Commercialization of Fired Paving Bricks with Class F Fly Ash from Illinois Basin Coals

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ABSTRACT

Burning coal for energy produces fly ash as one of the by-products. Fly ash is not currently regulated as a hazardous material by the US EPA and is discarded as waste, most often in impoundments or landfills. The development and marketing of commercial fly ash-containing bricks would benefit the coal industry, utilities, and brick manufacturers by converting discarded fly ash into an economical ingredient for brick making. With support and cooperation from the Illinois State government, the federal government and industry, this study has advanced the initial commercialization process by conducting commercial scale tests to produce paving bricks containing fly ash. Class F fly ash from three different sources was tested at a brick plant in Indiana. Four commercial-scale extrusions and firings produced a total of 8,000 commercial-size paving bricks for evaluation. The bricks were made with 20 volume-percent fly ash balanced with the conventional clay and shale raw material normally used by the brick plant. The effect of the mix's composition on the quality of the green extruded and fired products was evaluated. The produced bricks met ASTM standard specifications for pedestrian and light traffic paving brick.

BACKGROUND

More than six million tons of Class F fly ash is generated from burning about one hundred million short tons of Illinois Basin coal each year. Most of this fly ash is ponded or landfilled, and is readily available for value-added applications. For the past three years, researchers at the Illinois State Geological Survey (ISGS) and the University of Illinois (UIUC) have been working with brick manufacturers to develop high quality and marketable brick products using large volumes of Class F fly ash generated from burning Illinois coals[1,2,3]. In this process of making fired building and face bricks, fly ash is used as a substitute raw material for part of the clay and shale raw materials used in conventional fired bricks. Under the right conditions, the production of building and face bricks containing Illinois coal fly ash can be

commercially viable. The test bricks produced so far have met or exceeded ASTM commercial building specifications. With support and cooperation from the Illinois Department of Commerce and Economic Opportunity/Illinois Clean Coal Institute, the U.S. Department of Energy – National Energy Technology Laboratory, and the utility and brick industries, this study furthered the initial commercialization process and tested ponded Class F fly ashes from three different sources for making paving brick. The results will help brick plants to move one step closer to producing fired brick products containing fly ash.

RAW MATERIALS

Approximately 20 tons of each of the three fly ash samples (Ash M, Ash C, and Ash W) was shipped to the brick plant commercial facility for commercial-scale test runs.

The typical major and minor metal oxides and the unburned carbon content (measured as loss on ignition, LOI) of fly ash, clay, and shale samples are shown in Table 1. The ash materials are comparable to the clay and shale materials in their major metal oxides content. One concern in fired brick making is the formation of white scum on the surface of the brick when the raw material has high soluble salt (Ca and Mg) content. The calcium content, measured in oxide form, of all ash samples (CaO values ranging from 1.06 wt% to 3.71 wt%), was slightly greater than that of the shale and clay materials (CaO values ranging from 0.61 wt% to 0.70 wt%). However, the tests indicated that this slightly higher level of calcium content was not a problem for fired brick production.

Table 1. Metal oxides composition (wt%) of fly ash, shale and clay samples tested

Sample ID	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	LOI
Ash M (I)	52.90	19.71	15.14	0.99	0.04	1.05	2.46	1.27	2.45	0.20	2.93
Ash M (II)	34.00	13.29	38.59	0.71	0.05	0.65	3.71	0.35	1.53	0.15	5.80
Ash C (I)	59.13	26.32	5.04	0.85	0.05	1.38	1.06	0.60	3.52	0.09	1.16
Ash C (II)	54.78	24.36	5.48	1.22	0.06	1.04	3.00	1.11	2.75	0.23	4.95
Ash W (I)	49.20	21.47	7.75	0.84	0.03	1.34	2.83	1.52	1.36	0.35	12.75
Shale/Clay Mix*	59.64	18.29	6.49	1.10	0.12	1.91	0.61	0.85	3.08	0.16	6.93
Shale*	60.15	17.88	6.67	1.07	0.10	1.96	0.70	0.94	3.09	0.16	7.46

*Samples were analyzed after drying. Others are 'As Received' basis; (II) duplicated sampling

The amount of unburned carbon (LOI) of the dry and ponded fly ash samples were analyzed and compared with the raw materials of conventional bricks. Other than Ash W at 12.75 wt%, the LOI for the fly ash samples ranged from 1.16 wt% to 5.80 wt%, which is somewhat lower than the LOI of the shale and clay materials which ranged

from 6.93 wt% to 7.46 wt%. Despite the higher LOI associated with Ash W, the bricks made using this material have met all ASTM specifications. The data obtained in the earlier phase has shown that the unburned carbon content (LOI) of all the fired brick products with and without fly ash was less than 1 wt%, suggesting that unburned carbon is consumed during firing and that the amount of unburned carbon in the ash (LOI about 5.80 wt%) is not a concern for fired brick manufacturing. Therefore, the parameters used to produce conventional bricks such as firing aids and firing temperatures should also be applicable to the making of fly ash containing bricks.

COMMERCIAL-SCALE PRODUCTION (EXTRUSION AND FIRING)

The parameters developed at the brick plant for extrusion to consistently form high-quality face bricks with fly ash were applied to making paving brick. However, paving bricks are solid with no bore holes; therefore, they require firing conditions different from those for face bricks. For a preliminary in-plant firing evaluation, a small batch of commercial-size green paving bricks was made by mold-press at the ISGS bench-scale facility. These mold-pressed green paving bricks were then fired at the brick plant as a part of the commercial firing.

After preliminary in-plant firing tests, which produced high-quality, attractive, and strong paving bricks, commercial-scale extrusion and firing proceeded at the plant to produce commercial paving bricks containing 20 vol% fly ash from three different sources.

FINAL PAVING BRICK PRODUCTS EVALUATION

To evaluate paving bricks produced for commercial quality, the ASTM C902 specification for pedestrian and light traffic bricks was used[4]. For an average of five bricks, the ASTM C 902 sets the minimum compressive strength at 8,000 psi for Grade SX (severe weather); maximum cold water absorption at 8 wt%; maximum saturation coefficient not greater than 0.78; and the maximum abrasion resistance index at 0.11 for Type I brick that is exposed to extensive abrasion, as typically found in driveways or entrances to a public building. The saturation coefficient is defined by the ratio of cold water absorption to boiling water absorption. The abrasion resistance index is defined by the ratio of the cold water absorption to the compressive strength in percent. The results of four commercial-scale production test runs (Run-A, Run-B, Run-C, and Run-D) are shown in Table 2. The engineering properties of the final products from the four test runs met or exceeded ASTM specifications. The data also indicated that an additional 20 vol% of clay balance material (Run-C and Run-D) reduced cracking and chipping of the bricks, thereby significantly increasing the production yield.

Table 2: Engineering properties of paving bricks with 20 vol% of fly ash from four commercial-scale production runs.

		Run-A	Run-B	Run-C	Run-D
Max. water absorption	Cold water, wt% (Class SX <8 wt%)	4.97	1.75	7.42	6.81
	Boiling water, wt%	6.83	2.55	10.16	9.65
	Saturation coefficient* (Class SX <0.78)	**0.75**	**0.69**	**0.73**	**0.71**
Fired compressive strength, psi (Class SX >8,000 psi)		**30,263**	**29,910**	**24,320**	**23,540**
Suction rate, g (wt. gain/ minute)		6.67	2.50	16.4	20.8
Scum		Some	No	No	No
Modulus of Rupture, psi (>1,000 psi)		1245	1737	1520	1959
Abrasion Resistance Index (Type I < 0.11)		0.017	0.006	0.031	0.029
ASTM C902 Classification		Class SX Type I	Class SX Type I	Class SX Type I	Class SX Type I
Production Yield		30%	75%	100%	100%

ASTM C902 - Standard specifications for Pedestrian and Light Traffic Paving Brick. Run-A = 20 vol% fly ash M and 80 vol% shale; Run-B = 20 vol% fly ash C and 80 vol% shale; Run-C = 20 vol% fly ash W, 60 vol% shale, and 20 vol% clay; Run-D = 20 vol% fly ash C, 60 vol% shale, and 20 vol% clay

SUMMARY

This study indicated that paving bricks could be successfully produced with 20 vol% of Class F fly ashes from three different power plants burning Illinois Basin coals. The engineering properties of these paving bricks met or exceeded ASTM C 902 specifications. This study also indicated that a low level of clay material (20 vol%) in the raw mix containing fly ash improved the extruding ability of the mixed raw material and greatly improved the final product yield.

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