ABSTRACT

The overall goal of this continuation project is to develop, design, test and commercialize artificial supports (post and crib members) from coal combustion by-products based lightweight structural materials. This was proposed to be achieved over a three year funding period from September 1, 1994 to August 31, 1997. The developed artificial supports will be manufactured and marketed by the industrial co-sponsors of the project. Over the first two years of the project the investigators achieved some of the major objectives of this project including: 1) development of high volume (65 to 70%) coal combustion by-products (CCBs)-based structural materials with potential to fabricate elements which can be used as posts and cribs in mines; 2) development of elevated temperature curing cycles which can provide 28-day ASTM curing cycle compressive strength for prototype samples in 3-days; 3) fabrication and testing of small length-prototype and full size posts structural elements; 4) design of a commercial fabrication process for implementation and its economic analysis; 5) demonstration of the performance of small length-prototype elements in the laboratory to state and federal agencies; 6) input from mining companies in the region regarding interest in the products being fabricated; and 7) identification of in-mine testing location for the CCBs-based supports. CCBs-based supports can effectively compete with similar wooden products even without considering the environmental benefits of CCBs utilization and forest depletion.

Over the last year (September 1, 1996 - August 31, 1997) tasks addressed successfully include: 1) installation and testing of CCBs-based test supports at Old Ben No. 26 and Costain Coal Mine in Kentucky; 2) fabrication and testing of twenty eight (28) crib elements and eight (8) full size posts for quality control/quality assurance tests; 3) limited experiments utilizing waste glass fiber and waste nylon carpet fiber for reinforcement; 4) feasibility of developing lightweight material utilizing fly ash from the Lake of Egypt Power Plant; 5) testing of mixes utilizing alternate air-entrainment approaches; and 6) market survey by industrial cooperators to assess the market needs, and 7) technology transfer seminars in Benton, IL and Pinkneyville, IL.
EXECUTIVE SUMMARY

The overall goal of this continuation project is to develop, design, test and commercialize artificial supports (post and crib members) for use in mines, which are manufactured from coal combustion by-products based lightweight structural materials. Currently about 60 x $10^6$ cu. ft. of wood is utilized in the United States coal mines in form of artificial supports. The developed artificial supports will be manufactured and marketed by the industrial co-sponsors of the project. The activity chart for the three years is shown in Figure 1.

The results to date on the ongoing project (September 1, 1994 - August 31, 1997) can be summarized as follows.

1) CCBs-based lightweight structural materials with suitable load-deformation characteristics have been developed to replace wooden post and crib elements. These materials typically contain 65% to 70% coal combustion by-products, have densities ranging from 80 to 100 pcf. The 3 in. x 6 in. cylinders have compressive strength ranging from 2,000 to 3,300 psi, with elastic modulus of 350,000 to 700,000 psi.

2) Laboratory tests on small-size (5 in. x 5 in. x 24 in.) 90 pcf elements loaded axially (as a post) in compression in a servo-controlled stiff testing machine indicate compressive strength ranging from 2,500 to 2,800 psi, elastic modulus ranging from 500,000 to 600,000 psi, and desirable post-failure characteristics (similar to wood). These characteristics suggest feasibility of commercial application for use as posts and cribs, to replace the wooden posts and cribs, as artificial supports in mines.

3) Laboratory tests on 20 in. high 2 x 2 cribs constructed from 5 in. x 5 in. x 24 in. CCBs-based 90 pcf material indicate a load carrying capacity of about 110-115 tons as compared to only 70-75 tons for a similar wooden crib. Furthermore, CCBs-based cribs are about four times more rigid and should also provide better roof control.

4) A 300-ton compression testing machine with 3 ft x 3 ft base with 8 ft throat height was designed and fabricated for testing of full-size posts and cribs. Initial tests on full-length CCBs-based posts have been conducted using this machine. Testing of full-length CCBs-based posts in the 300-ton compression testing machine indicate performance superior to equivalent weight timber supports.

5) Field testing of CCB-based posts and cribs at Old Ben #26 Mine, and at Pyro Mine, indicate significantly superior performance compared to the control group of timber supports. Instrumentation for monitoring the in-mine performance of wooden as well as CCBs-based supports were designed and fabricated at the Department Of Mining Engineering, SIUC. Polyurethane-based load cells were designed, fabricated and tested for use in place of traditional flat-jacks/U-cells. Their performance in the field at Old Ben #26 and Pyro mines was very good.
An Overview of the 3-Year Proposed Research on Lightweight Coal Combustion Residues-Based Structural Materials for Use in Mines

Figure 1: List of major activities undertaken during the three years of the project
6) A hot water curing cycle has been designed and tested which can provide 28-day strength obtained by using ASTM curing cycle in three days. Hot water curing cycle provides strengths equivalent to that obtained from the steam curing cycles developed earlier, but with significantly lower variation in the quality of the product.

7) Experiments using 1.5 in. long commercially available polyester fibers instead of nylon fibers indicate them to be superior because of their non-wettable characteristics and higher elastic modulus. Additional experiments using polyester fibers of two different lengths (0.75 in. and 1.5 in.) in equal proportion indicate two different lengths should be utilized in commercial production. Limited experimentation has been conducted using waste glass fiber from the boat manufacturing industry, and waste nylon fiber from the carpet industry, to evaluate the potential of making the product more economically competitive with timber supports.

8) Based on an analysis of the current market and the cost of wood, it is expected that successful development and marketing of lightweight posts and crib members alone will utilize about $0.25 \times 10^6$ tons of PCC and FGD by-products in Illinois Basin coal mines. Nationwide, this could amount to about $2.5 \times 10^6$ tons. This amount will double if utilization in non-coal mines is also considered.

9) Facilities developed at Eagle Seal Inc., Benton, IL and Woodruff Supply Inc., Benton, IL and Madisonville, KY successfully demonstrated the commercial scale manufacturing of CCB-based supports using the industrial scale facilities. In excess of 40 large-size mixes have been prepared and used to make posts and crib members.

10) Two (2) laboratory demonstrations of the performance of small length prototypes of CCBs-based artificial supports to about 30 representatives from MSHA, coal industry, Office of Mines and Minerals, CINERGY (Gibson Power Plant), and Office of Coal Development and Marketing. Field-demonstration of the proposed manufacturing process was conducted for representatives from Mining Industry, Office of Coal Development and Marketing, Industrial cooperators and Regulators. Both these demonstrations indicated significant commercial potential for use of CCBS-based materials to replace wooden supports in mines.

11) Limited experimentation has been conducted to increase CCB utilization in the manufacturing of posts and cribs. Research is also being conducted in determining ways to increase waste utilization within the manufacturing process, with the goal of improving the competitiveness of the CCB-based supports. Experiments with 2-in. cube tests have allowed mix design improvement and optimization to increase CCB utilization in the manufacturing process. Experimentation utilizing alternate air-entrainment systems has been undertaken to a limited extent to cut
down on air-entrainment cost, which would also benefit production of ultra-light weight material using similar technology.

12) Technology transfer activities, in the form of presentations made by SIUC staff to the Holmes Safety Association, and contacts with mining companies by Gary Bruce of Eagle Seal and Larry Dugger of Woodruff Supply, were performed with encouraging response from industry.

13) Lake of Egypt Power Plant administration has expressed significant interest in locating the first commercial plant on their site, and further cooperation in developing similar products using their fly-ash.

14) A study has been conducted on twenty eight (28) 5 in. x 5in. x 24 in. samples to determine the variability in the density, compressive strength, and elastic modulus of the CCB-based material manufactured in a commercial setting. The results indicate about 25% variability in the compressive strength, which researchers believe can further be improved in final production where equipment for manufacturing is chosen specifically for the purpose of producing the lightweight material. Th standard deviation for elastic modulus is about 33%.

15) Mines have indicated their interest in the product and their willingness to take part in the larger field demonstration at their mine. This was revealed in the market survey conducted by industrial cooperators, who interviewed the supervisors of over 20 different mines within the region.

16) CCB’s based post elements (6 in. x 6 in.) were tested in the new 300 ton test machine located at the Illinois Coal Development Park. Post lengths varied from 46-72 inches. The ends of the posts were rough cut with a hand saw to simulate field conditions. The results of these tests are summarized in Table 2 and indicate an average load carrying capacity of 22-39 tons. Stiffness of CCBs based posts is significantly higher than wooden posts.

In summary, all the goals established in 1994 for this 3-year research program have been successfully met. The next step toward commercialization of the product is to develop a pilot scale facility and perform large demonstrations at one or two mines. Steps are currently underway to design a pilot scale facility at the Lake of Egypt power plant of Southern Illinois Power Cooperative.

The remainder of this report contains proprietary information and is not available for distribution except to the sponsors of this project.