Project Title: DEVELOPMENT AND DEMONSTRATION OF A PILOT SCALE FACILITY FOR FABRICATION AND MARKETING OF LIGHTWEIGHT CCBS-BASED SUPPORTS AND MINE VENTILATION BLOCKS FOR UNDERGROUND MINES

ICCI Project Number: 99US-1
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ABSTRACT

The overall goal of this program is to develop a pilot scale facility, and design, fabricate, and market CCBS-based ultra-lightweight blocks (30-35 pcf) for mine ventilation control devices, and lightweight crib elements and posts (80-90 pcf) for use in underground mines. This specific project was undertaken to 1) design a pilot scale facility to develop and demonstrate commercial production techniques, and 2) provide technical and marketing support to Fly Lite, Inc to operate the pilot scale facility.

Fly Lite, Inc is a joint venture company of the three industrial cooperators who were involved in research into the development of CCBS-based structural materials: Webb Oil Co., Eagle Seal, Inc., and Woodruff Supply Co. The Fly-Lite pilot scale facility is located in McLeansboro, Illinois, immediately adjacent to the Webb Oil/Eagle Seal complex. It is designed to produce CCBS-based post- and crib-elements as well as CCBS-based mine ventilation blocks, both developed at SIUC by the principal investigator. Construction of the facility began in December 1998, and limited production of mine ventilation blocks began in April 2000. The facility was to start with production capacity of about 20 tons per day (tpd) of dry material, increasing to about 100 tpd peak capacity as demand for the products increase and personnel become better acquainted with the equipment and processes.

A pilot scale facility has been developed and it is functional. Lightweight blocks for use in ventilation stoppings in underground mines have been successfully produced by the pilot-scale facility. To date, over 16,000 blocks have been sold to the mining industry. Commercialization of cribs and posts was delayed by almost one year since 1) square cross-section disposable molds could not be purchased commercially at a reasonable cost, and 2) efforts to get them fabricated through three plastics recycling companies failed. Alternate concepts are being developed now to produce and market both the crib and post elements.
EXECUTIVE SUMMARY

The overall goal of this program is to develop, design, fabricate, and market CCBs-based ultra-lightweight blocks (30-35 pcf) for mine ventilation control devices, and lightweight crib elements and posts (80-90 pcf) for use in underground mines. This specific project was undertaken to 1) design a pilot scale facility to develop and demonstrate commercial production techniques, and 2) provide technical and marketing support to Fly Lite, Inc to operate the pilot scale facility. This report summarizes all the work completed to date since project inception in 1999.

Three of the industrial cooperators involved in research into the development of CCBs-based structural materials, Webb Oil Co., Eagle Seal, Inc., and Woodruff Supply Co., formed a joint venture, Fly-Lite, Inc., to produce CCBs-based products on a commercial basis. The Fly-Lite pilot scale facility is located in McLeansboro, Illinois, immediately adjacent to the Webb Oil/Eagle Seal complex. It is designed to produce CCBs-based post and crib elements as well as CCBs-based mine ventilation blocks, both developed at SIUC by the principal investigator. Construction of the facility began in December 1998, and limited production of mine ventilation blocks began in April 2000. The facility was to start with production capacity of about 20 tons per day (tpd) of dry material, increasing to about 100 tpd peak capacity as demand for the products increase and personnel become better acquainted with the equipment and processes.

Experience accumulated over the past three years (1996-1999) during the fabrication of laboratory and prototype supports was utilized to design the 100-tons/day pilot-scale facility. The facility was designed to process CCBs in a continuous operation, producing quality blocks, and supports at the lowest possible cost. Toward this end, a highly automated manufacturing process was designed which requires a minimum of manpower to operate the facility. The only labor required for manufacturing the products, other than maintenance, is for mold preparation, curing operations and storage of the finished supports.

The location of the pilot scale facility complex is shown in Figure 1. Figure 2 shows the anticipated plant layout at full production. Manufacturing processes necessary for pilot scale facility include: 1) dry bulk materials handling system, 2) dry-mixing facilities, 3) wet-mixing facilities, 4) mold filling/handling system, 5) mold preparation and curing facilities, and 6) inventory and packaging facilities. These systems are housed under one roof to minimize handling and to facilitate automation. These are discussed in more detail in the main body of the report.

In order to gain acceptance within the mining industry, CCBs-based marketable products must not only possess superior strength characteristics, but also be cost competitive with other products in the market. A spreadsheet program (Microsoft Excel) was developed to evaluate the economic feasibility of manufacturing products. The program modules consist of: 1) Product parameter input, 2) Investment parameter input, 3) Loan repayment calculation, 4) Cash-flow calculation, and 5) Net present value calculation. Utilizing inputs provided by various individuals within the mining and power generation
industries, the program indicated that a minimum after-tax rate of return of 23% can be achieved for a debt to total investment ratio of zero and that, for a debt to total investment ratio of 70%, an after tax rate of return of over 40% should be possible. These rates of return are most sensitive to labor cost, production rate and energy cost.

**Mine Ventilation Blocks Production**

Ultra-lightweight blocks were the first to be developed and produced from the pilot scale facility. It was decided to produce 8 in. x 12 in. x 16 in. blocks with density of 30-35 pcf. The marketable blocks must be approved for strength and fire resistance before they can be used in mines as ventilation control devices. The Mine Safety and Health Administration approved the produced blocks for use in mines and approval letters are included in Appendix I. The first shipment of ventilation blocks was made on April 7, 2000. Over 10,000 blocks were sold during the period April 2000 to November 2000.

Some companies expressed interest in knowing if Fly-Lite blocks will hold up under water. Blocks were soaked in water for varying number of days. The blocks actually gained strength rather than losing strength. The maximum strength gain recorded was about 100%, from about 150 psi to about 300 psi.

Around November 2000, due to malfunctioning of the fly ash collection system at the SIUC FBC power plant, the quality of the fly ash supplied became very poor and previously developed mix designs for ventilation blocks did not provide good quality blocks. The fly ash contained significant amounts of coarser spent bed ash that was difficult to foam and had very poor cementitious characteristics. The customers complained about the quality of blocks. About 50 different alternate mixes, and about five alternate curing cycles were attempted to utilize the poorer quality fly ash in fabrication of blocks. The results of these studies provided two mix designs that could lead to good quality lightweight blocks. The mix designs utilized over 90% FBC ash with a slightly different curing cycle than was previously being practiced. These mix designs, however, would provide slightly heavier blocks (40 pcf) than were being marketed earlier (30 pcf).

Larger size mixes (producing 5-6 blocks) at one time, were made at McLeansboro, Illinois, using the alternate mix designs and slightly modified curing cycle. The results were positive. About 6,320 blocks were sold until February, 2001. Since then blocks have not been marketed since there is another product in the market that is competing with our product. Autoclaved fly ash blocks 8 in. x 8 in. x 24 in. is currently being dumped in the market place. These blocks are currently manufactured in Atlanta, Georgia, contain 65 % fly ash and are being marketed below the price of our block.

Highly variable fly ash quality has been the most significant problem in getting quality product out to the customers. Loss on ignition values are highly variable, from about 8 % to about 18 %. Particle size distribution is also highly variable, which affects foaming and curing characteristics.
Currently, efforts are underway to develop blocks which are lightweight but do not require foaming the fly ash. Several molds have been modified to cast such blocks and casting was first made on November 15, 2001.

**Commercialization of Crib and Post Elements**

This part of the project has been delayed by almost one year since cheap square cross-section, disposable plastic molds (5” x 5” for cribs and 6” x 6” for posts) originally proposed for the products are not available commercially. Three entrepreneurial companies, one in Kentucky, one in Canada and one in Indiana, expressed interest in fabricating such molds from recycled plastics. However, after working with these companies for over 12-months (providing technical support to develop such molds, and identifying markets for them), business arrangements could not be satisfactorily developed to supply square cross-section disposable molds. There were three major reasons for that: 1) crib elements and post elements have not been approved by MSHA to date since we have not fabricated them because molds were not available and 2) the companies wanted an order of at least 20,000 molds before they would invest monies on dies and extruders, and 3) companies were operating at over 90% of their equipment capacity during 1999-2001 and did not want to get involved unless there was guarantees for profits to be made.

Over the last three months (July-September, 2001), the PI and Fly Lite, Inc. have developed alternate concepts for crib element development. These concepts fall in two categories:

1) Instead of disposable plastic mold to protect element from breakage, steel reinforcement has been incorporated within the element. The casting is, however, done in conventional molds, which require demolding.

2) Geometry of the crib element has been changed to produce lightweight crib element without much foaming of the mix.

To date, about 60 crib elements have been fabricated and tested as 3-foot high cribs at the Illinois Coal Development Park facilities. The concepts appear sound but the overall strength of the crib is still low (40-50 tons). This should be doubled to about 100 tons. Efforts are underway to increase strength of elements through laboratory development of alternate mixes. The development of higher strength mixes will also be used for post-element production.

For production of posts, the PI and Fly Lite have decided to use PVC tubing as a disposable mold. Several 6-foot long and 6-inch diameter posts are supposed to be cast during the period of November 15-November 22, 2001.

In summary, the pilot scale facility subsystems are operating as designed. Lightweight blocks have been produced. Crib and post element production from the pilot scale facility is being emphasized now. It is expected that approvals to use crib and post elements in underground mines from MSHA can be obtained over the next three (3) months.
Figure 1 – Location of the Fly-Lite Complex Production

Figure 2 – Plan View, Fly-Lite Inc. at Full Production
OBJECTIVES

The overall goal of this program is to develop, design, fabricate, and market CCBs-based lightweight posts and crib members for use in underground mines, which are manufactured primarily from local sources of F-Type and FBC fly ash. The FBC by-products from the new powering unit at SIUC and F-fly ash from Southern Illinois Power Cooperative (SIPC) will be used in the manufacturing of ultra-lightweight blocks to be used as ventilation control devices, and artificial supports (cribs and posts). A pilot scale demonstration plant (Fly-Lite, Inc.), located in McLeansboro, Illinois, will be designed and constructed, and manufacturing techniques will be developed. In addition, the performance of the manufactured supports, and blocks will be monitored in the field after installation to ensure the desired level of performance. Finally, assistance will be given in the marketing of these products to mines in the tri-state area.

This project has been funded to assist Fly-Lite, Inc. in designing and constructing a pilot scale facility, producing marketable products on a pilot scale, and marketing them to area coal mines. SIUC has been providing technical support in the construction of the facility, developing quality assurance and quality control measures, developing adjustments to manufacturing techniques (where required), performing field performance testing of manufactured products, and providing assistance in marketing the supports and lightweight blocks.

BACKGROUND AND PROBLEM STATEMENT

The development of environmentally sound and economically viable technologies for the utilization of conventional coal combustion by-products (fly ash and bottom ash) and flue gas desulfurization by-products (scrubber sludge, FBC residues) is a well-recognized problem for the Illinois high sulfur coal industry. Recognizing the current complexities involved in a multifaceted problem such as this, near-term utilization technologies (1-10 years) should be either high volume-low value, or medium volume-medium value approaches. High volume-low value approaches would include back-filling abandoned mines to control subsidence and/or acid mine drainage, surface mine reclamation, or surface management to control acid mine drainage. Medium volume-medium value methods would include flowable fills, structural applications, concrete industry uses, and embankment and road construction materials. Furthermore, these technologies should emphasize utilization of fly ash and wet scrubber sludge, which have been designated by the U.S. Environmental Protection Agency as non-hazardous.

Over the past decade considerable research has been done on high volume-low value disposal/utilization technologies (disposal in surface mines, reclamation, and underground disposal) (Kim and Cardone, 1997). About five years ago, the principal investigator (PI) conceived the following two (2) medium-volume, medium-value utilization technologies:
1) Replacement of wooden supports (posts and cribs) in underground mines with similar supports made from CCBs; particularly F-fly ash, and FBC fly ash.

2) Development of ultra-lightweight blocks (ULB) for mine ventilation stoppings using high volume FBC fly ash and F-fly ash.

Two (2) advantages of these applications are that CCBs and FGD byproducts can be effectively utilized and then left behind in mines where the materials originated, and CCBs are uniformly distributed over a large area thus minimizing potential for negative environmental impacts. Wood prices have been steadily increasing over the past few years and are expected to increase at an even greater rate in the future. Wood can be supplied only seasonally while CCB-based materials could be supplied throughout the year (Yu, 1987). Furthermore, since the artificial supports are spatially distributed over a large area, the potential for negative environmental impacts is virtually non-existent. Additionally, the depletion of forests (and its associated ecological impacts) to provide over 60 x 10^6 ft^3 of wood required by U.S. coal mines can be avoided. One of the problems with this application concept is that inorganic cement-based products are typically heavier (140-150 pcf) than wood (40-50 pcf) and therefore will not be received favorably by industry without modification (Biron and Arioglu, 1983).

Ultra-lightweight blocks, currently available in the market, have low strength (<100 psi) and high deformability (<8000 psi elastic modulus). If these blocks can be made with high-volume fly ash, the potential exists to utilize additional fly ash in such an application.

Over the past 60 months or so, under contracts from Illinois Clean Coal Institute, and with support from the USDOE, the PI has developed, characterized, and demonstrated in mines posts and crib members fabricated from lightweight CCBs-based structural materials (Chugh et al., 1996). These materials were initially developed using fly ash from the Gibson Power Plant of CYNERGY located in Indiana across the Wabash River near Mt. Carmel, Illinois. The developed materials and artificial supports have received positive responses from coal industries and have commercial potential (Chugh et al., 1997).

**PILOT SCALE FACILITY DEVELOPMENT**

**Location**

The Gibson Power Plant was initially selected for supplying fly ash since it was centrally located in relation to the Illinois Basin coal industry and because about 50% of the coal it was burning was supplied by Wabash mine, located just south of Mt. Carmel, Illinois. Although management at the Gibson plant was enthusiastic about siting the pilot scale facility at their location, the power plant had severely curtailed the use of coal from Wabash mine and received most of its coal from mines located in Indiana.
therefore, recommended that the PI consider siting the pilot scale commercial facility within the state of Illinois.

The Lake-of-Egypt Power Plant of Southern Illinois Power Cooperative (SIPC) was considered as a possible siting location in 1997. Initial laboratory results indicated the possibility of developing lightweight structural materials from SIPC fly ash. However, the high amount of unburned carbon (> 10%), and high amount of iron oxides present in SIPC fly ash required large amounts of foam to reduce material densities to the target levels. Therefore, fly ash from AmerenCIPS Grand Tower Power Plant (GT) was tested and used in the development of mixes in the facilities at Carterville, Illinois. However, over the last one year this power plant has been closed.

During 1999, the PI also developed high quality ultra-lightweight blocks using about 80% fly ash from the SIUC circulating FBC plant. The developed blocks had superior characteristics than similar blocks currently available on the market and could be produced at a competitive price.

Three industrial cooperators, Webb Oil, Woodruff Supply, and Eagle Seal formed a joint venture to create Fly Lite, Inc. The Fly Lite management decided to locate the pilot scale facility in McLeansboro, Illinois, since it will be central to the tri-state area mines. The facility is located in McLeansboro, Illinois, immediately adjacent to the Webb Oil/Eagle Seal complex. It is designed to produce CCBs-based posts and crib members as well as CCBs-based ventilation blocks, developed at SIUC. The location of the facility is shown in Figure 1. Figure 2 shows the anticipated plant layout at full production. The facility was designed to process 100 tons per day of dry materials at full peak capacity. However, manufacturing operations were to begin incrementally, starting at about 20 tons per day.

**Characteristics of Proposed Facility**

Experience accumulated during the fabrication of laboratory and prototype supports was utilized in designing the pilot-scale facility for production of CCBs-based products and mine supports. This facility was designed to process large volumes of fly ash in a continuous operation, producing products of high quality. Toward this end, a highly automated manufacturing process was designed which would require a minimum of manpower to operate. The only labor required for manufacturing the supports, other than maintenance, would be for mold preparation, curing operations and stockpiling of the finished supports.

Initially, the facility will begin production at a capacity of around 20 tons per day (tpd) in a batch mode operation, increasing to around 100 tpd (continuous mode of operation) as demand for the products increase and personnel become better acquainted with the equipment and processes. The facility will produce post and crib elements as well as ultra-lightweight ventilation blocks of 30-35 pcf developed at SIUC.
Facility and Components

Manufacturing processes necessary for producing CCBs-based artificial supports on a pilot scale include: 1) dry bulk materials handling system, 2) dry mixing facilities, 3) wet mixing facilities, 4) mold filling/handling system, 5) mold preparation and curing facilities, and 6) inventory and packaging facilities. A computerized system is utilized where programmable linear controllers (PLCs) are adjusted to establish the mix parameters for each product.

Dry Bulk Materials Handling

Fly ash is a very fine pozzolonic material with mean particle size of about 20 microns. When dry it flows well, but it also becomes airborne easily. These characteristics indicated that the most practical option for bulk handling of this material should be an enclosed screw, or auger conveyor powered by an electric motor. A closed-conveyor system of this type can be readily programmed to produce dry mixes of differing percentages of fly ash and binders.

Steel silos designed for the storage and dispensing of fine dry bulk materials, shown in Figure 3, are the least-cost alternative for bulk storage of fly ash and binding agent(s). These silos are readily available, along with equipment designed for loading and unloading. In addition, pneumatic tanker trucks, as well as electric and pneumatic-flow vibrators for uninterrupted material flow are also available. The silos, installed at a height sufficient to provide a shallow conveyor angle (10-15°), discharge into a PLC-controlled conveyor leading to a dry bulk mixer. Capacity of the silos is around 100 tons each.

The design of the screw conveyors was determined from the Conveyor Equipment Manufacturers Association (CEMA) Screw Conveyors book. This manual provides for screw conveyor design parameters based on the type of material to be conveyed and takes into account material size, flowability, abrasiveness, and other miscellaneous properties. Designing the conveyors to deliver 17 tph of material should allow for capacity processing peak of 100 tons of dry material in 6 hours. This should allow sufficient time for cleanup of the facilities as well as any minor interruptions to production. Utilizing one screw conveyor size will simplify parts inventory and minimize conveyor downtime through parts interchangeability. A 12-inch diameter screw conveyor turning at 70 RPM will be required for conveying fly ash at 17 tph. Five (5) HP variable speed motors will be required for operating the conveyors.

Dry Mixing Facilities

In general, most fly ashes will blend easily and binders also seem to blend well with any fly ash. Laboratory experience indicated that premixing the dry constituents would greatly reduce the wet mixing time required to produce a homogeneous grout. For a high capacity system, a high-agitation continuous mixer, such as the ribbon mixer illustrated in Figure 4, would be utilized to thoroughly blend all dry mix constituents before
discharging it into another screw conveyor leading to the wet mixer. The capacity and mixing speed of the dry mixer should be indexed to the throughput capacity of the final mixer at 17 tph. Figure 5 shows the dry mixer installed at the facility.

**Wet Mixing Facilities**

Having utilized different types of mixers in the fabrication of CCBs-based materials in the laboratory and consulting with contractors and manufacturers, it was determined that some type of high-capacity, in-line, high-shear mixer would be required to properly mix the large volumes of relatively dry mixes required in the manufacturing of CCBs-based supports. A pug mill, illustrated in Figure 6, is a high-volume, high-shear, continuous mixer, designed to thoroughly mix large volumes of low-moisture content materials and should be ideal for such an application.

The shearing action in a pug mill is provided by the interaction of mixing paddles attached to parallel shafts. The pitch of the mixing paddles, shaft speed, and mixer volume all play a role in determining residence time and output rate of the grout mix. Adjustments to optimize the mixing process can be performed by changing the paddle angle and/or shaft speeds. The capacity and mixing speed of the pug mill should be matched to the throughput capacity of the dry mixer at 17 tons per hour. Figure 7 shows the wet mixer installed at Fly Lite. Figure 8 shows the wet-mixer in operation.

A precise flow of water is introduced uniformly, across the width of the mixer, onto the dry mix, shortly after it is introduced into the pug mill at a ratio of about 30% to 35% by weight for structural supports and about 50% by weight for the ventilation blocks. If utilizing foam as a density control agent, it will be introduced further down the length of the mixer, approximately ½ to ¾ of the way upstream in the direction of the mix. The optimal time for foam introduction into the wet mixer was later determined to be after wet mixing had been completed.

**Mold Design**

Producing large volumes of CCBs-based materials necessitates that provisions be made to handle large quantities of prefabricated molds (1050 post molds, 5400 crib molds, and 500 block molds per day). One of the goals in the design of the pilot scale facility was to try to produce a product utilizing a minimum of labor. Some amount of labor will be expended on mold preparation and loading and unloading the mold racks, and additional labor will be required to prepare the finished product for marketing. Three molding options were explored: permanent molds, disposable molds, and bulk casting.

Using permanent molds in the production of large numbers of CCBs-based supports would be very labor intensive. This is because permanent molds would require preparation and manual demolding of the cured supports. Additional manpower would then be required to prepare the loose support members for storage and shipping. In addition, a certain number of molds would require replacement yearly, adding to the cost of operations. Figure 9 shows a welded block mold for mine ventilation blocks.
Casting the grout into large slabs and cutting the cured material to the desired shape(s) was also investigated. This approach was eventually abandoned due to concerns about the amount of dust that would be generated by sawing operations, and the expense of purchasing a saw mill, converting it to handling large, heavy slabs of CCBs-based materials and providing the labor to operate it.

Utilizing disposable molds (casting grout in a plastic pipe or mold), illustrated in Figure 10, in the manufacturing of structural supports was viewed as the least-cost method of production, minimizing the number of man-hours spent preparing the racks and molds. Additional benefits to utilizing disposable molds, illustrated in the manufacturing process are the elimination of the humidity chamber in the curing cycle as well as reinforcing fibers, and the superior performance characteristics of supports cast into disposable molds. Because the sheath surrounding the grout prevents the movement of water between the CCBs-based material and the surrounding air, all of the moisture present in the mix is available for the curing cycle. A sufficient number of temperature-controlled chambers are all that will be required for curing operations. Ventilation blocks will still require the use of permanent molds, however.

**Mold Filling/Handling System**

Molding operations consist of preparing the molds, filling them with grout, and transporting them to the required location within the plant for curing. The mixed grout exiting the pug mill will flow into a surge hopper equipped with a slow-speed paddle mixer and pumps. The pitch of the slow-speed mixer blades should be adjusted to push the grout mix to the bottom of the bin, where the grout pump inlets will be located. The wet grout will then be pumped into molds, located in large racks, by use of a piping system utilizing multiple nozzles. Designing and optimizing such a system will require substantial field engineering and the design of the rack and nozzle system will be unique to a particular product.

For reliable plant operation, a robust pump assembly must be utilized for molding operations in a manufacturing facility. An extrusion pump or concrete pump should be utilized for this task in the pilot scale facility to ensure reliability. Other less expensive options were also investigated for use in advanced plant designs to help minimize capital expenditures.

To provide maximum process flexibility, mold racks were designed (Figure 11) for transportation in multiples, utilizing a forklift. Such a system should result in a shorter product-changeover time and greater control over the mold handling process. This will require a piping and nozzle arrangement that can be set up for different products with a minimum of time and difficulty. A fork lift operation of handling multiple molds is shown in Figure 12.
Mold Preparation and Curing Facilities

Preparation of the disposable molds would require trimming the tubing to the required length and capping one end. After the molds have been filled with grout, the open ends will be capped and the filled molds placed in the curing chambers. A 100% relative humidity environment will not be required because the wet grout will not be exposed to the air. Curing chambers at Fly Lite are shown in Figure 13.

Inventory and Packaging Facilities

After removing the cured supports from the handling racks, they must be prepared for shipment before they are placed in inventory. The number of support members to be bundled for shipping should be limited to about 800 pounds per shipping unit. The bundled supports are believed to have a infinite shelf life; specimens cast in permanent molds remained outdoors, uncovered, for an entire winter before they were taken below for a field demonstration of the technology and for much of that time they were covered in ice and snow. Metal banding of the support members and plastic shrink-wrap for the ventilation blocks should prove sufficient for bundling the supports into pallets for shipping. The turntable being utilized for applying the shrink-wrap to the palletized ventilation blocks is shown in Figure 14.

Figure 15 shows the computer-controlled auger conveying system from the bulk materials silos. This system serves as the input to the dry mixer, shown in Figure 5. After the dry mix constituents have been thoroughly blended, the “dry mix” is conveyed to one of two wet mixers, where precise amounts of water and foam are added to the mix to control product density and water/powder ratio. Figures 7 and 8 illustrate the wet mixers at Fly-Lite. The foam discharge nozzle can be seen in the upper left. Also shown in Figure 7 is the mold filling operation. Fly-Lite management has been pursuing suitable designs for more efficiently filling and handling large the large number of molds necessary for large quantity production. A double-diaphragm pump (blue) of the type used for emptying the mixers into the molds currently in use is seen in Figure 7. Propane-fueled fork-trucks, shown in Figure 12, are utilized for mold and product handling operations.

After curing, the blocks are removed from the molds and placed on pallets for shipping. For ease of handling and product durability, the stacked blocks are packaged in commercial, plastic shrink-wrap. This method results in durable, easy to handle pallets that are ready for shipment. The wrapper and turntable used for packaging operations is shown in Figure 14.

Status of Pilot Scale Facility

Construction of the pilot scale facility is complete except for the addition of a large capacity pug mill for the continuous production of CCBs-based posts, cribs, and ventilation blocks. Fly-Lite management has decided to delay the installation of the pug mill until all manufacturing processes have been finalized and sufficient markets
developed to justify the step up to a continuous casting mode of plant operation. Toward this end, the manufacturing process for the ultra-lightweight blocks has been fine-tuned to enable production operations to continue during stormy weather and the block molds have been modified to provide a product with improved dimensional tolerances.

**QUALITY ASSURANCE/QUALITY CONTROL PROCEDURES**

Before marketing the ventilation blocks to the mining industry, the Mine Safety and Health Administration (MSHA) requested that quality assurance/quality control (QA/QC) procedures be developed for fabricating the mine ventilation blocks at Fly-Lite. The following lists the mix constituents and manufacturing tolerances as well as the acceptable variance in the raw materials makeup of the product.

**Quality Control of Ingredients**

There are three (3) main ingredients in the fabrication of the fly ash-based mine ventilation blocks, whose quality should be controlled: 1) Fluidized bed combustion (FBC) fly ash, 2) cement, and 3) lime. All three are important to get a good quality product.

The performance of the fabricated blocks depends primarily on the following process factors: 1) percentage of fly ash, lime and cement by weight in the dry mix, 2) water to dry powder ratio, 3) thoroughness of mixing the dry ingredients, including waste fibers, with water, 4) casting density, and 5) curing cycle and curing times. Of these, items 2 and 4 are the most critical.

The manufacturing process will utilize ordinary Portland (Type I) cement and the supplier will provide a chemical composition data sheet for the material. Similarly, the lime supplier will be asked to supply the certified chemical composition sheet for the lime and the supplier will be asked to certify the quality of the Mearl foaming liquid, utilized in the manufacturing process for density control. All foaming liquids have a set shelf life and care will be taken to ensure that the liquid is used within the designated time span.

The quality of the fly ash, with respect to the loss on ignition (LOI) or unburned carbon, is most variable during the boiler start-up and shut-down periods. Therefore, the FBC fly ash will be collected during periods of relatively constant, normal loads. The operator of the FBC unit, Southern Illinois University, Carbondale (SIUC), maintains logs of the start-up, shutdowns, and plant loads to help ensure that quality fly ash is being supplied to Fly-Lite. Table 1 shows oxides composition for SIU FBC fly ash.

The quality of the fly ash varies somewhat, depending on the load on the powering unit and the quality of coal burned. However, relatively consistent quality blocks can be produced by adequately controlling the amount of loss on ignition and calcium oxide present in the fly ash (Wei, Naik, and Golden, 1994). Table 2 shows the limits proposed
for these compounds in the fly ash as well as the maximum water/powder ratio and minimum as-cast density.

Table 1 – Available Data on Oxides Composition of FBC Fly Ash from SIU Power Plant

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<td>18.0</td>
</tr>
<tr>
<td>Loss on Ignition</td>
<td>14.7</td>
<td>10.3</td>
<td>12.1</td>
<td>9.8</td>
</tr>
</tbody>
</table>

Table 2 – Proposed QA/QC Limits on Process Variables, LOI, and Calcium Oxide

<table>
<thead>
<tr>
<th>Item</th>
<th>Limit</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOI</td>
<td>&lt;15%</td>
<td></td>
</tr>
<tr>
<td>CaO</td>
<td>&gt;15%</td>
<td></td>
</tr>
<tr>
<td>Water to Dry Powder Ratio</td>
<td>&lt;38%</td>
<td>Excludes water from foam for air entrainment</td>
</tr>
<tr>
<td>Cast Density</td>
<td>&gt;35 lb/ft³</td>
<td></td>
</tr>
</tbody>
</table>

Quality Control of the Block Fabrication Process

Almost all of the fabrication process has been computerized to minimize human error and ensure quality blocks. More specifically, the plant and fabrication process has the following controls.

1) All ingredient feeds into the dry mixer(s) are controlled through computer-controlled auger conveyors.
2) Dry ingredient mixing time is computer controlled.

3) Mixing water temperature and mixing water weight is controlled for batch or continuous mixing.

4) Wet mixing time is computer controlled. Similarly, the amount of foam required to develop a set casting density is time controlled. Foam quality is controlled through the air pressure in the foam generator, the temperature of the water and the ratio of foaming liquid to water.

5) The curing cycle and curing temperature are controlled through a computer.

**Quality Assurance of Fabricated Blocks**

The use of quality ingredients and quality control of the fabrication process should result in a quality product of the required specifications. However, to ensure that the consumer receives the best possible product, quality assurance procedures should be utilized. These include:

1) Cement Quality: For each batch of supplied cement (20 tons), about five (5) pounds of cement will be sampled. Three (3), two-inch cubes of full-density will be cast as per ASTM (1994) test requirements. The cubes will be cured according to specifications and tested for unconfined compressive strength. The average compressive strength for the three samples should be within 95% of the manufacturer specifications.

2) Cement-Foaming Characteristics: Three (3), two-inch cubes of cement only will be cast at the required density of the ventilation blocks and cured according to the curing requirements of the blocks. The cured samples will be tested for unconfined compressive strength and the average of the results should be within 10% of the previous batches. This should ensure the quality of the cement, foaming liquid, and the foaming characteristics of the cement.

3) Lime: Hydrated lime (industrial grade) will be utilized. For each batch of lime supplied, three (3), two-inch cubes of 90% fly ash and 10% lime will be cast. The cubes will be cured according to specifications and tested for unconfined compressive strength. The average compressive strength for the three samples should be within 95% of each other.

4) Fly Ash: For each batch of supplied fly ash (20 tons), two batches of five (5) pounds will be appropriately sampled. From each batch, three, full-density, 2-inch cubes of fly ash-cement, in the same proportions as specified for the manufactured block, will be cast and cured as indicated in (1) above in this section. The cubes will be tested for unconfined compressive strength and the average values of the batches must be within 90% of each other and previous samples.

5) Two samples from each batch will also be tested for LOI. The average LOI values for the two batches must be within two (2) percentage points of each other.

6) The tests in (3) above will also be performed at the specified block density. The average values for the two batches must be within 90% of each other.
7) One of every 200 blocks produced will be tested for unconfined compressive strength. The compressive strength values for the samples must be within 25% of each other.

MANUFACTURING OF ULTRA-LIGHTWEIGHT VENTILATION BLOCKS

Ultra-lightweight blocks were the first to be commercialized. It was decided to produce 8 in. x 12 in. x 16 in. blocks with density of 30-35 pcf based on current products in the market. The industry wanted blocks weighing no more than 35 lbs. The blocks must be approved for strength and fire resistance before they can be used in mines as ventilation control devices. Mine Safety and Health Administration approved the produced blocks for use in mines and approval letters are included in Appendix I. The first shipment of ventilation blocks occurred on April 7, 2000. Over 10,000 blocks were sold during the period April 2000 to November 2000. The blocks had compressive strength of about 150 psi and elastic modulus of over 10,000 psi, which is considered good. A typical stress-strain curve for such block is shown in Figure 16.

Mold Modification

Feedback from Wabash Mine management indicate a problem with the dimensional tolerances of the delivered blocks. A significant number of the blocks were not sufficiently square and were difficult to stack properly. This required additional time to erect the ventilation walls, increasing production costs.

To remedy the situation, the material being used for fabricating the block molds (ultra-high molecular density polyethylene) is now being welded as well as screwed together as shown in Figure 9. This not only enables more consistent block dimensions, but aids in the removal of the cured product from the mold due to the radius added to the inside corners of the mold. Blocks produced in these molds are more easily removed after curing, resulting in fewer damaged units.

Effects of Wetting on Ventilation Blocks

Before committing to the purchase of ventilation blocks from Fly-Lite, management at the Old Ben #11 mine requested that tests be performed on the ventilation blocks to determine their tolerance to immersion in water for a span of approximately two months. Toward this end, a total of six (6) different blocks were tested for water tolerance. Blocks were soaked in water for varying number of days. The blocks actually gained strength rather than losing strength. The maximum strength increase recorded was 100% from 150 psi to about 300 psi.

Testing consisted of first, obtaining regular production blocks in the 35-40 pcf range and cutting them in half. One-half of the block was subsequently immersed in water and the other stored in a cool, dry location. Matching halves were then tested for unconfined compressive strength after one, four, eight, sixteen, and sixty days of submersion. The
results compare the compressive strengths of the saturated and dry blocks, shown in Figures 17, 18, 19, 20, 21 and 22, respectively.

The results of these ventilation block tests demonstrate that water-saturated Fly-Lite Lightweight Blocks showed no indication of a decrease in performance after submersion in water. In fact, the test results show that this material becomes stronger with exposure to water. This is more than likely due to the high percentage of FBC ash utilized in the grout mix, an additional amount of the FBC ash is reacting with the water as it penetrates into the interior of the block over time. The blocks were totally saturated after about eight days under water.

**Flexural Strength Tests on Block Walls**

Before a product may be marketed for use in underground mines, a product certification must be obtained from the Mine Safety and Health Administration. The certification is issued when the product meets the performance criteria prescribed in the Code of Federal Regulations (CFR), Part 30. Ventilation control devices, such as the ventilation blocks from Fly-Lite, must meet rigid standards concerning resistance to combustion and ventilation pressures.

For expediency, the Non-Destructive Testing (NDT) Group was chosen to conduct the pressure simulation, or flexural tests on the ventilation blocks. Three 4 ft × 8 ft walls were erected at NDT testing facilities on February 25, 1999. The blocks were dry-stacked and the joints sealed with Eagle Seal’s “Air Float” sealant. The test walls were allowed to cure for 28 days and were tested on March 25, 1999. The tests consisted of applying an increasing load to the center front of the wall as per ASTM E72-80, “Conducting Strength Tests of Panels for Building Construction” (1994). The results of the tests are summarized in Table 3.

The average flexural strength obtained exceeded the minimum 39 lb/ft² required by MSHA by almost 20%. A copy of the letter sent to Fly-Lite by NDT, certifying the test results is located in Appendix I.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Load (lb)</th>
<th>Flexural Strength (lb/ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1810</td>
<td>61.1</td>
</tr>
<tr>
<td>2</td>
<td>1415</td>
<td>47.8</td>
</tr>
<tr>
<td>3</td>
<td>905</td>
<td>30.5</td>
</tr>
<tr>
<td>Average</td>
<td>1377</td>
<td>46.5</td>
</tr>
</tbody>
</table>
Fire Resistance Tests for MSHA Approval

Fire testing of the Fly-Lite ventilation blocks was conducted by MSHA in accordance with ASTM E119-88 “Fire Tests of Building Construction and Material” (1994). After conducting the test, MSHA concluded that the Fly-Lite blocks meet the incombustible requirements of 30 CFR Part 75.33. A copy of the letter of approval sent to Fly-Lite from MSHA is located in Appendix I.

Around November 2000, due to malfunctioning of the fly ash collection system at the SIUC FBC power plant, the quality of the fly ash supplied became very poor and previously developed mix designs for ventilation blocks did not provide good quality blocks. The fly ash contained significant amounts of coarser spend bed ash that was difficult to foam and had very poor cementitious characteristics. About 50 different alternate mixes, and about five alternate curing cycles were attempted to utilize the poorer quality fly ash in fabrication of blocks. The results of these studies provided two mix designs that could lead to good quality lightweight blocks. The mix designs utilize over 90% FBC ash with a slightly different curing cycle than was previously being practiced. These mix designs, however, provide slightly heavier blocks (40 pcf) than were being marketed earlier (30 pcf).

Larger size mixes, producing 5-6 blocks at one time, were made at McLeansboro, Illinois using the alternate mix designs and slightly modified curing cycle. The results were positive. About 6,320 blocks were sold until February, 2001. Since then blocks have not been marketed since there is another product in the market that is competing with our product. Autoclaved fly ash blocks 8 in. x 8 in. x 24 in. are currently being dumped in the market place. These blocks, currently manufactured in Atlanta, Georgia, contain 65% fly ash and are being marketed below the price of our block.

Highly variable fly ash quality has been the most significant problem in getting quality product out to the customers. Loss on ignition values are highly variable from about 8% to about 18%. Particle size distribution is also highly variable.

Currently, efforts are underway to develop blocks which are lightweight but do not require foaming the fly ash. Several molds have been modified to cast such blocks and casting is planned during the week of November 12, 2001.

Manufacturing Process Modifications

A perplexing phenomenon was encountered while producing the ventilation blocks when a storm front was approaching. The micro-bubbles, introduced into the mix in the form of micro-cellular foam, would suddenly rise to the top of the mold with an accompanying segregation of fly ash and cement in the remaining material as weather conditions changed. Apparently, the amount of foam in the mix to achieve the desired density is at or near the maximum the grout will accept and a rapid decrease in barometric pressure triggers the release of the air bubbles from the mix.
Fly-Lite personnel discovered that adding foam to the dry material before adding water would enable the mix to remain stable enough to mold and cure without incident. Strength tests have concluded that this method of production has no adverse effects on the performance of the blocks. However, more foam is required to manufacture the blocks with this method and it will be limited to those periods when atmospheric conditions require it.

To facilitate the handling of large numbers of molds, a prototype mold-rack, illustrated in Figure 11, was fabricated and utilized in the manufacturing process. This device is mobile and was designed to transport eighteen (18) mold assemblies (54 blocks) to and from the curing chambers. Mounted on dollies, the rack can be moved by hand or with the aid of a forklift.

**COMMERCIALIZATION OF CRIB AND POST ELEMENTS**

This part of the project has been delayed by almost one year since cheap square cross-section; disposable plastic molds (5in. x 5in. for cribs and 6in. x 6 in. for posts) proposed for fabrication are not available commercially. Three entrepreneurial companies, one in Kentucky, one in Canada and one in Indiana, expressed interest in fabricating such molds from recycled plastics. However, after working with these companies for over 12-months (providing technical support to develop such molds, and identifying markets for them), business arrangements could not satisfactorily be developed to supply square cross-section disposable molds. There were three major reasons for that: 1) crib elements and post elements have not been approved by MSHA since we have not fabricated them because molds were not available, and 2) the companies wanted an order of at least 20,000 molds before they would invest monies on dies and extruders, and 3) companies were operating at over 90% of their equipment capacity during 1999-2001, and wanted to make sure that they will make profit.

Over the last three months (July-September, 2001), the PI and Fly Lite, Inc. have developed alternate concepts for crib element development. These concepts fall in two categories:

1) Instead of disposable plastic mold to protect element from breakage steel reinforcement has been incorporated within the element. The casting is done in conventional molds, which require demolding.

2) Geometry of the crib element has been changed to produce lightweight crib element without foaming the mix (Figure 23).

To date, about 60 crib elements have been fabricated and tested as 3-foot high cribs at the Illinois Coal Development Park facilities. The concepts appear sound but the overall strength of the crib is low (40-50 tons). This needs to be doubled to about 100 tons. Efforts are underway to increase strength of elements through laboratory development of alternate mixes. The development of higher strength mixes will also be usable for post-element commercialization. The results of these studies and included in the next section.
For commercialization of posts, the PI and Fly Lite have decided to use PVC tubing as a disposable mold. Several 6-foot long and 6-inch diameter posts are supposed to be cast during the period of November 15-November 22, 2001.

In summary, the pilot scale facility subsystems are operating as designed. Lightweight blocks were commercialized. Crib and post element commercialization is being emphasized now.

**Development of mixes for crib and post elements**

Thirty two (32) mixes were prepared using different proportions of fly ash, cement, lime, white sand and brown sand with appropriate amount of water. Some of the promising mixes were replicated in order to obtain a faithful representation of the relationship between the proportions of ingredients and the strength properties of mixes. Table 4 shows the observed data in the laboratory for different samples. A wide range of proportions was covered in the mixture design, and there were about 32 samples tested in the laboratory. As shown in Table 4, the proportions of fly ash, cement, lime, white sand and brown sand covered in the preliminary mixture design ranged 20% - 90%, 0 – 17.5%, 0 – 12.5%, 0 – 60% and 0 – 10%, respectively. With these proportions, the minimum and maximum strength values observed in the laboratory were 611.6 and 1549.8 psi. The minimum and maximum elastic modulus values were 12,750 and 115,770 psi. The average strength and elastic modulus value that was achieved in the laboratory was 1108.5 psi and 47596. 8 psi. These statistical values showed a large amount of variance among different samples as would be expected. A two-level factorial analysis using Design Expert was used to analyze the data. This was done to find out the dominant factors affecting strength and elastic modulus of the mixtures, and also the interaction among the dominant factors, to predict strength and elastic modulus.

All the above variables were chosen as independent variables, and compressive strength and elastic modulus were chosen as the two response variables. From the statistical analysis the model F-value found was 2.99, which implies the model is significant. There is only a 1.65% chance that this F-value could occur due to noise. Values of "Prob > F" less than 0.0500 indicate that the model terms are significant.

The following comments are significant

1. The amount of fly ash is most significant followed by cement and lime for strength. The brown sand and white sand amounts are not significant.
2. The above variables are also significant for elastic modulus. In addition, amount of sand is also important.
3. There is significant interaction between fly ash and lime, cement and lime variables for strength prediction.
4. For elastic modulus, interaction is significant between fly ash and cement, fly ash and lime, and lime and cement.
5. Strength and elastic modulus values should approach desired values for the following composition:

- Fly ash – 85%
- Lime - 7.5%
- Cement – 7.5%

Table 4 - Proportions of raw ingredients and strength properties

<table>
<thead>
<tr>
<th>Composition ( % )</th>
<th>Sample Number</th>
<th>Density (pcf)</th>
<th>Compressive Strength (psi)</th>
<th>Elastic Modulus (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly Ash Cement Lime Brown Sand White Sand</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90 10 0 0 0</td>
<td>C55</td>
<td>83.6</td>
<td>1353.4</td>
<td>39,629</td>
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<tr>
<td>90 0 10 0 0</td>
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<td>85.3</td>
<td>1020.0</td>
<td>30,659</td>
</tr>
<tr>
<td>90 5 5 0 0</td>
<td>C47</td>
<td>76.9</td>
<td>1225.9</td>
<td>103,377</td>
</tr>
<tr>
<td>85 7.5 7.5 0 0</td>
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<td>57,173</td>
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<td>85 7.5 7.5 0 0</td>
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<td>81.2</td>
<td>1210.3</td>
<td>37,504</td>
</tr>
<tr>
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<td>C38</td>
<td>82.3</td>
<td>1028.6</td>
<td>20,945</td>
</tr>
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<td>85 15 0 0 0</td>
<td>C33</td>
<td>98.9</td>
<td>659.0</td>
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<tr>
<td>85 7.5 7.5 0 0</td>
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<td>81.4</td>
<td>1373.2</td>
<td>68,915</td>
</tr>
<tr>
<td>85 7.5 7.5 0 0</td>
<td>C1</td>
<td>84.0</td>
<td>1527.4</td>
<td>76,300</td>
</tr>
<tr>
<td>85 7.5 7.5 0 0</td>
<td>C2</td>
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<td>1549.8</td>
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</tr>
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<td>C13</td>
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</tr>
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<td>75 7.5 7.5 0 10</td>
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<td>102.2</td>
<td>611.6</td>
<td>12,750</td>
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<td>82.9</td>
<td>936.4</td>
<td>47,380</td>
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<td>C6</td>
<td>82.9</td>
<td>983.8</td>
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<td>75 10 0 15 0</td>
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<td>94.6</td>
<td>702.9</td>
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<td>95.0</td>
<td>864.0</td>
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<td>90.1</td>
<td>976.0</td>
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<td>CN10</td>
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<td>1293.0</td>
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<td>79.7</td>
<td>1114.7</td>
<td>115,770</td>
</tr>
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<td>75 17.5 7.5 0 0</td>
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<td>75 17.5 7.5 0 0</td>
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<tr>
<td>30 15 0 55 0</td>
<td>S5</td>
<td>105.2</td>
<td>1365.4</td>
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<tr>
<td>20 15 0 60 0</td>
<td>S3</td>
<td>111.9</td>
<td>1301.6</td>
<td>65,470</td>
</tr>
</tbody>
</table>
Effect of Cure Time on Engineering Properties of Crib Elements

Prior to development of appropriate mixtures for crib elements as discussed in the previous section, crib elements were made with fly ash and varying amounts of lime based on success achieved for ultra-lightweight blocks. Several large size blocks (12 in x 6 in x 6 in approximately) to evaluate the effect of cure time on engineering properties of blocks. The data is summarized in Table 5. The results indicate that strength and elastic modulus increase with cure time.

Table 5 - Effect of Cure Time on Engineering Properties of Crib Elements

<table>
<thead>
<tr>
<th>Composition</th>
<th>Fabrication Date</th>
<th>Sample Number</th>
<th>Test Date</th>
<th>Compressive Strength (psi)</th>
<th>Elastic Modulus (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 sec of foam with P and W 100 lb Fly Ash + 6.75 lb Lime + 35 lb Water + No Fiber</td>
<td>17th August, 2001</td>
<td>C1-P</td>
<td>6th Sept, 2001</td>
<td>1,014</td>
<td>65,180</td>
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<tr>
<td></td>
<td></td>
<td>C1-P</td>
<td>14th Sept, 2001</td>
<td>1,101</td>
<td>130,875</td>
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<tr>
<td></td>
<td></td>
<td>C1-W</td>
<td>6th Sept, 2001</td>
<td>1,000</td>
<td>152,114</td>
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<tr>
<td></td>
<td></td>
<td>C1-W</td>
<td>14th Sept, 2001</td>
<td>1,059</td>
<td>76,238</td>
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<tr>
<td></td>
<td>20th August, 2001</td>
<td>C2-P</td>
<td>6th Sept, 2001</td>
<td>599</td>
<td>31,410</td>
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<tr>
<td></td>
<td></td>
<td>C2-P</td>
<td>14th Sept, 2001</td>
<td>811</td>
<td>40,902</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C2a-P</td>
<td>24th Sept, 2001</td>
<td>819</td>
<td>63,095</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C2b-P</td>
<td>24th Sept, 2001</td>
<td>840</td>
<td>54,848</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C2-W</td>
<td>6th Sept, 2001</td>
<td>403</td>
<td>13,834</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C2-W</td>
<td>14th Sept, 2001</td>
<td>629</td>
<td>27,430</td>
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<tr>
<td></td>
<td>21st August, 2001</td>
<td>C3-P</td>
<td>6th Sept, 2001</td>
<td>933</td>
<td>53,842</td>
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<tr>
<td></td>
<td></td>
<td>C3-P</td>
<td>14th Sept, 2001</td>
<td>1,103</td>
<td>79,832</td>
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<tr>
<td></td>
<td></td>
<td>C3a-P</td>
<td>24th Sept, 2001</td>
<td>997</td>
<td>115,134</td>
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<tr>
<td></td>
<td></td>
<td>C3b-P</td>
<td>24th Sept, 2001</td>
<td>850</td>
<td>108,325</td>
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<tr>
<td></td>
<td></td>
<td>C3-W</td>
<td>6th Sept, 2001</td>
<td>798</td>
<td>31,627</td>
</tr>
<tr>
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<td>C3-W</td>
<td>14th Sept, 2001</td>
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<td>C3a-W</td>
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<td>1,077</td>
<td>61,547</td>
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<td>C3b-W</td>
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<td>978</td>
<td>54,090</td>
</tr>
</tbody>
</table>

Limited experiments were performed to determine if replacement of lime by cement, and the type of mold (wooden or plastic) have an effect on strength and elastic modulus. The
results of these studies are summarized in Table 6. FAC and FAL represent fly ash- 
cement, fly ash-lime compositions and S1P and S1W represent plastic and wooden 
molds, respectively. The results indicate that

1. FAC is slightly better than FAL, which can be expected.
2. Wooden molds appear to give higher modulus value. This may be because wood 
is absorbing some of the water from the sample.

These studies are continuing to finalize mix compositions, which should be utilized for 
fabricating crib and post elements. The desired strength and elastic modulus values for 
these elements are about 1,200 psi and 100,000 psi respectively.

Table 6 - Effect of Cure Time on Engineering Properties of Crib Elements

<table>
<thead>
<tr>
<th>Composition</th>
<th>Sample (Crib)</th>
<th>Sample Size L(in) x W(in) x H(in)</th>
<th>Test Area (sq. inch)</th>
<th>Compressive Strength (psi)</th>
<th>Elastic Modulus (psi)</th>
<th>Test Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAC</td>
<td>1</td>
<td>12 x 5.5 x 5.5</td>
<td>66</td>
<td>882.0</td>
<td>37,822</td>
<td>8th August, 2001</td>
</tr>
<tr>
<td>FAL</td>
<td>2</td>
<td>12 x 6 x 6</td>
<td>72</td>
<td>823.3</td>
<td>26,352</td>
<td>8th August, 2001</td>
</tr>
<tr>
<td>S1-Plastic</td>
<td>S1P</td>
<td>12 x 5.5 x 5.5</td>
<td>66</td>
<td>1,057.0</td>
<td>64,244</td>
<td>24th August, 2001</td>
</tr>
<tr>
<td>S1-Wood</td>
<td>S1W</td>
<td>12 x 5.75 x 5.75</td>
<td>69</td>
<td>1,096.5</td>
<td>107,731</td>
<td>24th August, 2001</td>
</tr>
</tbody>
</table>

CONCLUSIONS

• Pilot-scale manufacturing facility for producing CCBs-based products has been 
constructed and it operates as planned.

• Quality ultra light-weight ventilation blocks can be produced as long as quality fly 
ash can be received from the power plant.

• Most of the design and process modifications for ventilation blocks are complete.

• The PI is confident that CCBs-based crib and post elements will be successfully 
produced form the facility given adequate time.

• Fly ash quality is the most important variable in producing quality CCBs –based 
products.

RECOMMENDATIONS

• Efforts to produce and market CCBs-based crib and post elements should be 
continued.
• Efforts to produce light-weight blocks, using un-foamed mixes, should be explored.
• Other markets (mining and non-mining) using these technologies should be explored.

FUTURE PLANS

• Near-term future plans are focused on development of crib and post elements. It is expected that MSHA approval for use of CCBs-based post and crib elements can be obtained by March 2002.
• Work will also continue in the facility to streamline operations and provide a continuing increase in the level of automation within the plant. Plant personnel are currently investigating the possibility of developing an automated method of removing the cured ventilation blocks from the molds, reducing the man-hours required in production as well as the number of blocks damaged in this phase of the manufacturing process.
• Longer-term future plans at Fly-Lite, Inc. call for the installation of a pug mill for producing structural supports, as well as ultra-lightweight ventilation blocks, as acceptance of CCBs-based materials grows within the mining industry. SIUC research staff will assist Fly-Lite personnel in the installation and adaptation of the pug mill for integration into the plant. In addition, SIUC personnel will work closely with Fly-Lite in designing and implementing an efficient, continuous manufacturing process for producing large volumes of high quality CCBs-based structural supports.

REFERENCES


“Coal Data 1993”, National Coal Association, Washington D.C.


Figure 1 – Location of the Fly-Lite Complex Production

Figure 2 – Plan View, Fly-Lite Inc. at Full Production
Figure 3 – Silos for Storage of Fly Ash and Binders

Figure 4 – Ribbon Mixer
Figure 5 - Dry Mixer with Screw Conveyors at Fly-Lite, Inc.

Figure 6 – Typical Pug Mill
Figure 7 – Wet Mixer, Fly-Lite, Inc.

Figure 8 – Wet Mixer Operation, Fly-Lite, Inc.
Figure 9 – Welded Block Mold

Figure 10 – Support Cast into Disposable Mold
Figure 11 – Mold Rack

Figure 12 – Fork-Lift Truck Operation Putting Filled Molds in Curing Chamber
Figure 13 – Curing Chambers at Fly-Lite, Inc.

Figure 14 – Packaging Wrapper and Turntable for Stretch Wrapping
Figure 15 – Programmable Control Systems for Pilot Scale Facility

Figure 16 – A typical stress-strain curve of a block
Figure 17 – One Day Water Immersion

Figure 18 – Four-Day Water Immersion
Unconfined Compressive Strength
8 Day Water Submersion - Block #3

Figure 19 – Eight-Day Water Immersion

Unconfined Compressive Strength
16 Day Water Submersion - Block #4

Figure 20 – Sixteen-Day Water Immersion
60-Day Immersion Test Comparison, Block #1

Figure 21 – Sixty-Day Water Immersion, Block #1

60-Day Immersion Test Comparison, Block #2

Figure 22 – Sixty-Day Water Immersion, Block #2
Figure 23 – Redesigned Crib Element
Appendix I
Letters of Approval From MSHA

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**Non-Destructive Testing Group**

*Quality by Integrity and Knowledge*

Tested For: Flylite Inc.  
PO Box 32  
McLeanboro, IL 62859  
Attn: Bob Young

Date: March 26, 1999  
Lab No. 990297  
Work Order 99-9197

Transverse Load Tests per ASTM E 72

On February 25, 1999, Messrs. Gary Bruce and Curtis Gunter representing Flylite, Inc. were present at NDT Group’s Physical Testing Department to construct three, 4-ft x 8-ft block wall panels.

The walls were made using Flylite “Lightweight” blocks dry stacked to build the 4-ft x 8-ft walls. The joints were sealed using Eagle Seal “Air Float” trowel grade at a minimum of 4-in x 1/8-in thick.

**Test Set-up and Procedure**

The panels were built on 8 inch wide steel panels with spaces on the bottom to lift the panels for testing. The test frame was set up to connect one side together. The 4-ft x 8-ft block panel was then placed against one side of the test frame. The top and bottom supports were 6 inches wide for bearing. A jack was positioned at the center front of the loading frame for application of the load. The space between the load cell and the rear bearing frame was filled with spacers. The other side of the test frame was connected together. The load was then applied through the jack and the maximum pressure was recorded.

On March 25, 1999, the testing was conducted at NDT Group’s facility on walls which were previously constructed on February 25, 1999. The walls were allowed to cure for 28 days. The walls were then tested for flexural strength, 1/4 point load on an 10 inch clear span, using a calibrated hydraulic jack assembly. The results are as follows:

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Maximum Load-Pounds</th>
<th>Flexural Strength-PSF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1810</td>
<td>61.1</td>
</tr>
<tr>
<td>2</td>
<td>1415</td>
<td>47.8</td>
</tr>
<tr>
<td>3</td>
<td>905</td>
<td>30.5</td>
</tr>
<tr>
<td>Average:</td>
<td></td>
<td>46.5</td>
</tr>
</tbody>
</table>

Effective Area = 29.61 Square Feet

Respectfully submitted,

[Signature]

Peter Merther, PE  
Non-Destructive Testing Group, Inc.
February 18, 2000

MEMORANDUM FOR JOHN P. LANGTON
Acting Chief, Safety Division
Coal Mine Safety and Health, Arlington

THROUGH: STEVEN J. LUZIK
Chief, Approval and Certification Center

FROM: HARRY C. VERNON
Chief, Engineering and Testing Division

SUBJECT: Suitability of a Non-Traditional Practice Wall Assembly Stopping System Manufactured by Fly-Lite, Inc., for use under 30 CFR Part 75.333

Fly-Lite, Inc., P.O. Box 32, Highway 14 East, McLeansboro, Illinois, 62859, has submitted information and test data concerning their new stopping system called Fly-Lite “Light Weight” Blocks. The stopping system combines dry stacked Fly-Lite “Light Weight” Blocks and Eagle Seal “Air-Floated” Mine Sealant. The system is judged to meet the noncombustible requirements of 30CFR Part 75.333, as determined by testing according to ASTM E119-88, “Fire Tests of Building Construction and Materials.” The product also provides a structurally equivalent (at least 39 psf) ventilation control to an 8-inch hollow core concrete block stopping with mortared joints as determined by testing according to ASTM E72-80, "Conducting Strength Tests of Panels for Building Construction." Section 12-Transverse Load-Specimen Vertical, load only and meeting the strength requirements of 30CFR Part 75.333.

The construction of the stopping system consists of:

1. Fly-Lite “Light Weight” block.
2. Eagle Seal Air Floated Mine Sealant.
The stopping system is constructed in the same manner as a traditional dry stacked block and sealant stopping. As a minimum, the sealant is applied on all joints on the high pressure side or both sides of the stopping, at least 1/8-inch thick and 4 to 6 inches wide. An Installation Procedure is attached.

Since the Eagle Seal Air Floated Mine Sealant used with this stopping contains water-soluble ingredients, it should not be used where standing or running water exists. The water may degrade the performance of this product.

This stopping system must be maintained to be in compliance with MSHA requirements. During mine inspections, this stopping system should be evaluated to determine if it is being maintained and if it is providing the intended ventilation control. If deficiencies or problems are found during mine inspections, it is requested that documentation provided to the Division of Safety for tracking and possible follow-up action, also be forwarded to Harry Verakis or Mark Schwartz at the Approval and Certification Center. The documentation should include operator name, mine name and I.D. number, date of inspection, product involved, nature and cause of the deficiency, and the length of time the product was in use at the mine.

As for toxicological precautions, use of proper safety equipment, such as safety goggles and proper gloves, is recommended for handling this product. Personnel involved in the handling of this product should observe precautionary statements on the packaging and Materials Safety Data Sheets (MSDS) information. Precautionary handling information may be obtained by calling the manufacturer at 947-970-5200.

Definite toxicity standards have not been established for mining products. It is the responsibility of the manufacturer to provide appropriate safety and health guidelines for handling products that may promote sensitization, cause skin irritation, or emit potentially harmful vapors.

If we can be of further assistance, please contact Harry Verakis or Mark Schwartz at (304) 547-0400.

Attachments
DISCLAIMER STATEMENT

This report was prepared by Dr. Y. P. Chugh of Southern Illinois University at Carbondale with support, in part by grants made possible by the Illinois Department of Commerce and Community Affairs through the Office of Coal Development and Marketing and the Illinois Clean Coal Institute. Neither Dr. P. Chugh of Southern Illinois University at Carbondale nor any of its subcontractors nor the Illinois Department of Commerce and Community Affairs, Office of Coal Development and Marketing, Illinois Clean Coal Institute, nor any person acting on behalf of either:

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