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POTENTIAL PRODUCTS FROM NORTH DAKOTA LIGNITE FLY ASH

By
Gary R. Anderson

June 1980

Work Performed Under Contract No. FG03-78CS20028

Energy Development Board
Hazen, North Dakota

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U. S. DEPARTMENT OF ENERGY

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POTENTIAL PRODUCTS
FROM NORTH DAKOTA LIGNITE FLY ASH

A final report on fly ash product development and research funded and performed by the Energy Development Board of Mercer County, North Dakota. This technical feasibility study and an economic feasibility study being prepared for the EDB, when read together, will give an overview of potential fly ash products from Mercer County, North Dakota.

by

Gary R. Anderson
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June 1980

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CHAPTER 1

EXECUTIVE SUMMARY

BACKGROUND

A logical question to ask is how did the Energy Development Board (EDB) of Mercer County become involved with fly ash. For those readers who are not familiar with the EDB, a brief statement as to the organization's role is necessary. The EDB is a Department of Energy (DOE) funded experimental organization intended to deal with identification and mitigation of impacts resulting from large-scale energy development in rural America. Two of its original goals were economic diversification and energy conservation both during and after the energy development. One method of energy conservation that is widely accepted is the utilization of the waste products from energy conversion plants. This can be in the form of waste heat, or other waste products such as ash or sulfur. If an economically sound production plant using waste products can be found, then both of the above goals will have been met.

Mercer County had three power plants in operation at the time this study was started. The quantity of ash generated within the county as a result of the burning of lignite coal was significant. It was decided to study the waste product that was already an abundant problem, i.e., ash. Depending upon the power plant design and the boiler design, the ash residue can be bottom ash, slag, fly ash, or a combination of the three. Bottom ash and slag are removed from the bottom of the furnace and can be

handled either wet or dry. Fly ash is collected by electrostatic, or mechanical precipitators or bag houses. Depending upon power plant design, the fly ash may be handled wet or dry. The quantity of fly ash currently generated by the three power plants is approximately 250,000 tons per year. Obviously, if a beneficial use for this fly ash alone could be found, the energy conserved by not having to dispose of it would be great, in addition to the economic diversification that such a function would provide.

Ash generated by coal-fired energy conversion plants has been around for many years. Coal literature is full of examples of worldwide uses of both bottom and fly ash in the construction industry as well as agriculture, and as a building material additive or filler. The National Ash Association routinely publishes literature on new and innovative ways to utilize ash. Most of the previous work and publications have dealt with the utilization of ashes from anthracite, bituminous, or sub-bituminous coals. Few have dealt directly with the ash generated from the burning of lignite coals. The National Ash Association states that of 48,300,000 tons of ash generated per year, 8,400,000 tons were utilized. This is from the latest data available and represents the year 1978.

One of the barriers to widespread utilization of fly ash has been institutional in nature. Standards throughout the United States for the construction or building industry were never written with the thought in mind of utilizing fly ash or bottom ash. Gradually over the last 15 years these barriers have been

reduced in scope. As an example, fly ash is now utilized as a replacement filler in asphalt highways, in concrete highways, and in concrete building products. The American Society for Testing and Materials (ASTM) has just, within the last few years, established standards for the testing of products, asphaltic and concrete, with fly ash as an additive. Some building codes still would prevent the utilization of ash today.

Professor Oscar Manz of the University of North Dakota, Engineering Experimental Station and Civil Engineering Department, has been working on ash utilization for 15 years. He is currently director of the Coal By-Products Utilization Institute at the University of North Dakota. The EDB in its ash work, has relied heavily on Professor Manz's expertise as well as on his well-equipped chemical and engineering laboratories. The majority of Professor Manz's work has been in the area of asphalt and concrete filler additives using fly ash. He has also worked a great deal with bottom ash and bottom slag, again primarily in the construction and building materials area. When the EDB started searching for ash products that would meet both energy conservation and economic diversification criteria, we called upon Professor Manz in many areas of ash utilization that were relatively new. He has been a great assistance to us and a good portion of the credit for this paper rightly belongs to him and his organization.

Because the EDB's first objective was one of overall economic diversification and energy conservation, we did not take the approach of using ash (either fly or bottom ash), in the

construction industry to be our only goal; rather, we decided to take a more broad-brush approach. To this date, we have looked at four major areas where ash can be utilized: (1) conventional construction products, i.e., building blocks, poured concrete and soil stabilization; (2) ceramics; (3) un-conventional construction products; and (4) other un-conventional products (i.e., such as wallboard). To date we have accomplished the following in each of the four major areas.

- (1) In the concrete products area the EDB had 1,400 standard sized, 8" x 16", concrete building blocks manufactured utilizing fly ash as a replacer for portland cement at the ratio of 50 percent. These blocks are being used in Mercer County, North Dakota, to build three experimental buildings. One is a passive solar animal shelter and the other two are penalty boxes for an outdoor ice-hockey rink. We could find no literature that indicated anyone had used fly ash at such a high ratio for a portland cement replacer. Plans have been drawn up for an ice-skating rink warming house to be built entirely of poured concrete, with fly ash as a replacer for portland cement at the ratio of 50 percent.

Assistance has been given to the Hazen Airport Authority for an improved runway. The airport authority is attempting to create a better surface than the original dirt runway. The EDB and

the Coal By-Products Utilization Institute determined a possible mix ratio of fly ash, portland cement and local soil for a stabilized soil runway.

(2) The EDB has spent a great deal of time and money with a process for the utilization of fly ash and crushed glass, another waste product, in the formation of a ceramic-like material. This work was patterned after the Electric Power Research Institute's (EPRI) work performed in California between the years 1976 and 1979. Unfortunately, the EPRI work did not use lignite fly ash, so the EDB was forced to prove that the methodology and concept would work using lignite fly ash. To this date the EDB has successfully manufactured, in a laboratory environment, several ceramic products. They include small fence posts, electric distribution insulators, and floor or wall tile. These ceramic products will be the main thrust of this report.

(3) The EDB is aware of a firm in Canada that is using sulfur as a replacement for portland cement in the manufacturing of road-building products. The EDB wondered if it could replace the aggregate with ash, resulting in a mixture of pure sulfur and pure ash. With very limited time and money the EDB has successfully made one sample

and tested it in an engineering laboratory. This product shows promise in the areas of strength and durability.

- (4) The EDB further wondered if it was possible to make a dry wallboard, such as gypsum board, from ash. Again, due to limited money and time, only one specimen has been made and it holds promise. Letting one's imagination wander a bit, there are many other products that might be possible. For example, is it possible to make such a product as clay pigeons by pressing a combination of fly or bottom ash with some other material? The EDB has not been able to try this, but we think it merits investigation. As the reader can see from the above approach, the EDB is interested in finding any use for lignite ash.

The approach for the past year has been from the technical and economic feasibility points of view. The EDB commissioned (with a grant from the Economic Development Administration and North Dakota's Business and Industrial Development Department), an economic feasibility study on any fly ash product manufactured in Mercer County and shipped to other markets. The results of this economic feasibility study will be available in June 1980 and will not be delineated in this report. This paper will concern itself entirely with the technical aspects of the above-mentioned areas of potential products.

RESULTS

The results to date in all of the four categories mentioned above have been most encouraging. Taking them one at a time, we have: The concrete building blocks with fly ash replacing 50 percent of the portland cement have proven to be successful using current ASTM standards for concrete building blocks. Initially the blocks tested too weak, but upon repeated testing later in time, have shown that they will age to a strength that meets current standard requirements. A more technical discussion can be found in Chapter 2 of this paper.

The results to date in the ceramics area have shown that we can make a ceramic-like product using lignite fly ash. This product is stronger than similar products created by EPRI utilizing bituminous and sub-bituminous ashes. The product is created from fly ash and crushed glass with a small amount of clay as a green binder. Products made utilizing lignite fly ash have proven to be stronger in the flexural strength and compressive strength areas than similar products made of other ashes. This is attributed in part to the percentage of intact cenospheres that compose the make-up of fly ash. There is no doubt in the author's mind that successful ceramic products can be made using lignite fly ash, however, the economics will dictate the ultimate feasibility of this product line. Technical details are covered in Chapter 3 of this paper.

The results of the sulfur ash, as a building material, hold great promise due to its very strong nature; however, much more work needs to be done in this area. Sulfur and ash results are covered in Chapter 4.

The results of the wallboard work, again, have been most promising technically, but due to the limited amount of work, much more work needs to be done. The results of this can be seen in Chapter 5 of this paper.

RECOMMENDATIONS

The results of the economic feasibility study going on concurrently with this technical feasibility work will prove or disprove that fly ash products can be shipped economically from mid-North Dakota sites to major market areas. This author feels compelled to recommend strongly that much further product development and research should be done utilizing North Dakota lignite fly ash. I feel that a production test facility or pilot plant should be created immediately. Interested industries should create an organization of some nature to continue full-scale product development using lignite fly ash. This need not be a major research program, rather it should be a practical applications group oriented to product development.

It is the opinion of the author that the production test facility should be funded privately. An alternative is to fund it by the electric utility industry, which is currently having to stand the cost of ash disposal, and other interested industries such as the concrete producers and construction groups. A third possibility is state and federal research grants.

This author feels that such a product development organization should be resident in western North Dakota near the generation sites of the ash and the attendant resident technical staff.

The preferable site is Bismarck, due to the availability of the technologies, such as machine shops, etc., plus the availability of centralized travel and communications services. The author also feels that the organization could possibly be a satellite of the Coal By-Products Utilization Institute of the University of North Dakota under the direction of Professor Oscar Manz. I do not recommend that the product development site be resident at the University for the reason that it is too remote from where the ash is being generated. This is not intended to be a research program as much as it is a product development program, based upon research already performed and documented through this and other papers at the University of North Dakota. For the purposes of conversation and planning, it is the author's opinion that such a product development test group could be created and operate for two (2) years with a total budget of between \$500,000 and \$1 million. It could fully develop potential products from the four product areas mentioned above.

CHAPTER 2

CONVENTIONAL CONSTRUCTION PRODUCTS

° BACKGROUND ON CONCRETE/FLY ASH BUILDING AND BUILDING BLOCKS

Since 1979, the EDB has planned the construction of two buildings primarily out of concrete, but with a high percentage of fly ash as a portland cement replacer. Work started in 1979 with the completion of the architectural and engineering drawings on the two buildings. The two buildings are an animal shelter for Mercer County to be located in Hazen and a warming shelter for an outdoor ice skating rink to be located in Beulah. They are to be constructed of concrete blocks and poured concrete, respectively. Both buildings include passive solar heat in their design. The percentage of fly ash used as a portland cement replacer was not established until late 1979. Consultations with Professor Manz and a literature search indicated that the usual percentage of fly ash as a portland cement replacer, is between 15 and 35 percent by weight of the portland cement. The EDB decided to manufacture concrete blocks for the animal shelter where fly ash replaced portland cement by 50 percent of the portland cement weight. As near as we could determine at the time, that is the highest replacement level that has been used on a large scale basis.

MANUFACTURE

Arrangements were made with Supercrete Industries, Inc., Mandan, North Dakota, to manufacture 10 batches of portland

cement/fly ash standard 8-inch by 16-inch building blocks. Their standard dies, equipment, aggregate, and water were used. The variance in their standard mixture came in using only 50 percent of the normal amount of portland cement by weight. The other 50 percent was dry fly ash from the Basin Electric Leland Olds Power Plant, Stanton, North Dakota. This effort led to the manufacture of 1,400 standard 8-inch by 16-inch concrete blocks. See Figures 1 and 2.

The blocks were cured overnight in the standard curing kiln at Suprecrete. This curing process involved two hours at ambient temperature, then five to six hours at 165 to 170°F and 100 percent humidity.

Figure 1 -- Concrete/Fly Ash Blocks Being Manufactured at Suprecrete, Inc., Mandan, North Dakota.

Figure 2 -- A Close-up of a Concrete/Fly Ash Block.

TESTING

Shortly after manufacture, three of the concrete/fly ash blocks and three standard concrete blocks as controls were delivered to the Coal By-Products Utilization Institute Laboratory at UND for testing. All six blocks were tested on December 6, 1979, with the following results. The concrete fly ash tested at 984, 1,016, and 1,555 pounds per square inch, respectively. The regular concrete blocks as controls tested at 1,297, 1,383, and 1,516 pounds per square inch, respectively. As can be seen from these values, the standard concrete blocks were well above the ASTM minimum requirements of 1,000 pounds per square inch whereas the concrete/fly ash had one failure. The

ASTM standard further states that if any single block fails to meet the 1,000 pounds per square inch, further testing must be done.

RETESTING

Since one of the fly ash blocks had failed, arrangements were made for more testing. Figure 3 shows that additional testing was done at the end of December, again in early April, late April, and May of 1980. The second set of tests, run at the end of December 1979, was performed on six concrete/fly ash blocks. Of those six, four failed to yield the ASTM minimum of 1,000 pounds per square inch. Greatly disappointed, the EDB did not do any further testing for the next three months except for three concrete/fly ash blocks in a freeze/thaw testing machine at the Coal By-Products Utilization Institute.

The freeze/thaw testing is a very slow process and requires approximately three months to test specimens for approximately 360 freeze/thaw cycles. This automatic freeze-thaw machine is designed to meet ASTM standard C-666. Our three concrete/fly ash blocks were put in on December 31. One of the blocks disintegrated and was replaced in early February. All of the blocks were taken out of the freeze/thaw machine in April 1980. We then subjected the three blocks that had been in freeze/thaw to compression testing along with three standard blocks and three more concrete/fly ash blocks. The results were quite startling as can be seen in Figure 3. The concrete/fly ash blocks that had been in freeze/thaw averaged 2,277 pounds per square inch with none of

FIGURE 3
CONCRETE / FLY ASH BLOCKS
(50:50 RATIO)
STRENGTH VS. TIME

them testing less than 2,000 psi. Three additional concrete/fly ash blocks that had been stored outside were tested at the same time. These yielded values of 906 psi, 1,049 psi, and 1,763 psi respectively. The overall average of the six blocks was well in excess of 1,700 pounds per square inch with only one failing to meet the 1,000 psi minimum of ASTM. These results clearly indicate that some kind of aging process was going on with the concrete/fly ash, either due to freeze/thaw cycles or to a natural aging process of concrete with fly ash in it. We tested again on April 24 with three blocks that had been stored inside all winter and not subjected to a single freeze/thaw cycle and three that had been stored outside throughout the winter. None of these six tested below 1,000 psi. The averages were 1,720 psi for the inside blocks and 1,196 psi for the outside blocks.

The results of the above set of testing seemed to indicate that inside storage resulted in better curing than outside and being subjected to the freeze/thaw process. In the middle of May, we tested 11 more concrete/fly ash blocks and three standard concrete blocks in compression. Of the 11 concrete/fly ash blocks, six of them had been stored inside throughout the winter in an un-heated building; that is, subjected to freeze/thaw but no other natural elements. Five had been stored outside, exposed to all natural elements. The results are as follows: The six inside concrete/fly ash blocks had an average compressive strength of 1,554 psi. The five outside blocks had a value of 1,712 pounds per square inch average. The results of this test seemed to contradict the previous results which indicated that

inside curing was better than outside curing. However, of the 11 not a single one failed to meet the 1,000 pounds per square inch ASTM minimum requirements. It should be pointed out that one was close, testing at 1,007 pounds.

CURRENT STATUS

The animal shelter is under construction. It is scheduled for completion in mid-1980. The concrete/fly ash block walls have been built and the blocks presented no problems during construction.

In late fall of 1979, two penalty boxes for an outdoor ice-hockey rink were also constructed using the excess concrete/fly ash blocks. The walls of these structures have been observed throughout the past winter and spring. There were no problems during construction and none have appeared as of this date. The blocks have developed a white coating on their surface. This effervescence is excess sodium sulfate coming to the surface due to the water in the mortar and natural rainfall. It is expected that this will stop, but when is not known.

The design and engineering details of the poured concrete warming shelter have been completed. However, construction has not started.

RECOMMENDATIONS

As can be seen from the above discussion and a review of Figure 3, it is obvious that concrete/fly ash blocks go through some sort of curing or aging process that does not follow the

standard concrete curing curve. Previous work using fly ashes from bituminous or sub-bituminous coals have not yielded results that are in concert with this data. The author does not feel that sufficient data is available to make a recommendation that concrete product manufacturers should immediately start using 50 percent fly ash as a portland cement replacer.

It is known that lignite fly ash has a higher percentage of intact cenospheres and a different chemical composition by percentage weight than ashes from bituminous or sub-bituminous coals. A logical question is -- does lignite fly ash present different results due to curing or aging that are unique to the lignite fly ashes or is it an aging process that has merely been overlooked? The author recommends additional study in this area of product development or improvement, utilizing lignite fly ashes. As can be seen from the photo in Figure 2, this concrete/fly ash block has all of the appearances of a standard concrete block and to the best of our knowledge should have a potential use in the building industry. A word of caution -- concrete/fly ash building blocks effervesce after immersion in water. Potential problems caused by this are unknown. If this effervescence prevents painting, this could be a serious hindrance to the economic development of concrete/fly ash blocks at a 50-50 mix ratio.

CHAPTER 3

CERAMICS

BACKGROUND

In its quest for products that could be made from fly ash the EDB became aware of a project that the Electric Power Research Institute (EPRI) was working on in the middle of 1979. Further investigation showed that EPRI was using fly ash, crushed glass, and clay to make a ceramic-type product. Their goal was to make a ceramic power pole as a replacement for wooden electric utility poles. The EDB contacted EPRI and asked them if they had used lignite fly ash. The answer was no, and they did not know if lignite fly ash would work in their process. They encouraged the EDB to use their process and North Dakota lignite fly ash in an attempt to reproduce a ceramic product similar to the one they were making using sub-bituminous ash.

Starting in September 1979 the EDB proceeded to try and create a sample product using North Dakota lignite fly ash, crushed glass, and clay to make a ceramic product. The EDB made a verbal report to the electric utility industry representatives in October 1979 and a second report in written form on February 1, 1980. At both of these meetings, electric utility industry representatives made suggestions and some of these have been incorporated into this product development effort. The February 1 report is included as an Appendix to this report. The reader is invited to read the Appendix as it contains a great deal of background information and some technical data on the

status of the fly ash/glass ceramic work at that time. After the February 1 presentation, work continued well into March with specimen production, with some testing going on as late as May of 1980. This chapter will deal with the total effort from September 1979 to May of 1980. It will reflect a more complete overview of the complete effort than the Appendix. Certain aspects of the work performed will be highlighted in this chapter whereas other aspects are adequately covered in the Appendix (Progress Report) and will not even be discussed in this chapter.

MANUFACTURING PROCEDURE

The procedure for creating a ceramic product out of fly ash, crushed glass and a small percentage of clay is relatively simple and straightforward. Basically it can be outlined as follows: (1) mix the dry components, crushed and screened, in the correct proportions; (2) add the correct amount of water; (3) mix until the correct consistency is obtained; (4) extrude the material with the appropriate extruder die; (5) perform any handcutting or shaping on the green material; (6) air dry; (7) oven dry; (8) perform any last cutting or shaping operation; (9) fire in a kiln; and (10) anneal. After a slow cooling, perform the appropriate mechanical and chemical tests.

The above outlined procedure can be visualized by looking at Figures 4, 5, 6, 7, 8, 9, 10, 11, 12, and 13. The collection and handling of materials for this research program were handled basically by hand as shown in Figure 4. Dry fly ash collected at either the Basin Electric Leland Olds Power Plant or the United

Figure 4 -- Material Handling, Weighing and Mixing.

Power Association (UPA) Stanton Plant were shipped to the laboratory in barrels or five-gallon buckets. The fly ash as collected and delivered required no further crushing or screening. The second raw component, glass, came from using clear glass pop bottles acquired from the Grand Forks Coca-Cola Bottling Company. These bottles were broken into pieces by hand, smashed into smaller pieces with a hammer mill at the UPA Stanton Plant, and then crushed to a powder-like consistency in the ball mill shown in Figure 5. After the glass had run through the ball mill, it was screened using a standard 100 mesh sieve. Only the material passing through the 100 mesh sieve was used for the process. The residue was put back into the ball mill for further crushing.

Figure 5 -- Ball Mill Used for Crushing Glass.

The clay was received from the Hebron Brick Company and was a white plastic clay. It was dried at 250°F and crushed in the roller mill shown in Figure 6. After crushing, it was screened and only that material passing through a minus 100 mesh sieve was utilized in the mixture.

Figure 6 -- Roller Mill Used for Crushing Clay.

The three ingredients in the correct proportions were dry mixed in a large food mixer as shown in Figure 7. After dry mixing for approximately 15 minutes, the correct amount of water was added and the mixing continued wet. When the correct consistency was obtained, the material was hand-fed into the extrusion machine, Figure 8, loaned to this project by the Hebron Brick Company, Hebron, North Dakota. The specimens were extruded to the chosen size and length as shown in Figures 9 and 10.

Figure 7 -- Mixing Dry and Wet Material.

Figure 8 -- Three-Inch Extruder.

Figure 9 -- Extruding a Three-Inch Hollow Post Sample.

Figure 10 -- Various Specimens From a Representative Batch.

FIRING

The green material was allowed to air dry for eight hours or longer. It was then oven dried at 150°F to 200°F for eight hours or longer at which time any final cleanup, cutting or shaping operations were performed. The dried material was then placed in an electric kiln as shown in Figure 11, fired and annealed at the appropriate temperature for that particular batch.

Figure 11 -- Kiln Loaded with Various Specimens. Note Pyrometric Cones for Temperative Confirmation.

TESTING

After the material had been fired and allowed to cool, the specimens were removed from the kiln and taken into the mechanical engineering testing laboratory for testing. Shown in Figure 12 is the Riehle testing machine at the Coal By-Products Utilization Institute which was used for some testing in this project. This machine was used for testing materials in flexure as shown in Figure 13. It can also test compression, and the cantilever tests performed on the electric insulators.

Figure 12 -- Riehle Testing Machine with Specimens for Testing in Foreground.

Figure 13 -- Specimen Broken in Flexure Test.

The EDB produced 31 batches of material using the procedure outlined above which resulted in a total of 378 specimens being created of which 315 were tested. The difference represents material destroyed because it was improperly handled during the manufacturing process, destroyed in the firing process (some of it blew up in the kiln), material accidentally broken, or specimens reserved for demonstration purposes. As shown in major paragraph 2 in the Appendix, some of the goals of this effort were to determine whether lignite fly ash could be used as a material for ceramic products, the optimum fly ash to glass mix ratio and the fineness of the materials. All of the testing was oriented towards those goals. Some of the results of this testing are shown in Figures 14, 15, 16, and 17.

The first technical goal was to determine if North Dakota lignite fly ash, crushed glass and clay could be used for a ceramic product that was as strong as the EPRI product. The two mechanical values that could be used for comparison are flexural strength and impact strength. Figure 14 shows the final flexural strength plotted against the mix ratio, with the mix ratio being parts of fly ash versus parts of glass, with the fly ash on the left of the ratio symbol. Figure 14 represents the data from 177 one-inch diameter specimens, all of which were produced in lengths of from 6 to 10 inches. The length was kept short due to the size of the kiln. As can be seen from Figure 14, there does appear to be an optimum strength for the ceramic product at a mix ratio of between 60-40 and 70-30. It should be noted from that figure that the EPRI average corresponds to a mix ratio of 50-50,

FIGURE 14
FLEXURAL STRENGTH
VERSUS MIX RATIO
1" DIAMETER

FLEXURAL STRENGTH IN PSI

the only mix ratio that EPRI used. The EDB, wishing to confirm that the mix ratio of 65-35 was indeed the best, has also performed impact tests as shown by Figure 15. Again the curve indicates optimum strength at the mix ratio of 65-35. Figure 16 shows the percent of water absorption plotted against the mix ratio. This curve also shows optimization in the range of 60-40 to 70-30 mix ratio. It must be pointed out that the number of specimens created at the 50-50 ratio and the 80-20 ratio is significantly less than the number of specimens produced in the 60-40 to 70-30 bracket. This reflects a lack of time and money and is, admittedly, a weak point in the data.

In order for this ceramic product to be utilized as a fence post, it would have to be able to withstand continuous outside weathering effects. Ten specimens from two different batches were arbitrarily selected and placed in the freeze/thaw testing machine at the Institute for a total of 336 freeze/thaw cycles. This took approximately three months and Figure 17 represents the plot of the weights of these 10 specimens versus the freeze/thaw cycles. It can be seen that nine of the 10 have approximately the same absorption curves. Specimen No. 25.17 obviously has started to absorb a great deal of water on cycle 200 and would probably have destructed soon if the testing had been allowed to continue. The freeze/thaw methodology includes total submersion in water which should be much more severe, from an absorption point of view, than normal outdoor weathering. It is the author's opinion that this data suggests that properly made ceramic products would have a high degree of resistance to natural weathering effects.

FIGURE 15
IMPACT STRENGTH
VERSUS MIX RATIO

FIGURE 16
PERCENT OF WATER
ABSORPTION VERSUS
MIX RATIO

FIGURE 17
SPECIMEN WEIGHT VERSUS
FREEZE - THAW CYCLES

The EDB investigated a method of non-destructive testing for prediction of strength in our specimens. We attempted to use sonics (sound waves) to determine the resonant frequency of the specimens and then correlate to the strength as determined by a destructive flexural test. The data gathered indicates a relatively high degree of prediction accuracy, approximately 80 to 85 percent. However, no data is included in this report because of the fact that if non-destructive testing is to be done in a production facility, a large body of empirical data would have to be established first, as baseline, before accurate non-destructive predicting could take place.

RESULTS

As pointed out throughout this report, the EDB's quest was for additional types of products that could be produced from fly ash. As shown in Figures 9, 10, 18, and 19 and on the cover of this report, the EDB has produced a variety of ceramics products. They include fence posts as shown in Figure 18, electric line insulators as shown in Figure 19, and a tile as shown on the cover sheet (identified by the number 2). Figure 10 shows the diverse number of products that can be made from one batch by changing the dies on the extruder. Shown in that figure are two three-inch hollow specimens, representing fence posts, two two-inch solid pieces, seven one-inch specimens and one insulator. Figure 20 shows an insulator in its die after extrusion. The piece of wood is the thread die used to create threads for the electric insulators.

Figure 18 -- Fly Ash/Glass Ceramic Post Examples.

Figure 19 -- Fly Ash/Glass Ceramic Electric Line Insulators.

Figure 20 -- Insulator in Forming Die with Thread Die Inserted.

The results of the EDB effort seem to indicate clearly that North Dakota lignite fly ash, crushed glass and clay can create a ceramic product that is stronger than a similar ceramic product created by the Electric Power Research Institute. The exact reasons are beyond the scope of this report and this product development effort. However, some possibilities can be put forth.

There are three basic known differences between lignite fly ash and other ashes generated and used elsewhere in the United States: (1) North Dakota lignite fly ash has a much lower carbon

content commonly referred to as Loss on Ignition (LOI). North Dakota lignite fly ashes have a LOI content of between 0.2 percent and 3 percent, nominally, whereas other fly ashes have a LOI content of between 3 and 18 percent, nominally. This means that when placed into a product that will be fired in a kiln, the carbon which is resident in other ashes burns leaving voids in the material. North Dakota lignite fly ash does not have that characteristic. (2) As shown in the Appendix, Figures 13 and 14, North Dakota lignite fly ash does have different chemical constituent percentages. It is estimated that the lower aluminum oxide and higher sodium oxide content may contribute to the higher strength in the ceramic products. (3) The exact figures have not been determined, but it is known that North Dakota lignite fly ash has a higher percentage of intact cenospheres. A cenosphere is a hollow glassy-like particle within the fly ash and ranges in size from approximately one micron to 20 microns in diameter. Since an intact sphere is a strong geometric figure, it has been hypothesized that the higher percentage ratio of intact cenospheres to the total weight of fly ash may be a contributing factor to the increased ceramic strength.

The questions shown in major paragraph 7 on page 21 of the Appendix, were the goals for the last three months of this product development project. Lack of time and money prevented studying all of the questions. However, the first six answers were obtained and these are shown below, along with the questions (for reader convenience).

1. Determine if 65-35 ratio is best for all lignite fly ash.

An attempt was made to do this and the results were inconclusive. One other fly ash was used, that came from a different type of boiler. It was easier to work with in the mixing and forming stages, but produced weaker specimens. Its optimum mix ratio was never determined.

- a. Chemical and mechanical tests for larger data base base (trending).

This was accomplished and the results are reflected throughout this paper.

2. Determine if minus 100 is the best mesh for glass and lignite fly ash.

These results were also inconclusive. There is no doubt that changing the fineness of the glass will affect the strength of the product. The indications are that a mesh of glass finer than minus 100 does not enhance the strength. This is in contradiction to the EPRI finding and should be further investigated.

3. With 1 and 2 determined, can the percentage of clay be reduced or raised.

Reduction of the percent of clay in the mixtures of both fly ashes resulted in increased flexural strength of the specimens.

4. Determine if extrusion speed is really such a big factor.

In this case, the faster the extruder speed (in RPM), the weaker the final product. This could be caused by the physical size of the extruder used in this project.

5. Audio testing procedures and methodology.

Audio-testing does appear to work but much more work needs to be done in that area.

6. Try to extrude flat pieces for electric element holder.

This was accomplished, but the electric element holders cannot withstand the heat from an electric element and consequently, that experiment was considered a failure. However, thin plates of ceramic material created for this goal demonstrated that thin products could be made and resulted in the production of sample wall and floor tile.

In addition to the remainder of the list shown in the Appendix, the following questions are still unanswered: (1) Does the sodium sulfate effervescence that appears on the surface of all materials during the drying process and is burned off in the firing of the kiln present an environmental problem? (2) Can a stronger material be created with higher pressure from a bigger machine? The implications are yes, but it cannot be proven conclusively. (3) For reasons that are not clear, some of the material, when subjected to the freeze/thaw cycle, disintegrates while others do not. Since all freeze/thaw specimens for this project had previously been broken in flexure, it is possible that some of the freeze/thaw failures were the result of hairline

cracks induced in the material through the testing process. Freeze/thaw data should be confirmed with materials manufactured expressly for that purpose. (4) One of the anomalies noted from the empirical data is that in every batch where the initial amount of water was inadequate, a second addition of water created a batch that was weaker than all batches where water was only added to the dry material once. No explanation for this is known and this consideration should be investigated further.

The last major effort during the production phase of this study was devoted entirely to the production of insulators. Despite our best efforts, the minimum standard cantilever strength was never attained. The maximum reached was 58 percent of rated value. It is speculated that this may be due wholly or in part to the small size of the extruder. It may be due to the production method, and if that is the case, other methods (not tried by the EDB) may be successful in producing the required strength.

Some progress was made in glazing the insulator and tile products. Several nice samples were made before this effort was stopped so that more time could be devoted to insulator production and the production method. There is optimism, but no proof, that a satisfactory production glaze for fly ash/glass ceramics can be found or created.

Sufficient data on insulator specifications and production methodology was attained to enable the economic feasibility study to include insulators as a potential product. However, much more work needs to be done with insulators in a production test

facility. Appropriate technologies and equipment would have to be made available for this effort to have a chance to be successful.

CONCLUSIONS AND RECOMMENDATIONS

The author feels that the work to date has demonstrated with sufficient data that North Dakota lignite fly ash can indeed be used to make a satisfactory ceramic product. We have demonstrated that we can make several ceramic products. It is beyond the scope of this report to discuss the economic details, which will be published in a separate paper in the month of June 1980. The technical feasibility has been demonstrated within certain limitations. The mechanical strengths in flexure and impact would seem to indicate sufficient strength for products such as fence posts and tile. To date the cantilever strengths achieved by the insulators has not been up to requirements. This is thought to be due to equipment size limitations. Even with this failure, the author feels that products can be produced using similar methodologies.

Some observations that do not show up in the data, but are germane to this report are: (1) That the texture of the material seems to vary depending upon the extrusion speed and the amount of water added. On some occasions, spalling of surface material was noted but this did not seem to weaken the material in any way. (2) There are at least six different fracturing patterns that show up in the specimens when broken in flexure. No attempt was made to study the fracturing mechanics, as that was

considered beyond the scope of this product development program. (3) Compression test results indicate a very high compressive strength in the neighborhood of 10,000 pounds per square inch. There is no doubt that a very strong brick-like product could be created from this material but the author knows of no requirement in the marketplace for a product with that high of a compressive strength. (4) It should be noted that the firing curve as shown in Figure 12 of the Appendix is very representative of the firing curves utilized throughout this entire product development project. One anomaly was noted, that is, if the material is cooled too fast it will go through a thermal shock and crack. We found it to be best to not remove the material until it attained a temperature of approximately 150°F or cooler.

Regardless of the outcome of the economic feasibility study, this author would like to strongly recommend continued product development and research using North Dakota lignite fly ash mixed with glass and clay. It is not felt that a commercial manufacturing plant should be set up at this time. Additional study needs to be done in the area of product development and production engineering. This need not be a large effort, but it must be thorough and should include experienced industrial, production, and ceramics engineers. This production test facility should be located in western North Dakota, near the coal fields and the largest electric utility firms generating electricity and hence fly ash. The recommended site is the Bismarck vicinity with its technical, communication and transportation facilities. It must be emphasized that this test facility should be oriented

toward practical product development, rather than toward strictly theoretical research. It is felt that a relationship between this proposed facility and the Coal By-Products Utilization Institute at the University of North Dakota at Grand Forks is an absolute necessity. The Institute can perform testing and studies of a theoretical nature that may be necessary to answer questions arising from the effort to produce a practical product.

The author recommends that the funding for this organization should come from the private sector. The second possibility for funding would be a non-profit corporation which could utilize funding supplied by the private sector as well as federal and state grant money. It must be pointed out that one of the unknowns resulting from this work is the environmental concern regarding the sodium sulfate effervescence which burns off in the firing process of the kiln. Therefore, out of necessity, there should be some environmental studies involved and perhaps some environmental grant moneys as well as economic development funds.

CHAPTER 4

UN-CONVENTIONAL CONSTRUCTION PRODUCTS

BACKGROUND

In late 1979, the EDB became aware of a Canadian firm that was using sulfur as a 100 percent replacer for portland cement in a concrete-like product used for building and road products. This Canadian firm has the process patented and copyrighted under the name of Sulfurcrete.

This particular product has several advantages: (1) It can use any aggregate; that is, the gravel and sand does not have to be crushed and screened to a particular size; (2) It is just as strong as concrete products made from portland cement; (3) The product can be made and put down for road surface repair at any temperatures, including those below zero; and (4) Even at cold temperatures it will set up to full strength in a matter of hours, compared to a matter of days in the case of standard concrete. However, this product does have some disadvantages, foremost of which is that the sulfur has a melting point of approximately 260°F. If the product is made into building blocks and the building has an interior fire, the walls start to come down when the inside temperature reaches 260°F. Obviously, one would not want to use this product in load-bearing wall construction. After becoming aware of this product and reading the literature on it, the EDB wondered if fly ash could replace the aggregate; that is, the sand and the gravel.

EDB EXPERIENCE

The EDB decided to try and answer that question by making some sulfur/ash products. The first step was to reproduce the Canadian material in the laboratory. Through the chemical and the mechanical laboratories at the Coal By-Products Utilization Institute at UND, Professor Oscar Manz and his staff were able to create a sulfur concrete product utilizing standard aggregate. The next step was to make a batch of sulfur and fly ash. After several false starts, three batches were made and poured into cubes. They were successfully created by mixing melted sulfur with hot fly ash, stirring it while it was hot, and pouring it into molds. The material was poured into 2-inch by 2-inch standard ASTM cubes. After a few minutes of cooling, the material set up to a strength allowing for removal from the cubes while it was still warm. After cooling to an ambient room temperature, the three blocks were tested in compression.

The three batch mixtures were: (1) 53% fly ash and 47% sulfur, (2) 40% sulfur and 60% crushed bottom slag, and (3) 30% sulfur, 10% fly ash and 60% bottom slag. When tested in compression these cubes withstood the following weights: Cube No. 1 composed of sulfur and fly ash withstood a weight of 29,500 pounds or 7,400 pounds per square inch. Cube No. 2, the sulfur and bottom slag combination, tested at 15,500 pounds or a compression value of 3,875 pounds per square inch and Cube No. 3, the sulfur, fly ash and bottom slag specimen tested to a load of

28,750 pounds or a compression value of 7,188 pounds per square inch. The stronger two of these three reflect compression values that are approximate to compression values for standard brick.

CONCLUSIONS AND RECOMMENDATIONS

From the above information it is clear that a product can be made with high compression value. Because of its flexibility and its curing to full strength at any temperature, as far as is known, this product might hold some potential as a patching material for asphalt or concrete roads in wintertime.

Since we do not know any parameter except the compression strength it is obvious that much more study needs to be done on whether or not the sulfur and ash mixture will make a potential product. Because the nature of the study would be research as opposed to product application or product design, it is the recommendation of this author that any additional future study be done at the Coal By-Products Utilization Institute at the University of North Dakota.

CHAPTER 5

OTHER UN-CONVENTIONAL PRODUCTS

BACKGROUND

The Energy Development Board in its quest for a sound economic product that would fulfill both the waste product utilization and the economic diversification goals of the original EDB charter, has looked around at other products that can be made from fly ash. Not limiting their search to standard conventional building products, the EDB decided to determine if fly ash could be used in building products such as gypsum board. The search for an alternate product has at this time been concluded by the EDB. However, as the photograph in Figure 21 shows, the EDB was successful in producing a prototype wallboard that may have potential as an economically sound product.

Figure 21 -- Prototype Ash Wallboard.

PROCEDURES

The Coal By-Products Utilization Institute, with EDB funding, studied the possibility of making a wallboard out of some ash product from coal conversion facilities. After studying current methods of manufacturing gypsum board, the Institute attempted to make a wallboard utilizing fly ash, bottom ash, a foaming agent and standard wallboard paper, by placing it under pressure. After many failures the effort was successful in producing a board that had sufficient strength to be tested in flexure as well as other mechanical testing parameters. The test results were encouraging in that the specimens tested as strong as current wallboard and would take nail penetration equally as well. However, the product is approximately 10 percent heavier than today's marketable products.

CONCLUSIONS

Unfortunately the EDB and the Institute, were unable to continue production and testing of a wallboard product. It is the opinion of the author that the meager information gleaned above should lend optimism to the possibility of a future product being developed. It is the recommendation that this effort be continued at the Coal By-Products Utilization Institute at UND under the direction of Professor Manz to see if indeed a product can be developed that will meet all of the current standards for strength, durability and weight.

CHAPTER 6

SUMMARY

In trying to accomplish part of its original charter, the EDB has spent a great deal of time and money investigating conventional and un-conventional products created from a waste product, fly ash. The investigation of its uses in un-conventional products has led the EDB into a more research-oriented posture than perhaps was originally intended. This has come about for the simple reason that some of the questions about potential products simply could not be answered. It is safe to say that the EDB has uncovered some very interesting facts that in turn lead to more interesting questions. Admittedly, it would be presumptuous at this time to make an absolute claim that the EDB has succeeded in identifying new marketable products made from the ash residue of coal conversion.

However, the work to date and the engineering data indicate reasons for optimism about the role of fly ash in un-conventional products. Since technical feasibility is only half of the picture, it is emphasized that this report be read only as a technical assessment. The economic feasibility study, in progress and in parallel with this technical feasibility study, is also due for final publication in June of 1980. Reading these two documents together should give the reader an overall understanding of what the EDB has accomplished to date in the area of waste product utilization and economic diversification.

There should be much optimism after reviewing the results of Chapter 2 on the concrete/fly ash building products. Although it cannot be absolutely stated that fly ash as a portland cement replacer at the ratio of 50-50 will meet all current building standards, the implication of the data is very clear. It is a possibility and deserves additional study.

The author also feels that there is reason for optimism that North Dakota lignite fly ash can be utilized in a ceramics-type product. What this product will be will depend entirely upon the results of the economic feasibility study. It is the opinion of the author that no one single product will have economic viability in a production facility, but rather that a ceramics industry, producing many ceramic-like products is the probable result. What these products may be can't be known at this time. However, there is a fair degree of certainty in the area of fence posts. Insulators, tile, and other ceramic products will need a great deal of work in the area of production feasibility as well as product testing before money should be committed to a commercial production facility.

Sulfur ash as a road repair material and as a potential building product needs much more investigation. Since sulfur is also a waste product from both the coal gasification process and from the desulfurization process currently used in North Dakota oil production, the abundant quantity of elemental sulfur would indicate an availability for mixing with the already available fly ash. This should create a production environment that certainly needs to be investigated.

Although the data on wallboard production and testing is meager, it should be interpreted from an optimistic point of view. If one piece can be produced and be reasonably close to the current standards, it is a safe assumption that this product can be improved through further research and development.

All of the products discussed in this final report should leave the reader with a feeling of optimism regarding the utilization of North Dakota lignite fly ash in products that should have some sound economic opportunities. However, since the real world free market is tough, it is the opinion of the author that a fly ash utilization product development group should be established to further study the many products that have been tried and reported in this report. More detailed study by people with the appropriate backgrounds in a full-time environment would answer the many questions that have been left unanswered in this report.

APPENDIX

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A PROGRESS REPORT
ON
LIGNITE FLYASH UTILIZATION

by

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February 1980

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A PROGRESS REPORT ON LIGNITE FLYASH UTILIZATION

I. INTRODUCTION AND BACKGROUND

In 1976 the Electric Power Research Institute (EPRI), Palo Alto, California, started a research project on the utilization of coal flyash and crushed scrap glass in an attempt to make power poles that could replace wooden poles. Their research has been ongoing until late 1979 and their final report has yet to be published. In August of 1979 the Energy Development Board (EDB) contacted EPRI expressing an interest in EPRI work. We asked the question, "had they used North Dakota lignite flyash in their experiments?" EPRI had limited their research to utilizing bituminous and subbituminous flyash only thus could give the EDB no assurances whether lignite flyash/glass would or would not work. The EDB elected to use EPRI's procedures to test a lignite flyash/glass prototype fence post. The rationale being that we need a waste product saleable to the rural Mercer County trade area and perhaps several states and Canada. In September the EDB staff members and Professor Oscar Manz of UND's Coal Byproduct Utilization Institute used the Hebron Brick Company's facilities to make 5- to 6-foot 2½-inch diameter fence posts. In early October, the EDB gave a verbal report to the electric utility industry of North Dakota regarding our progress to that date. Based upon questions and suggestions at that meeting, the EDB and Professor Manz have conducted research and testing at UND. We will discuss the results of that work today.

II. EDB GOALS (See Figure 1)

When the EDB started addressing a ceramic product made out of lignite flyash/glass, there were several unanswered questions that were the real goals of our product development; they are:

1. Can North Dakota lignite flyash be used as a material for ceramic poles similar to the EPRI product?
2. If yes, at what flyash to glass mix ratio?
3. If yes, at what fineness does the glass need to be crushed?
4. Will lignite flyash/glass be as strong?
5. Are there problems that EPRI did not encounter?
6. Is there a different type of product other than poles?
7. Is it an economical process for North Dakota lignite flyash/glass considering shipping costs, labor, etc.?

III. THE PROCEDURE (See Slides)

The slides shown here will provide you with a visual concept of the procedures used for flyash/glass ceramic products. Basically, they can be outlined very simply as shown below.

1. Mix the dry components, crushed and screened, in the correct proportions.
2. Add the correct amount of water.
3. Mix until the correct consistency is attained.
4. Extrude the material with the appropriate die.
5. Perform any hand cutting or shaping on the material.
6. Air dry for eight hours.
7. Oven dry at 250°F for eight hours or longer.

FIGURE 1

EDB FLY ASH RESEARCH GOALS

1. CAN ND LIGNITE FLY ASH BE USED FOR CERAMIC PRODUCTS SIMILAR TO THE EPRI PRODUCT?
2. IF YES, AT WHAT FLY ASH TO GLASS MIX RATIO?
3. IF YES, AT WHAT FINENESS FOR THE GLASS?
4. WILL ND LIGNITE FLY ASH/GLASS BE AS STRONG AS EPRI?
5. ARE THERE PROBLEMS THAT EPRI DID NOT ENCOUNTER?
6. IS THERE A DIFFERENT TYPE OF PRODUCT OTHER THAN POLES?
7. IS IT AN ECONOMICAL PROCESS FOR ND LIGNITE FLY ASH/GLASS CONSIDERING SHIPPING COSTS, LABOR, ETC.?

8. Perform any last cutting or shaping operations.
9. Fire in a kiln. Achieve 1900°F and hold for one-half hour.
10. Anneal at 1350°F for one hour.
11. After cooling, perform appropriate tests.

IV. THE PROTOTYPE

The initial objective was to use the Hebron Brick facilities and manufacture a number of prototype fence posts to demonstrate the product feasibility. In addition to the demonstration, data would be gathered regarding the fineness of the crushed glass versus strength and an attempt would be made to learn speed of production for the economists. As many of you know, an unforeseen problem was encountered in the Hebron run. Mainly, we melted most of our material. However, we did recover 14 samples capable of being tested in an engineering laboratory. That data clearly indicated a strength similar to that of EPRI's and suggested that further laboratory research work should be done at UND to more closely identify the correct mixture ratio and crushed glass fineness.

A. Hebron

The Hebron prototype effort required a 16-hour working day and led to the production of 36 posts. The problems encountered and the test results led us to believe there were differences between lignite flyash/glass and subbituminous flyash/glass in the ceramics field. The test results were the opposite of what was expected based upon the EPRI data (see Figure 2).

HEBRON RUN
GLASS MESH VERSUS
FLEXURAL STRENGTH

EOB-ERQ
1/29/80

B. UND

In November 1979 the EDB staff and Professor Manz's laboratory staff proceeded to make a series of specimens patterned after Hebron's prototype mixtures but under more closely controlled conditions. The data that resulted was most discouraging in that we were not able to reproduce the strengths achieved at Hebron. The question, of course, was why. It was decided that the only logical approach was to step back and start all over and to ascertain the correct parameters for the ceramic product utilizing North Dakota lignite flyash/glass.

V. STARTING OVER -- NOVEMBER 1979

On November 6, 1979, we started to produce 1-inch diameter by 8-inch long samples in the laboratory at UND. Each batch of mixed material was varied in only one parameter, that is, the mixing ratio between flyash and crushed glass was the only variable that was changed between batches. All other materials used were the same and the screening of the crushed glass was held consistent at minus 100 mesh. That testing has continued through today and we have at this time produced 19 batches and over 120 specimens. From this effort we have learned that North Dakota flyash/glass is a better material for this type of a ceramic product than bituminous or subbituminous flyash/glass. However, North Dakota lignite flyash/glass does appear to be a more difficult material to work with because of the varying chemical nature of the lignite coal. In late December 1979, in addition to the fence posts and as a direct result of the October briefing of industry, we attempted to make electric distribution line insulators from our flyash/glass

ceramic material. To this date we have successfully extruded 11 insulators. Not all of the test results are in yet but the insulators look promising. We have also succeeded in producing a 3-inch diameter hollow fence post. That post has tested out very strong in comparison to EPRI's results in California. (See Figures 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12.)

VI. THE RESULTS

A. Strength

North Dakota's lignite flyash/glass ceramic products have proven to be nearly twice as strong in flexural mechanical strength. We have obtained an average value of near 11,000 pounds per square inch flexural strength. One specimen tested as strong as 26,511 pounds per square inch, more than twice the strength that EPRI ever obtained. Compression and impact strengths have also been demonstrated to be of sufficient strength to make a useful product.

B. Density and Absorption

Density and absorption have also tested out well. Density of finished product is comparable to that of EPRI's product and at the right mix ratio the absorption value is lower. The low absorption value is significant in that at 0.2 to 0.4 percent, achieved at the correct mix ratio, it is comparable to other products and results in good reaction to the freeze-thaw cycle.

C. Impact Tests (See Figure 8)

These tests were limited to the one-inch diameter samples (testing machine limitations). No attempt has been made to correlate this data with firearm impact values.

Figure 4

FLEXURAL STRENGTH
VERSUS MIX RATIO
ALL 94 SPECIMENS

Figure 5

403

EOB - BR
1/29/80

Figure 6

EOB-~~ML~~
1/29/80

Figure 7

HCL
1/10/80

Py. Q. Jan 10, 1970
HLL

IMPACT STRENGTHS VERSUS MIX RATIO

Figure 8

Figure 9

EXTRUDER SEQUENCE VS
FLEXURAL STRENGTH
BATCH 14 EXTRUDED AT SPEED 6

Figure 10

Figure 11

1/23/80
EOB-ARA

Figure 12

D. Audio Tests (See Figure 9)

These tests were an attempt to learn if a non-destructive test could determine if a given sample had a flaw or was normal. We are encouraged, but much needs to be done.

E. The Mixture (See Figures 13 and 14)

EPRI's material was all at the same mixture ratio of 50 parts flyash and 50 parts glass. With lignite flyash, the best mix ratio is 65 parts flyash and 35 parts glass. This is good news indeed for those of us who are trying to get rid of flyash. This higher flyash mix ratio will have a large effect on the economics in that the most expensive component of the EPRI work was crushed glass. Therefore, the less you use, the less expensive your product.

F. Slag

We have investigated the use of bottom slag (black beauty) as a substitute for glass. The results are not encouraging primarily because of the higher melting point. We have been unable to even use it as a glaze material for our insulators. However, a batch has been made and will be fired soon in an attempt to identify its melting point more closely.

G. Insulators

We have tested four unglazed insulators for electrical flashover and penetration values. The dry flashover value is 30,000 volts. One specimen punctured at 24,500 volts. All specimens tested 0 volts wet flashover. These results indicate that an insulator created with North Dakota flyash/glass will have to be glazed. We have tried three different glazes to date. The first was a glaze created out of slag. Our specimens melted before the slag produced a glaze. The

Figure 13

A COMPARISON OF FLY ASH CONSTITUENTS

VALUES SHOWN ARE RELATIVE DIFFERENCE
FOR EACH CONSTITUENT.

EOB-~~ARC~~
1/29/80

60-

Figure 14

A COMPARISON OF PRODUCT CONSTITUENTS

VALUES SHOWN ARE PERCENTAGE
OF TOTAL WEIGHT FOR EACH CONSTITUENTEOB-~~ARA~~

1/29/80

50-

-60

-50

-40

-30

-20

-10

-0

40-

30-

20-

10-

0

76

20

second and third are commercial glazes and we have had some success with one of those two. We have yet to test glazed insulators electrically and mechanically. We feel that the mechanical strength will be strong enough to meet the mechanical requirements but as yet cannot prove that.

VII. WHAT STILL NEEDS TO BE DONE

The following is a list of questions that we feel still need to be answered, at least in part, before a firm and accurate opinion can be expressed. The priority of this list reflects data the EDB needs for a more complete economic analysis and does not reflect the utility industry or the Coal Byproducts Utilization Institute priorities.

1. Determine if 65-35 ratio is best for all lignite flyash.
 - a. Chemical and mechanical tests for larger data base (trending).
2. Determine if -100 is the best mesh for glass and lignite flyash.
3. With 1 and 2 determined, can the percent of clay be reduced or raised.
4. Determine if extrusion speed is really such a big factor.
5. Audio testing procedures and methodology.
6. Try to extrude flat pieces for electric element holder.
7. Try silica sand again at a higher temperature and with the sand crushed and screened.
8. Try sodium silicate (water glass) again at different mixtures.
9. More sulfur-crete work.
10. Gypsum board.
11. More testing of Portland cement/flyash concrete blocks.

VIII. FUTURE DIRECTION

The future of flyash/glass ceramic products in North Dakota has not yet been determined. We do know that we can make a strong fence post and possibly a good insulator. The results of the economic feasibility study will not be in until June 1980. It is our feeling that research should continue at UND with further investigation of the insulator properties and perhaps an attempt should be made to create a third product. However, the EDB feels that it needs the support of industry to continue this work. We would welcome your suggestions and questions.