FINAL TECHNICAL REPORT
September 1, 1997, through August 31, 1998

Project Title: **UTILIZATION OF LIGHTWEIGHT AGGREGATES MADE FROM COAL GASIFICATION SLAGS**

ICCI Project Number: 95-1/4.1B-2
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## ABSTRACT

The integrated gasification combined-cycle (IGCC) coal conversion process has been demonstrated to be a clean, efficient, and environmentally acceptable method of generating power using high-sulfur Illinois coals. However, the process generates a solid waste consisting of vitrified mineral matter (termed slag) and unconverted carbon. A 400-MW power plant using 4,000 tons of 10% ash coal per day may generate over 440 tons/day of slag, the disposal of which represents significant costs. As coal gasification technologies find increasing commercial applications, it becomes imperative that slag utilization methods be developed and commercialized in order to minimize disposal.

This project was funded by the Department of Energy, the Electric Power Research Institute (EPRI), and the Illinois Clean Coal Institute (ICCI), along with considerable industry involvement. Its primary objective was to demonstrate the technical and economic feasibility of commercial production and utilization of slag lightweight aggregates (SLA) and ultra-lightweight aggregates (ULWAs). The economic incentive for developing this technology depends on the market prices of target applications: conventional LWAs made from expansible clays sell for $40/ton and ULWAs made from expanded perlite sell for $150/ton.

In Phase I, over 10 tons of SLA with unit weights varying between 20 and 50 lb/ft$^3$ were produced using a direct-fired rotary kiln and a fluidized bed calciner using two slag samples. A slag sample from an Illinois basin coal slag generated at the Wabash Gasification Facility in Terre Haute, Indiana, was subsequently added to the project. Blends of slag and expansive clay were extruded to produce coarse lightweight aggregates to confirm that slag can partially replace conventional materials used in existing plants. Phase II focused on demonstrating specific utilization applications The results indicate that SLA is an excellent substitute for conventional LWA in roof tile, block, and structural concrete production. In addition, slag-based near-ultra-lightweight material may be used as a partial substitute for expanded perlite in agricultural and horticultural applications. The preliminary economics indicate that SLA costs would be considerably lower than those of conventional materials due to the absence of mining costs, significantly lower temperature of expansion (1400-1600$^o$F vs. 1800-2000$^o$F for conventional clays) and, possibly, a credit for the avoided cost of disposal. The

technology demonstrated under this project indicates a good opportunity for developing value-added products from slag.

## EXECUTIVE SUMMARY

This document represents a summary of work done during the reporting period from September 1, 1997, through August 31, 1998, for the project entitled "Utilization of Lightweight Materials Made from Coal Gasification Slags." The project consisted of two phases. In Phase I, a 20-ton sample of slag (primary slag) was collected, processed for char removal, and pyroprocessed to produce expanded slag aggregates of various size gradations and unit weights, ranging from 12 to 50 lb/ft$^3$. In Phase II, the expanded slag aggregates (SLA) were tested for their suitability in manufacturing precast concrete products (e.g., masonry blocks and roof tiles), structural concrete, and insulating concrete, first at the laboratory scale and subsequently in commercial manufacturing plants. The SLA products were evaluated using ASTM and industry test methods. Technical data generated during production and testing of the SLA were used to assess the overall technical viability of the technology. Relevant cost data for physical and pyroprocessing of slag to produce expanded slag aggregates was also gathered for comparison with (i) the production costs for conventional materials which the slag aggregates would replace, and (ii) disposal costs for slag or similar wastes. In addition, a market assessment was done to evaluate the economic viability of these utilization technologies including specific benefits or potential problems for commercial production of slag-based LWA.

A third slag sample generated from an Illinois Basin coal was added to the project to extend the project findings to cover slags of interest to the State of Illinois. This sample was obtained from the Wabash River Repowering Project IGCC power plant owned and operated by PSI Energy and Destec (now Dynergy Corp.). The R&D effort focused primarily on char removal and production of SLA suitable for high-strength structural and roof tile applications. The initial work was done using an advance 5-gallon sample tested at the laboratory scale to establish the potential for char removal and LWA production. Based on the positive outcome of the laboratory tests, the decision was made to obtain a large (ten 55-gallon drums) sample of the Wabash slag. This was first processed for char removal and then used to produce SLA products at the pilot scale for testing and evaluation. The results of the project, including those for the Illinois slag, are summarized below.

### Preparation of Slag Prior to Commercial Utilization

Coal gasification slag consists of vitrified mineral matter and unburned or unconverted carbon (char). Typically, as-generated or raw gasification slag contains 15-30% char whose presence has proved to be a hindrance to large-scale utilization. Currently, most plants dispose of their slag as solid waste at a cost of $6-12/ton, thus also wasting the energy content in the char. Therefore, removal of the carbon from the slag was seen as an important preparatory step for safe slag utilization. The steps involved in this process are outlined below.

**Separation of Char from Slag Prior to Utilization.** Praxis Engineers, Inc. developed, tested and demonstrated at the pilot scale a process for separating the char from the slag with the objective of making two byproducts, namely, clean or essentially char-free slag and char. A 400-lb/hr capacity pilot plant for slag/char separation was set up to process over 20 tons of slag feed using the various slags from different gasification processes and coal feedstocks used in the project. The as-received slag, which had carbon contents as high as 30%, was processed to recover char-free slag and a char concentrate fraction containing approximately 65-60% carbon (or 35-40% ash). The char-free slag produced during the project was utilized as a marketable by-product for a number of applications including aggregate in cement concrete and raw material for the production of lightweight aggregates. Evaluation of the recovered char indicated that it may be recycled to the gasification process or used as a boiler fuel when mixed with coal.

Laboratory- and pilot-scale test results performed by Praxis were confirmed by vendor testing using commercially available equipment. High-ash (~100%) slag and a 35-40% ash (or 65-60% carbon) char were consistently produced from laboratory and commercial equipment units. Commercial separation is considered to be a relatively simple and cost-effective operation due to its high capacity. The results of the char/slag separation process for the various slags tested to date, including those for the Illinois coal slag sample, are listed in Table 1. These results were presented to Dynergy and PSI Energy personnel to consider application of this technology at the Wabash plant.

**Table 1. Slag/Char Separation Results**

| Slag | Feed | | Clean Slag | | Char | |
|---|---|---|---|---|---|---|
| | Wt% | Ash % | Wt% | Ash % | Wt% | Ash % |
| Slag 1 | 100 | 91.2 | 85.7 | 100 | 14.3 | 38.3 |
| Slag 2 | 100 | 84.9 | 70.0 | 99.4 | 30.0 | 51.1 |
| Slag 3 | 100 | 85.8 | 74.3 | 100 | 25.7 | 45.1 |
| Slag 4 | 100 | 83.7 | 73.1 | 99.3 | 26.9 | 41.0 |
| Slag 5 | 100 | 75.1 | 62.7 | 100 | 37.3 | 32.9 |
| Slag 6 | 100 | 68.7 | 46.3 | 100 | 53.7 | 41.2 |

**Reprocessing of Char to Upgrade Carbon Content.** Laboratory tests were performed to establish that char can be further upgraded such that it contains 70-80% carbon (or 20-30% ash). The process parameters for this step are highly slag dependent and must be established for each slag by laboratory testing.

**Dewatering of Slag and Char Products.** The recovered slag product can be dewatered using mechanical dewatering equipment to achieve the product moisture desired by the client. The recovered char product can be thickened and returned to the coal grinding system in slurry form for recycle to the gasifier.

**Evaluation of Illinois Slag as a Feedstock for LWA Production**

A laboratory-scale study was performed to determine the feasibility of producing lightweight aggregates generated from an Illinois basin coal slag. The study confirmed that lightweight aggregate products with unit weights of 40-50 lb/ft$^3$ could be produced from Slag 3 in both discrete particle form and after blending with 50% clay. A fired product with a low unit weight of 22.1 lb/ft$^3$ could also be produced from Slag 3 particles at a laboratory furnace temperature of 1600°F. Subsequently, ten 55-gallon drums of the Illinois slag were obtained from the Wabash Plant to produce SLA. This sample was processed for char removal prior to processing for lightweight aggregate production. The product was identical to those produced from other project slag samples.

**Economic Analysis of Expanded Slag Production**

SLA production costs were developed, both with and without a credit for the avoided costs of disposal, and compared with those for conventional LWAs and ULWAs. These production costs include capital costs for a modern facility located at the gasifier site capable of handling approximately 440 tons/day of slag generated by a 400-MW IGCC facility. Operations include processing the raw slag for char removal and kiln processing of the slag to produce LWA from +50 mesh slag and pelletized LWA from the minus 50-mesh fines after mixing with an expansible clay binder and extruding. Fifty percent of the energy required for pyroprocessing is assumed to be supplied by the char recovered from slag, with the remaining 50% supplied by coal, which is easily available on site. The economic analysis was carried out for two different pyroprocesses, i.e., a rotary kiln and a fluidized bed expansion system. A 15% contingency is allowed for capital costs, and the facility is depreciated over 20 years. Necessary utilities are assumed to be available at prevailing market rates at the gasifier site. Production costs for the rotary kiln and the fluidized bed processes were calculated at $24.40 and $21.87 per ton of product, respectively. These costs compare very favorably with current LWA production costs of about $30/ton. When these numbers are modified to reflect the $15/ton avoided costs of slag disposal, the economics of SLA production become even more attractive.

**Testing of Expanded Slag for Production of Lightweight Blocks**

The objective of this task was to use commercial-scale concrete block manufacturing equipment and techniques to produce blocks from expanded slag. This work was done at the facilities of Harvey Cement Products, Inc., a major block manufacturer and distributor in the greater Chicago area. Harvey Cement was selected as they are located close to the Wabash River IGCC plant which is a potential long-term source of slag and hence slag-based LWA. The mix designs used for laboratory testing were identical to those currently used at the plant. For lightweight blocks, the cement-to-aggregate ratio was 1:6.6, and for regular blocks it was 1:8.7. Water was added on an as-required basis depending on the overall workability of the aggregates and the cement paste in the mix. Test specimens (2" x 4" cylinders) were made from the concrete and stored in a curing chamber used to cure commercial blocks. A total of nine blocks was made for each batch, which allowed three blocks per compression test. These tests were conducted after 3, 7, and 28 days of curing. For the last batch, only six specimens were made, which were tested after 3 and 28 days of curing. The compression test results indicate that at the 1:8.7 and 1:6.6 cement-to-aggregate ratios, the 28-day strength was below the ASTM requirement of 2000 psi for load-bearing blocks. These strength values may be increased by adding a higher proportion of cement to the mix or increasing the slag sand or limestone sand content.

A large batch of slag-based concrete (4,222 lb excluding water) was then produced using 60 $ft^3$ aggregate. Some minor modifications were made to the mix design by increasing the quantity of fine material. Over 250 masonry blocks were produced using the automated block production machine. The target specification for 8" lightweight blocks was a concrete unit weight of <115 $lb/ft^3$ which would result in a block dry weight of approximately 27 lb. The compressive strength target of the concrete was 2,000 psi. The results were very successful and matched or exceeded the laboratory-scale test results. The product met all ASTM requirements.

### Testing of Expanded Slag for the Structural Concrete

The expanded slag was tested for the structural concrete application. The results indicate that structural concrete can be made to meet the ASTM compressive strength requirement of 2500-4000 psi at the corresponding unit weight of 105-115 $lb/ft^3$ using 50/50 SLA (i.e., pelletized expanded product made from 50/50 slag/clay). Tests conducted with 50/50 SLA using 6 sacks of cement/$yd^3$ concrete resulted in 7- and 28-day concrete strength measurements of 2910 and 4210 psi respectively. The 28-day value exceeds the ASTM requirement of 4000 psi at a unit weight of 115 $lb/ft^3$. These results were far superior to those of tests done using SLA (3/8" combined) at the same cement level, as well as to the test using a control sample consisting of commercially manufactured aggregates which had a strength of 3400 psi.

Tests conducted at a higher (6.5 sacks/$yd^3$ concrete) cement level resulted in increased compressive strengths of 3480 and 4380 psi for the 7- and 28-day curing periods, respectively, at a unit weight below 115 $lb/ft^3$ . The compressive strength results for the control tests using clay LWA were 4040 and 5100 psi which is in a comparable range. These results exceed the 3440 psi 28-day compressive strength of concrete made from a commercial LWA at the 5/8" size designation. These data indicate that blending slag and clay results in a high-quality product.

### Application of Slag/Char Process at Wabash Plant

The information generated was presented to PSI Energy and Dynergy who are jointly operating the IGCC power plant at the Wabash River Repowering Station. The presentation included a description of Praxis' slag/char separation process and results indicating the potential for production of lightweight aggregates from the Wabash slag.

### Conclusions

The following conclusions were drawn from the development work on this project:

- Slag has a high potential for utilization in the production of lightweight aggregates as a partial or total substitute for conventional shale- or clay-based aggregates.
- Slag may also be blended with clay to produce lightweight aggregates in existing plants to extend their current resource base.
- The aggregates produced may be used in the production of lightweight structural concrete, lightweight masonry blocks, and aggregates for concrete panels.

- Slag-based lightweight aggregates may also be used in nursery applications as a partial substitute for expanded perlite which at $150/ton is a very high value product.