ultra-fine ash produced by primary and secondary classification and product FUFA was produced with flotation as well as primary and secondary classification.

As expected, flowsheets not incorporating secondary classification produced products that were coarser. As such, the levels of water reduction achieved by these coarser products were also lower. The water requirements for the coarser EP and FP products was 96 to 98%, while for the finer UFA and UFA products, water requirements were lower (93 to 96%).

The EP product (d_{50} =14.3 μm) achieved a Strength Activity Index (SAI) of 85% of control strength in 7 days, 100% in 28 days and 130% in 56 days. The FP product (d_{50} =19.2 μm) performed similarly after 7 and 28 days, but achieved only 103% of control in 56 days. The highest strengths were obtained with the finer products UFA (d_{50} =3.2 to 6.0 μm) and FUFA (d_{50} =3.8 to 5.5 μm). Several bulk products of UFA and FUFA were produced under a variety of operating conditions and results are sown as a range, with the finest products producing the higher strengths. Both UFA and FUFA products provided SAI of 102 to 110% of control in 7 days and 126 to 140% of control in 56 days.

The mortar air requirements for each product were essentially the same as those for the standard mortar, a result that may be a particularly advantage for these products. These results suggest that the unburned carbon (i.e. LOI) remaining in these samples did not increase the amount of air entraining admixture (AEA) required to achieve constant 16% mortar air. These results were confirmed by burning the products at 750 ^{o}C to remove all of the carbon prior to making mortar cubes and results were nearly identical to results obtained with ash that was not burned to remove carbon. These results essentially confirm that the carbon present in the Ghent pond ash does not have an affinity for AEA. The propensity of carbon to adsorb AEA is a primary reason for limiting LOI in fly ash for it's use as a pozzolan. The higher dosages of AEA to achieve constant air for the finer products is attributed primarily to increased fineness, and as was the case for the EP and FP products, was essentially the same as for the control mix.

Table 3. Summary of Product Evaluations in Mortar.						
			Flowsheet 1	Flowsheet 2	Flowsheet 3	Flowsheet 4
Unit Processes	Primary Classification		X	X	X	X
	Spiral Concentration		X	X	X	X
	Froth Flotation			X		X
	Secondary Classification				X	X
Product			EP	FP	UFA	FUFA
d50	Microns		14.3	19.2	3.2 - 6.0	3.8 - 5.5
Water Reduction	%		96	97 - 98	93 - 95	93 - 95
S.A.I @20% Substitution	% of Control	7 day	85	80 – 85	102 – 110	102 – 107
		28 day	100	93 – 100	129 – 135	122 – 129
		56 day	130	103	132 - 140	126 – 133
Mortar Air	ul of AEA to Achieve Constant 16% air		620	500	700 - 1600	820 – 1180

Product Evaluations in Concrete

Concrete testing was conducted using a Kentucky Transportation Pavement Mix design and substituting Trimble ash or UFA at a substitution rate of 20%; results are shown in Figure 3. The KYTC Pavement Mix was selected for comparison since it represents a typical high volume mix design in the Ghent marketing region while Trimble ash was used for comparison since it is representative of the type of ash currently available in the same region. The Trimble ash achieved 87% of control strength after 7 days and increased to 102% after 56 days. Two series of tests were conducted with UFA and although there were some differences particularly for the early strengths, the UFA outperformed the Trimble ash with 87-90.5% of control after 7 days, 105 to 107% after 28 days and 109.5 to 112% after 56 days.

Another series of concrete cylinders were poured using a Kentucky Transportation Cabinet High Performance Mix Design (MA designation) and results are shown in Figure 4. The UFA cylinders showed an expected delay in strength development during the early stages of curing and outperformed the control after approximately 20 days.

The effect of UFA substitution on concrete strength is summarized in Figure 5. At 5% UFA substitution, SAI was 101% after 1 and 7 days and increased to 106% after 28 days. At 15% substitution, SAI decreased to 89.5% after 1 day and 98% after 7 days, but the longer term strength gains were apparent after 28 days as a SAI of 113% was attained. At 25% substitution, early strengths were diminished and, again, a SAI of 119.5% was achieved after 28 days. At the highest substitution level tested (35%), early strengths were the lowest and SAI increased to 105% after 28 days. These results illustrate that higher substitution levels certainly delay early strength development, but surpass control strength after 28 days while lower substitution levels provide both early and longer term strength.

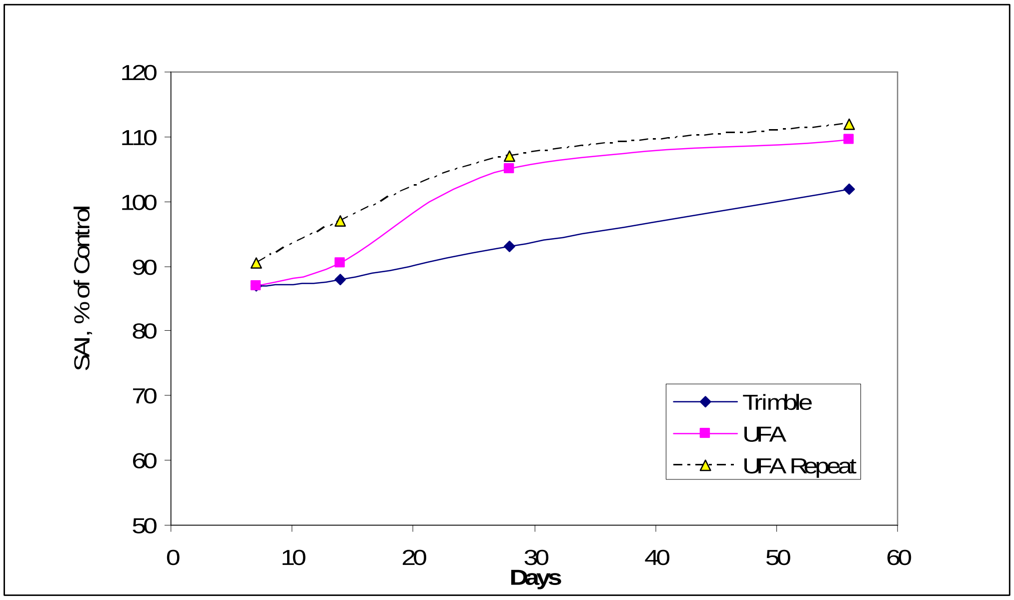

Figure 3. Concrete test results for pavement mix design using Trimble ash and UFA.

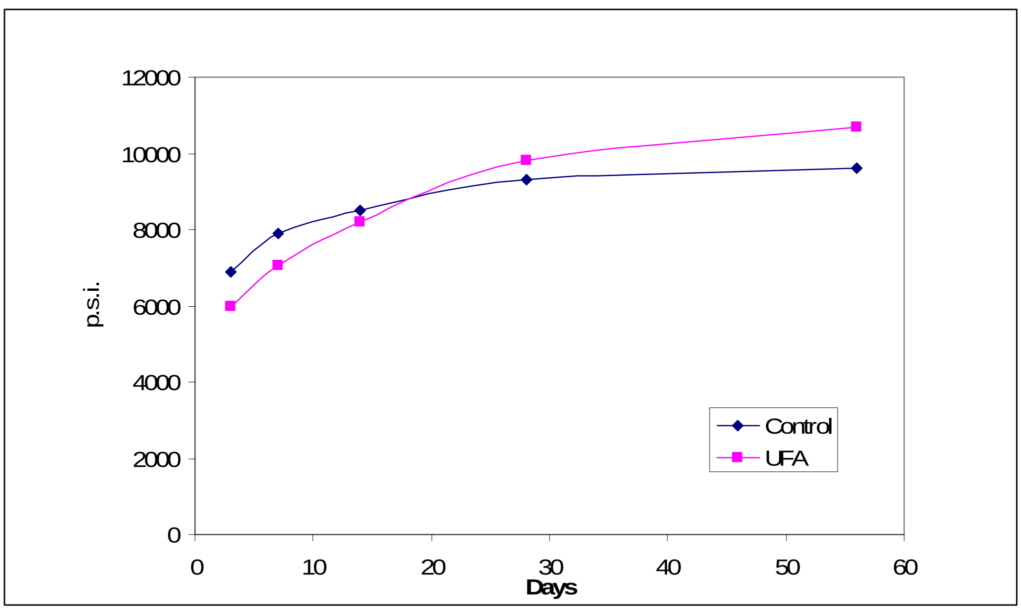

Figure 4. Concrete test results with high performance mix design.

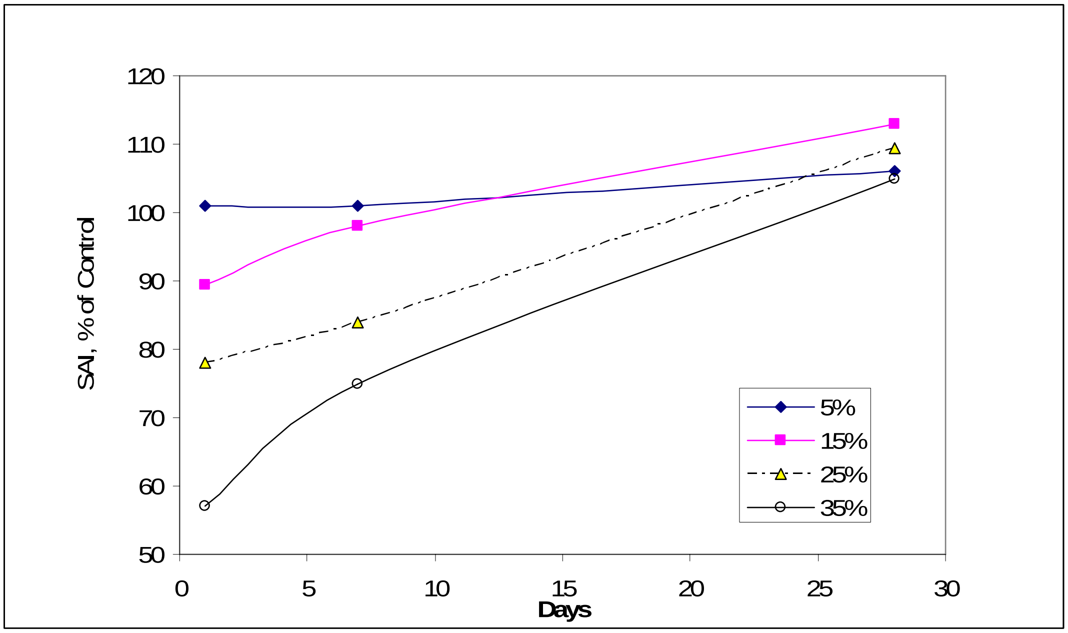

Figure 5. Effect of UFA substitution on concrete strength.

One of the most significant benefits provided by using UFA in concrete mix designs is the improved resistance to chloride permeability. While it has been known for some time that using fly ash in concrete reduces permeability, using finer ash provides a significant improvement in this area as shown in Table 4. Chloride permeability testing was conducted using four different concrete mixes; control, 20% Trimble ash, 20% UFA and 40% UFA. Chloride permeability was improved when Trimble ash was used. Significant further reductions were demonstrated when UFA was used, achieving an ASTM Chloride Rating of Very Low.

Table 4. Chloride permeability test results for concrete.

Concrete Mix	Rapid Chloride Permeability (coulombs)	ASTM Chloride Rating
Control	2418	Moderate
Trimble Ash 20%	1200	Low
UFA 20%	426	Very Low
UFA 40%	150	Very Low

The effect of Trimble ash and UFA on concrete flexural and tensile strength were also evaluated. Results (Table 5) showed that marginal improvements is flexural strength were realized with Trimble ash and were somewhat higher when UFA was used in the mix design. Tensile strength was essentially unchanged when UFA was used and decreased for the Trimble ash.

Table 5. Concrete tensile and flexural strength at 56 days.				
Sample	Flexural Strength (psi)	Flexural Strength Deviation	Tensile Strength (psi)	Tensile Strength Deviation
Control	890	19.1	613	27.7
Trimble Ash 20%	930	4.9	526	70.3
UFA 20%	1056	35.4	625	38.3

Product Evaluations as Process Addition

While the traditional approach to using fly ash in concrete is to utilize the ash as a direct replacement for Portland cement in concrete, an alternative approach was considered, namely as a process addition in the production of cement clinker. This approach offers several potential advantages for the cement kiln. Most notably, production capacity can be increased with minor capital investment by essentially extending the clinker by incorporating low levels (2.5 to 5%) of UFA into the clinker itself. This alternative would be lower in cost to the more traditional approach of using ground granulated blast furnace slag (GGBFS) at the same levels. Results show that early and ultimate strengths can be improved, particularly at the 2.5% substitution level while offering the advantage of improved grinding efficiency since the UFA is fine enough to preclude the necessity of further size reduction. A further benefit would be increased clinker production without increased CO_2 generation. The advantages to the project is that the need for a thermal dryer would be eliminated and initial marketing of the UFA during the early stages of the commercial phase would be simplified.

To evaluate this approach, a series of laboratory scale evaluations were conducted using UFA produced as a stable, pumpable slurry (70% solids w/w) and the following solids properties: d_{50} 3-5 µm, density 2.41 g/cm^3, 3.0% LOI and 1.5% C. For comparison, 6 µm Grade 120 GGBFS was also used. Mortar cubes were produced with either UFA or GGBFS at 2.5% and 5% substitution levels. The results are shown in Figure 6 and indicate that GGBFS and UFA slightly improved the 1 day strength activity at 2.5% substitution; at 5%, strength was 94 – 96% relative to control. UFA consistently exhibited higher 1 day strength activity relative to GGBFS at 2.5% and 5%, while GGBFS and UFA showed similar 28 day strength activity at 5%, which ranged between 104 – 107%. At 2.5%, 28 day strength activity was higher for GGBFS (113%) than for UFA (99%).

Based upon these results and the potentially significant benefits that are offered by using UFA as a process addition, it is recommended that an industrial trial be conducted using 2.5% UFA in accordance with ASTM C465. It is also recommended that mortar and concrete testing of industrially ground cement be conducted by CAER and Cemex.

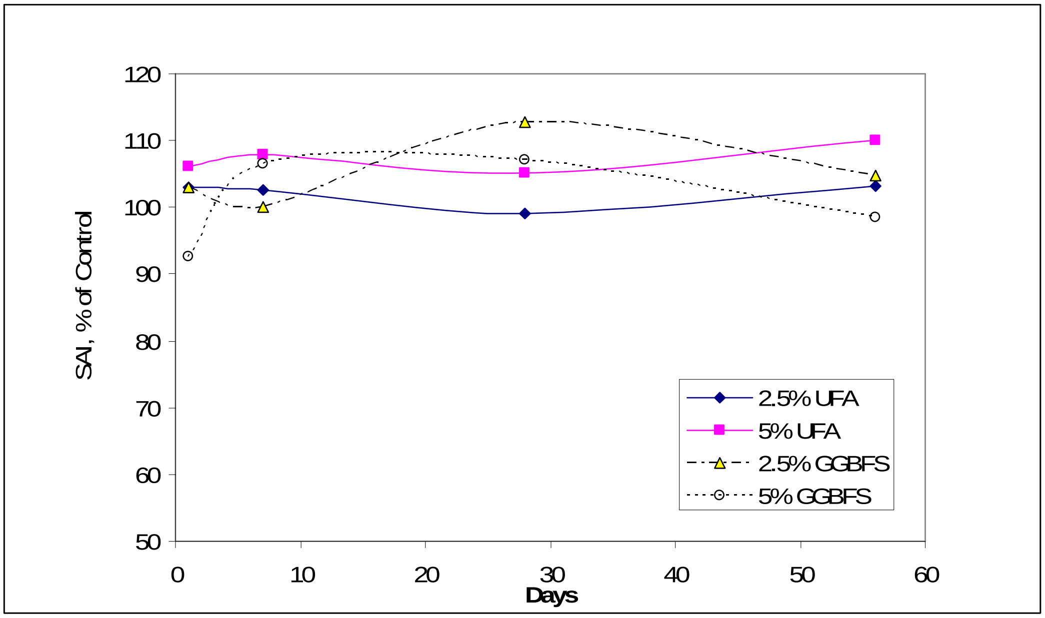

Figure 6. Effect of using UFA and GGBFS as process addition.

CONCLUSIONS

Secondary classification tests were concluded using primary classification overflow as feed with and without flotation to produce UFA. While flotation did provide a lower grade UFA by removing fine carbon, some of the carbon reduction was attributed to changes in stockpile feed grade. A dispersant dosage of 2 to 2.5 g/kg was adequate to provide UFA grade (3.8 to 4.4 μm) and recovery (53 to 68% 5μm recovery). The UFA yield without incorporating flotation was ~33% and lower (~20%) when incorporating flotation due to the amount of material reporting to the flotation froth product. Flotation did reduce the amount of unburned carbon in the UFA product from 4.5% to 2.5% LOI.

Demonstration plant product evaluations showed that water requirements in mortar were 93% to 98%, with finer products providing better water reduction. Coarser products EP and FP achieved 100% of control strength in 28 days followed by further strength gain to 130% in 56 days for the EP product, but only 103% for the FP product. The highest strengths were obtained with the finer products UFA and FUFA which achieved 110% of control strength in 7 days and 140% in 56 days.

The mortar air requirements for each product were essentially the same as those for the standard mortar, a result that may be an advantage for these products, suggesting that the unburned carbon (i.e. LOI) remaining did not increase the amount of air entraining admixture (AEA) required to achieve constant mortar air.

Concrete testing at a substitution rate of 20% showed that the UFA product outperformed a typical ash by achieving 105% to 107% of control strength after 28 days and 109.5 to 112% after 56 days. Higher substitution levels were shown to delay early strength development, but surpass control strength after 28 days while lower substitution levels provide both early and longer term strength.

One of the most significant benefits provided by using UFA in concrete mix designs is the improved resistance to chloride permeability while some improvements in flexural strength were realized and tensile strength was essentially unchanged.

Potentially significant benefits may also be offered by using UFA as a process addition in the manufacture of cement clinker.

List of Acronyms and Abbreviations.

AEA	Air Entraining Admixture
CAER	UK Center for Applied Energy Research
d_{50}	Mean particle diameter on volumetric basis (a.k.a D_{50})
EP	Econosizer Product
FUFA	Ultra Fine Ash that has undergone froth flotation
FP	Flotation Product
GGBFS	Ground Granulated Blast Furnace Slag
HPC	High Performance Concrete
KYTC	Kentucky Transportation Cabinet
LOI	Loss on Ignition
SAI	Strength Activity Index
UFA	Ultra Fine Ash