

Center for By-Products Utilization

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MILWAUKEE

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By-Product Lightweight Aggregates From Fly Ash

by B. W. Ramme, T. Nechvatal, T. R. Naik, and H.J. Kolbeck

Synopsis: This paper describes the history of by-product lightweight aggregate development from fly ash. Compositions and processes are discussed whenever information could be obtained including manufacturing experience.

The technology for the production of lightweight aggregates made from clay, shale, slate, and blast furnace slag and their use in various types of lightweight concrete has been established for over fifty years. Research on production of lightweight aggregate from fly ash was started in the 1950's. There are three processes for producing lightweight aggregates using fly ash: sintering, hydro thermal, and cold bonded.

Plants producing lightweight aggregate from Class F fly ash using the sintering process were constructed starting in the early 1960's in the United States and Europe. Most of these plants were capable of producing good lightweight aggregates which met ASTM specifications and found acceptance in the construction industry for structural lightweight concrete used in buildings and for lightweight masonry blocks. However, various problems surfaced which ultimately contributed to the closing of all of these early plants in North America by 1977.

Problems were caused by variability in the fly ash materials, improper plant design, and inadequately developed technology. Another factor contributing to the closing of these plants was the increasing cost of energy due to the energy crisis in the mid 1970's.

Since that time, technology has advanced and so has the cost of ash disposal which has renewed interest in lightweight aggregate production from fly ash.

Naik and Associates was contacted by Wisconsin Electric Power Company in 1987 to develop an assessment of technology for lightweight aggregate manufacturing and use of lightweight aggregate in concrete, masonry, and other products.

Allis Minerals Corporation was contracted by Wisconsin Electric Power Company to perform several series of bench-scale pelletizing and sintering tests using a rotary kiln process. The results of these tests were successful in establishing that high quality lightweight aggregates can be produced using fly ash. Production runs at a pilot plant were performed to confirm process parameters obtained in the bench-scale tests to permit scale-up to commercial production. Sufficient quantities of aggregate were produced to perform tests to establish conformance of these aggregates to ASTM specifications and building code requirements, and to confirm the aggregate's suitability for actual use in various lightweight concrete applications. A large scale commercial facility is in operation in Milwaukee, Wisconsin utilizing this rotary kiln fired process.

Special emphasis is given, to the patented Minergy process and production of a new rotary fired lightweight aggregate in Milwaukee, Wisconsin.

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INTRODUCTION

The main objective of this paper is to review the various processes used for producing lightweight aggregates from fly ash and other materials and, to review the qualitative requirements of these lightweight aggregates.

A literature review was conducted in 1988 to provide information on various production facilities and process designs for lightweight aggregates produced from fly ash (1). The review included information on operating and abandoned production facilities, and on research and development work (completed or in progress) dealing with lightweight aggregate materials. The review also included information on previous efforts by Wisconsin Electric (WE) and others to produce lightweight fly ash aggregates using fly ash from WE's power plants.

In order to achieve the objectives of this report, a thorough library search was conducted covering the period from 1920 through the present. Published reports by federal and state organizations, engineering periodicals and journals, and professional organizations were reviewed. An exhaustive computer database search was also conducted. These included:

- ACI Journal
- ACI Materials Journal
- ACI Structural Journal
- ACI Concrete International: Design and Construction
- ACI Special Publications
- ASTM Proceedings
- ASTM Journal of Testing and Evaluation
- ASTM Journal of Materials
- ASTM Special Technical Publications
- Cement and Concrete Research, An International Journal
- ASCE Journal of Engineering Mechanics Division
- ASCE Structural Division Journal
- ASCE Geotechnical Division Journal
- ASCE Civil Engineering Magazine
- ASCE Transportation Engineering Journal Concrete (Concrete Society, London)
- Magazine of Concrete Research (London)
- Electric Power Research Institute (EPRI) Publications
- Concrete Construction Magazine (USA)
- Concrete Library International (Japan Society of Civil Engineers)

and, many other special technical journals and reports.

Additional investigations were made in USA, England, Netherlands, and Germany by contacting and/or meeting with persons presently or previously involved in fly ash lightweight aggregate production and/or research and development to obtain their perspectives on the technology.

HISTORY

During the last forty years, a number of lightweight fly ash aggregate production facilities were constructed at power plant locations in the United States and Canada. Other facilities were in various stages of planning before being terminated for various reasons. Development of lightweight fly ash aggregate production plants also occurred in various locations overseas, including England, the Federal Republic of Germany and the Netherlands most of which are still in operation today.

In North America the overall rate of success for operating lightweight aggregate plants using fly ash has not been good for a variety of reasons. The major reasons for failures of operating plants and the abandonment of proposed plants are both technical in nature as well as economic. However, a new rotary kiln lightweight aggregate has been introduced into the North American market in 1994 by Minergy Corporation. This unique patented process utilizes coal ash and wastewater solids to produce a high quality structural grade lightweight aggregate material.

LIGHTWEIGHT AGGREGATE PROCESSES

Basic Methods of Production:

Two basic steps have to be performed to produce an aggregate from fly ash: agglomeration of the fine fly ash particles to form aggregate-size pellets, and bonding of the material in the pellets. This gives the pellets strength and other properties necessary to meet the criteria for a lightweight aggregate. (13)

Agglomeration

Agglomeration (also called "pelletizing") can be performed by two distinct methods. One is by agitation, where fly ash particles are introduced onto an inclined rotating disk along with a wetting agent and an appropriate binder. Balling of the material occurs by the formation of 'seeds' which ultimately grow into pellets of a certain maximum size, usually about 3/8 in. to 5/8 in. in diameter. The other method is the pressure or extrusion method where agglomeration is accomplished by using a continuous piston-type press where more or less rectangular or cylindrical pellets are formed, that are 3/8 in. to 1/2 in. in size. The extrusion process generally results in a product having a higher density than the spherical pellets produced by agitation (13).

Bonding

Bonding of the green pellets can be accomplished in three ways: firing, hydrothermal processing, and cold bonding.

The firing method can be accomplished several ways. One method is the continuous rotary kiln whereby the material is heated in a rotating, almost horizontal kiln to produce the lightweight aggregate product. Another method utilizes a traveling sintering grate that transports the material through a sintering oven. In either method, firing is initiated by an outside source of heat (oil or natural gas) and supported through the sintering process, as much as possible, by the combustible portion of the pellets. The combustible portion is provided by the organic portion of component materials (such as the carbon fraction of the fly ash as measured by a loss on ignition test (21)). Additional heat required during the firing process can be supplied by oil, natural gas or fuel that is added to the fly ash prior to pelletizing.

In the hydrothermal process, bonding is accomplished by adding lime and/or cement to fly ash in order to achieve a chemical reaction that will bond the materials together. After the fly ash and lime have reacted, the mixture is pelletized in an inclined rotating drum. The pellets are then placed in an autoclave to harden under pressurized saturated steam conditions.

Cold bonding is a process where lime and/or cement is added to fly ash, along with other substances such as limestone, clay or shale. The mix is then pelletized and allowed to harden. The product from the cold bonding process is thought to possess properties inferior to those of the other two processes due to the lack of firing (13).

Of the various processes described, the agitation method coupled with the firing method for bonding is considered the best approach for producing a high quality lightweight aggregate. This process yields an aggregate with a low unit weight that can be used to produce a good quality structural grade lightweight aggregate. Applications for the products from the hydrothermal and cold bonding processes appear to be limited primarily to production of concrete blocks. The success of a lightweight aggregate will depend on selecting applications appropriate for their use.

REVIEW OF LIGHTWEIGHT AGGREGATE PLANTS USING FLY ASH IN THE UNITED STATES AND CANADA

Consolidated Edison Lightweight Aggregate Plant

Based on a 1961 pilot plant study, Consolidated Edison Company, New York, built a plant that commenced operation in 1963. The facility consisted of a storage silo and a feed bin with a rotary-vane feeder.

The feeder supplied fly ash to a revolving-drum conditioner where water was added (approximately 17 percent by weight). The mix was then conveyed to a three-compartment feed bin which discharged to three large diameter pelletizers. At this point the moisture content was raised to about 22 percent. The raw pellets were then conveyed to a drying hood where some moisture was removed before they were conveyed to the traveling grate sintering oven. The fly ash pellets were heated to about 2300° F in the sintering oven. The product discharged from the sintering oven was transported by means of a shuttle conveyor to a storage pile. It was then conveyed by means of a reclaim tunnel to storage bins for truck loading. Fines were captured after sintering by bag filters and recycled to the feed bins prior to conditioning.

Problems encountered at this plant included excessive dust conditions at various points which were solved by installing proper seals, airlocks, venting, and water sprays.

Plant capacity was approximately 365,000 tons/year, which was marketed in the New York City area. The material met City of New York Building Code Requirements. In 1972 the plant equipment was taken out of service due to excessive operating costs and moved to Syracuse, New York for production of shale lightweight aggregates. Later it was moved to Colorado where it is now used for sintering iron pellets (2).

Detroit Edison Lightweight Aggregate Plant -q

This plant, commenced operation in 1963, and was very similar to the Consolidated Edison Plant. The plant was owned and operated by the Waylite Company. Detroit Edison supplied the fly ash and received a royalty on the sale of the product. The plant had a capacity of about 200,000 tons/ year, which was marketed mostly in the Detroit area and Michigan as Waylite by the Waylite Company. Fly ash was brought from different sources and there were occasional LOI deviations that required blending of the ashes to keep the LOI in the 5-6 percent range. Carbon content in excess of this range caused fusion of pellets on the traveling grate, while insufficient carbon content resulted in incomplete sintering of these pellets due to the lack of an internal source of the necessary heat energy. Other problems encountered included inadequate balling in the pelletizer, which

usually occurred when recycled sintered or incompletely sintered particles were re-mixed with the new feed stock. To correct this problem, a clay 'slip" binder was injected in the feed to assure proper pelletizing. Most problems were solved in the initial start-up period. The plant basically operated well and produced a proven aggregate of several sizes. Dust control was handled adequately with the installation of bag filters. No other environmental controls were required at the time for emissions. The plant operated around-the-clock to avoid difficult and costly shut-downs and start-ups.

The aggregate met ASTM C-330 standards (19) but an equally important aspect was the need to obtain building codes approval. Tests were conducted by the Fire Council of Underwriters' Laboratories, Inc. and this material was approved for use in lightweight masonry construction. As a result, the material was accepted in building construction (5).

Production of this lightweight aggregate was suspended in 1972 when the power plant supplying the fly ash was converted from coal to oil-fired operation. The plant was significantly modified for use in processing recycled high iron steel mill slag by Huron Valley Steel of Detroit.

Penn-Virginia Materials. Corporation, Willoughby, Ohio

Penn-Virginia Materials Corp. operated a plant at East Lake, Ohio, which produced a lightweight fly ash aggregate which was marketed in Ohio and in other eastern and southern states. The material was called Pennvalite and was used in structural concrete applications.

The plant was constructed next to the East Lake Power Plant of the Cleveland Electric Illuminating Company and was placed in operation in 1974. The plant used the patented Corson process with rectangular pellets made in an extrusion press. The plant had a design capacity of 250,000 tons/year but was derated to about 150,000 tons/year due to operating constraints. This derating was required so that the pellets would be conveyed through the sintering oven at a rate that allowed complete combustion to occur. This was in spite of the use of a down draft system in the sintering chamber which was found to be more effective than the up draft system used at some other plants.

The process included an iron oxide separator which reduced the high iron oxide content (15-18 percent) of some of the fly ash which came from older generating units equipped with mechanical precipitators. This was needed because excess iron oxide caused the aggregate to fuse too early. Fly ash furnished by newer generating units using different coal and equipped with electrostatic precipitators had a lower iron oxide content and was used without problems.

The bulk unit weight of this aggregate was about 44 lb./ft'. The aggregate met

ASTM C-330 for use in structural concrete (20). The plant was closed in 1977 for economic reasons which included:

- a) the variability of the fly ash proved to be beyond the ability of the plant operators to control the process and make quality lightweight aggregate;
- b) ammonia injection in the power plant boilers resulted in unacceptable and variable quality of ash;
- c) there was a lack of cooperation for quality control on the part of the power plant management;
- d) the power plant used several types of coal; and,
- e) the carbon content and iron oxide content variations were a problem.

Duquesne Power Company

A plant producing lightweight fly ash aggregate was placed in operation in the late 1960's at Duquesne Power Company's Eirama Power Station. The plant was operated by the Freeport Brick Company on a cost-plus basis after the initial arrangement of joint ownership proved to be financially difficult for Freeport. The material was marketed in Pennsylvania and West Virginia under the name Freelite. It was also approved by Underwriters' Laboratories, Inc. for use in lightweight units (5).

The plant was equipped with a roller-type pelletizer that made rectangular pellets by extrusion and compression. The extruding mechanism experienced excessive wear. The sintering grate was of inadequate design and thus, could not provide the heavy-duty service expected of it. Moisture control was also difficult and deviation from normal moisture in mix components resulted in production of excessive fines (up to 30 percent of total). Variability of fly ash LOI also caused problems of excessive or inadequate fusion, resulting in additional operating problems.

The operators considered replacing the roller-type pelletizer with inclined disc pelletizers and installing two additional sintering lines, but these changes were never implemented (7).

The plant was closed in the early 1970's and dismantled in order to provide space for the installation of flue gas desulfurization equipment for the Elrama Power Station.

Florida Power Corporation's Aardelite Plant

A plant using the Aardelite process commenced operation in the spring of 1988. This process uses cold-bonding curing which was developed in the Netherlands by B. V. Aarding, in the late 1970's. The plant was constructed at Florida Power Corporation's Crystal River Power Station near St. Petersburg. It had a capacity to process approximately 1 50,000 tons of fly ash per year.

The material produced by the Aardelite process meets specification ASTM C-331 "Lightweight Aggregates for Concrete Masonry" (20). The basic market for Aardelite is the concrete block industry.

The plant uses Class F fly ash which is mixed with lime, proprietary additives, and sand. Apparently a higher LOI fly ash can be utilized in this process. Lime must be hydrated to calcium hydroxide before agglomeration to prevent pellet failure due to large volume increases. The cost of the lime additive is minimized and pelletizing is enhanced through thorough mixing of calcium hydroxide and fly ash. The pellets are cured on a continuous conveyor using low-pressure steam as the heat source. Pellets are crushed to obtain proper aggregate gradation. Dust collected during the process is returned to the mixer for re-use.

The material apparently does not meet the requirements of the ASTM C330 for use in lightweight structural concrete (15,19). Its average unit weight is 58 pcf.

Agglite Lightweight Aggregate Plants

Southern Electrical International (SEI), a subsidiary of Southern Company, and Resource Technology, Inc. (RTI) planned to construct a lightweight aggregate plant at Georgia Power Company's Hammond Plant near Rome, Georgia. The plant planned to have a capacity of about 1 50,000 tons/year, based on an eight hour per day operation. It would use a Class F fly ash produced at Hammond. The intended market for the product is the concrete block industry.

There was an agglite plant reportedly built at Virginia Power's Chesapeake Station near Norfolk, Virginia by Agglite of Virginia Corp.

The additives include a surfactant foam, a dry catalyst, accelerators and Portland cement. Portland cement rather than lime is used because of its lower cost and superior performance in producing earlier strength without further temperature curing. The material is cured 47 hours in a green stock pile before being graded and conveyed to the finished product stock piles (16, 18).

Ontario Hydro - Lakeview Fly Ash Processing Plant

A lightweight aggregate plant was constructed at Ontario Hydro's Lakeview Power Plant near Toronto in the early 1970's. It was designed by Harold Stirling, Pittsburgh, and included air classification, carbon removal, iron separation, and production of sintered fly ash. Rated plant capacity was approximately 75,000 tons/year.

A major problem in operating this plant was encountered with the carbon separation system. Substantial variation in the high carbon content of the fly ash (10-15 percent) occurred since the Lakeview plant operated as a peaking plant. Another

problem was caused by high variability in fly ash particle size distribution. Low efficiency precipitators at the generating station produced low quantities of extremely fine fly ash particles. The plant did not function well and was closed after it became apparent that these problems could not be economically resolved.

Wisconsin Energy - Minergy Plant

Wisconsin Energy constructed a plant that began operation in 1994 in Oak Creek, Wisconsin. The plant was constructed within a retired portion of Wisconsin Electric's Oak Creek Power Plant. This allowed the use of an existing structure and also had the advantages of being near rail and Great Lakes transportation as well as a source of fly ash used for the process. The plant was designed and constructed by Allis Minerals Systems, located in Waukesha, Wisconsin. The plant has a total production capacity of 95,000 tons/year and consumes 85,000 tons of fly ash and 60,000 wet tons of wastewater solids in the process. The process can also provide 40,000 pounds/hour of steam from the excess energy.

The intended markets for this aggregate include lightweight precast and structural concretes, lightweight and medium weight concrete block, thermal and sound insulated concrete products, landscaping and geotechnical applications, lightweight filler for manufactured products, lightweight and abrasive aggregates for asphalt paving, etc.

REVIEW OF LIGHTWEIGHT AGGREGATE PLANTS USING FLY ASH IN EUROPE

Fly Ash Lightweight Aggregate Plants in England

The lightweight aggregates market in England has been dominated by Lytag Ltd., which is owned by Boral Ltd. of Australia. The first plant commenced production in 1960 after almost ten years of research activities which in turn were supported by the British Government's Building Research Establishment. Lytag owns several lightweight aggregate plants which are located at power plants operated by the Central Electricity Generating Board of England. While the first plant used a vertical kiln, which proved to be unsuccessful, later plants utilized traveling grate sintering strands.

These lightweight aggregates have a maximum size of 5/8 in. and are spherical in shape. The material has been used for structural lightweight concrete for cast-in-place as well as precast concrete construction. It has also been extensively used in the production of concrete blocks. Structural lightweight concrete has been used in building construction, including high-rise buildings, and in the construction of large bridges and off-shore oil drilling platforms. The material produces concrete ranging from 80 to 110 pcf, having 500 to 8,000 psi compressive strengths (3, 9, 10).

German Lightweight Aggregate Plant

A lightweight aggregate plant was constructed about 1970 at the Scholven Power Station of VEBA Kraft Werke Ruhr, GMBH, near Essen. The plant is equipped with fly ash blending silos to permit adjustment of carbon content. Any upward adjustment of carbon content is handled by either an addition of powdered coal or additional high carbon ash.

Control of fly ash fineness is very important to this process. It was found that pelletizing works best when 30 to 35 percent of the fly ash is retained on a 70 micron sieve (USS 200 mesh). Problems were found to occur when fly ash is coarser than 20 to 25 percent retained on a 90 micron sieve.

Fly ash carbon content is maintained at 5 to 6 percent. An automatic probe is used to measure carbon content of the fly ash as it is transported from the precipitators to an intermediate storage hopper (6). Rapid determination of carbon content was made possible by using an established correlation between carbon content and the capacity of the fly ash to absorb water. Fly ash is blended prior to agglomeration to adjust carbon content as needed.

Two to three percent water is mixed with the fly ash to control dust and the mixture is then fed into 13 ft. diameter pelletizers, where the water content is increased to a

range of about 12 to 16 percent. Additives of salt, sugar, clay, and cement have been experimented with, but were apparently not very effective in promoting increased green pellet strength. Lack of pellet strength has been attributed to the fly ash being too coarse. Sintering has generally worked well. After crushing, the sintered material is conveyed to storage. Aggregate bulk density is about 47 pcf and maximum size is 5/8 inch.

REVIEW OF RESEARCH ON LIGHTWEIGHT AGGREGATE USING FLY ASH Michigan Technological University, Houghton, Michigan

A team of researchers at Michigan Tech have developed and patented a low-temperature fly ash agglomeration process for making lightweight aggregates. Additives for agglomeration include calcium hydroxide. The pellets are steam-hardened at about 200°F. The researchers claim that this process is suitable for making lightweight aggregates for medium weight concrete, including highway construction, bricks, blocks and prefabricated building components. No reference was made as to whether the material from this process meets ASTM requirements for lightweight aggregates (5, 8).

United States Department of Energy and Iowa State University, Ames Iowa

Research on the technical feasibility of producing lightweight aggregates from coal cleaning wastes and fly ash was performed at Iowa State University. The coal cleaning waste is ground during a preparation step. The major minerals present in this material are illite, kaolinite, quartz, calcite and iron pyrite. The ground material is then blended with fly ash, agglomerated in a rotary pan pelletizer, and sintered at about 1750°F. The product was tested and met the weight requirements for lightweight aggregate; but the researchers did not report conformance with ASTM requirements (1).

San Diego Regional Water Reclamation Agency, San Diego, California

A state-funded experimental plant operated by the San Diego Regional Water Reclamation Agency produced a lightweight aggregate by mixing thickened sewage sludge (45 percent solids) with clay to produce pellets with an extrusion press. The pellets are then sintered in a rotary kiln at about 2000°F. These aggregates meet ASTM C-330 requirements for gradation (19). The unit weight of fine aggregates is 55 lb/ft³. The process, known as Coordinate Chemical Bonding Absorption was developed at the 3M Company (12).

Resource Technology, Inc., Tucker, Georgia

A process developed by Resource Technology, Inc., produced a lightweight aggregate made from either Class C or Class F fly ash, or combination thereof. Additives include a surfactant, foam, an accelerator (Styroset 1201 produced by Resource Technology, Inc.) and portland cement. Following agglomeration in a pan pelletizer, the pellets are fired at about 1800°F. The resulting lightweight aggregates have a weight of 40 to 70 lb./ft³ and a one-day age compressive strength of concrete of 450 to 1,700 psi. These lightweight "foamed" aggregates have sufficient physical properties to meet ASTM C-331 requirements for use in lightweight concrete masonry (11, 20).

Resource Technology, Inc., Tucker Georgia, and Atlantic Development Company, Baltimore, Maryland.

This process uses fly ash which is mixed with cement and other chemical additives and fed into a pan-type pelletizer, where an accelerator is sprayed onto it. The green pellets are conveyed to a green pile for 48 hours of storage to allow final hardening. The aggregate is then ready for shipping- after hardening.

This is a cold bonding process where the elimination of the sintering step results in reduced capital cost. However, feed material costs are higher.

The material has been marketed as Agglite which meets ASTM specification C-331, "Lightweight Aggregate for Concrete Masonry Units". (16, 17, 20)

The process was patented by Atlantic Development Company in 1987.

REVIEW OF MATERIAL REQUIREMENTS FOR PRODUCING FLY ASH LIGHTWEIGHT AGGREGATE

A review of the material requirements of various lightweight processes is difficult because detailed information is usually proprietary, and therefore, not readily available. Processing details significantly impact comparisons among processes. This review includes comments about known feed stock materials, as well as operating problems encountered to date.

DESCRIPTION OF VARIOUS PLANT MATERIAL

REQUIREMENTS:

Consolidated Edison Lightweight Plant (2)

Fly Ash:	ASTM C-618, Class F
Additives:	None mentioned
Initial Moisture:	Add 17 % water before pelletizing
Final Moisture:	Increase to 22 % during pelletizing
Pelletizer Diameter:	19 ft.
Type of Sintering:	Travel grate, 8 ft. wide by 120 ft. long.
Sintering Temperature:	2300* F
Plant Capacity:	1000 tons/day (250,000 tons/year)

Detroit Edison Lightweight Plant (Waylite)

Fly Ash:	ASTM C-618, Class F
Binder:	Clay Slip
Desired LOI:	5 to 6 percent
Pelletizer Diameter:	19 feet
Type of Sintering:	Traveling Grate
Material Specifications:	Met ASTM C-330 & C-331. Approved by Fire Council
of	Underwriter's
Laboratories, Inc. for	Masonry
Construction	
Plant Capacity:	200,000 tons/year
Critical Parameters:	Carbon Content (LOI) Control of fineness for pelletizing

Penn Virginia Materials Corporation Lightweight Aggregate Plants (Pennvalite)

Tests were performed by Wheelwright Corp. for Penn Virginia in 1974 using various types of Wisconsin Electric's (WE's) Oak Creek Power Plant (OCP) fly ash. Aggregate from OCP Units 1 & 2 ash (1.28% carbon) had excessive clinkering. OCP Units 3 & 4 ash (8.1 % carbon) and OCP Unit 5 ash (6.8% carbon) produced good aggregate with occasional clinkering. Blended ash from OCP

Units 5, 7 & 8 (4% carbon) had satisfactory ignition and maintained sustained burn.
Good aggregates were produced.

Duciesne Power Co., Lightweight Aggregate Plant (Freelite)

Type of Fly Ash:	ASTM C-618, Class F
Additives:	None
Pelletizer:	Rotary-type Extrusion (Corson Process)
Production:	2000 tons/month (25,000 tons/year)
Special Problems:	Excessive fines (30 percent), caused mostly by the wrong type of pelletizer.

Florida Power Co. (Aardelite)

A wide range of recipes can be used for producing Aardelite aggregate. Their quality and types of use depend upon various proportions of the constituents used. Aardelite may be produced from the following ranges of materials:

<u>Ingredient</u>	<u>Percent of Total</u>
Fly Ash, ASTM C-618, Class C or Class F - 94.0	40.0
Sand or Bottom Ash 55.0	0.0 -
Lime, Including Active CaO in Ash 6.0	3.0 -
Water, Chemically Bound 1.6	1.2 -

Aardelite made at the Florida Power Company plant uses 92 to 96 percent ASTM C-618 Class F fly ash, which produces a lightweight aggregate particularly suitable for use in concrete masonry units, meeting ASTM C-331 (19).

A one ton per hour pilot plant located in Tampa, Florida, and a three ton per hour pilot plant in the Netherlands are available to test various mixes and arrive at optimum recipes.

In this process, lime is converted to calcium hydroxide (prior to production of the pellets and after its resulting volume change). It is then mixed with the fly ash for agglomeration. Due to its cost, the lime quantity is kept as low as possible. The lime binder must be intimately mixed in the process to achieve maximum calcium hydroxide - fly ash reaction. The pellets are cured by steam heat in the curing silos.

The pellets travel from the top to the bottom of the silos, on successive curing shelves. In this process crushing or sticking of the pellets can be a problem and must be prevented (15, 18).

Agglite

This process uses cold bonding. The recipe includes:

Fly Ash: ASTM C-618, Class F
Additives: Surfactant foam Dry catalyst Accelerators (styroset #201)
Portland cement
Pelletizer: Pan type
Curing: No external heat required

The process is patented by Resource Technology, Inc., and the materials meet Specification ASTM C-331 "Lightweight Aggregate for Concrete Masonry Units," and ASTM C-90 "Hollow Load-Bearing Concrete Masonry Units" (11, 16, 18, 20).

Lytag Process

The Lytag process requires ASTM C-618, Class F fly ash. It is important that the fly ash is well blended with respect to gradation as well as loss on ignition. A typical plant would have an 8-hour storage capacity. The ash is fed by rotary feeder into a surge hopper and from there to a weigh belt feeder for measuring the weight of the ash fed to the pelletizers. The weighed ash is fed into a drum mixer where a measured amount of water is added to properly bind the ash. The ash-water mixture is then conveyed to inclined pelletizers where additional process water is added.

The pellets formed are conveyed to the sintering line through a feed hopper and pivoting belt conveyor which spreads the green pellets evenly on the traveling sinter screen. The pellets pass through the ignition chamber where an oil fired flame ignites the carbon in the green pellets. A down draft is maintained through the bed of pellets as it travels along on the sintering strand to maintain the continuous combustion of the carbon fractions in the pellets. Dust created along all the points in the process is returned to the ash storage silo for reuse.

Lytag stressed the importance of knowing the physical and chemical characteristics of the fly ash including particle size and distribution, surface area, LOI, density (particle and bulk), silica and lime content, change in acidity and alkalinity, temperature, and variations in input. The latter parameter requires knowledge of seasonal, or loading fluctuations, which are again dependent on plant operating characteristics.

Lytag had stated that pellet sintering in some cases may be more advantageous with a rotary kiln. Lytag emphasized that a plant process should consider the following points: (a) the plant and process should be kept as simple as possible; (b) limit instrumentation only to the minimum that is necessary; (c) eliminate as many variables as possible; (d) minimize the need for operator adjustment and discretion;

and, (e) pay close attention to maintenance to assure continuity of operation (9).

Opinions by others formerly engaged in fly ash lightweight aggregate production are divided on whether the Lytag aggregates as produced in the 1960's and 1970's could conform to ASTM C-330 requirements for structural lightweight aggregates. This material is considered to be a good 'product and has been used in England for many structural applications.

Wisconsin Energy/Minergy Plant

Fly Ash:	ASTM C-618, Class C or F
Additives:	Proprietary binders, Wastewater
Solids	
Pelletzer Diameter:	15 ft.
Type of Firing:	Rotary Kiln
Firing Temperature:	20000 F
Plant Capacity:	95,000 tons/years
Dry Loose Unit Weight:	38 lbs/ft ³ to 49 lbS/ft ³ (depending on gradation and hardness)
Dry Bulk Specific Gravity:	1.3
R-Value;	Approximately 0.8/inch

Minergy's patented technology is now processing 150,000 tons of fly ash and sludge annually at a commercial facility in Oak Creek, Wisconsin. The result, a product called MINERGY LWA, is a strong, low density aggregate - superior to natural aggregates for lightweight structural concrete and lightweight concrete masonry units, and meets ASTM standards for these applications. Minergy LWA also finds a ready market in insulating concrete, as a lightweight and fire resistant mineral filler, or as landscaping ground cover.

The Minergy process accommodates a broad range of raw materials. Combustion ashes with high or variable loss-on-ignition levels, ashes containing ammonia or other residuals from air emission controls, and sludges with varying levels of metals and organic compounds. The blended raw materials are processed in a high-temperature rotary kiln rendering them inert and environmentally benign. The vast majority of the heat required is supplied by the sludge and carbon in the ash. Residual heat from the process is recovered to produce steam and/or electricity.

The process starts with storage silos of the required raw materials (fly ash, wastewater sludge, proprietary binders, etc.) that are mixed and fed to an inclined pelletizer to form "green" balls of varying desirable graduation. The material is then transported to a drier for drying and then fired in a rotary kiln whereby the organic materials in the ash and the wastewater solid are combusted providing the energy for the process. Temperatures in the rotary kiln are in excess of 2000°F. The lightweight aggregate pellets that have been manufactured are cooled by air and transported to an outdoor storage pile. The aggregate can be used as produced or can be crushed to obtain required gradations. The spherical shape of the material improves the workability and pumpability in concrete applications. The aggregates produced are high quality and meet ASTM C330 and C331 requirements for use in masonry block and structural concrete. These aggregates are high quality materials that are comparable to, and for some properties superior to, commercially available lightweight aggregates.

SUMMARY AND CONCLUSIONS

From the literature available, it can be concluded that after forty years of research and actual commercial applications, while there are still risks involved in designing and operating a plant producing commercially viable lightweight aggregates from fly ash, significant improvements continue to be developed.

Process Types

Plants that successfully operated or are operating include rotary kiln firing, sintering, and the cold bonded type. The sintering plants in the United States include Consolidated Edison (New York), Detroit Edison (Waylite), Penn Virginia Co., Plant near Cleveland, and Minergy (Wisconsin). Three sintering plants (Lytag Ltd.) are operating in England. One Lytag plant is in operation in the Netherlands also. The German Scholven Plant operates only during the winter season when peak generation occurs. The cold bonded plants include the Aardelite process (Florida Power and Light) and the Agglite process (Agglite of Virginia). The only known rotary kiln fired plant is owned and operated by Wisconsin Electric Power Company using the Minergy process.

All plants appear to have used or are using ASTM C-618 Class F fly ash as the primary material. Of the two types of processes, each has certain advantages that need to be considered.

Advantages of Sintering /Rotary Kiln Firing Processes

Based on experience to date:

- a. sintering/rotary kiln firing utilizes the carbon content of the fly ash along with other organic materials to furnish process heat;
- b. generally the sintered/rotary kiln fired lightweight aggregates can meet

both ASTM C-330 (used in structural concrete) and C-331 (used in masonry blocks), while the cold bonded lightweight aggregates can only meet ASTM C-331;

- c. sintered/rotary kiln fired lightweight aggregates have lower bulk density than cold bonded lightweight aggregates;
- d. sintered/rotary kiln fired lightweight aggregates have more strength than cold bonded lightweight aggregates;
- e. sintered/rotary kiln fired lightweight aggregates require less process time from agglomeration to finished product than cold bonded lightweight aggregates;
- f. the additive content tends to be lower for sintering/rotary kiln firing plants;
- g. sintering/rotary kiln firing creates a ceramic shell around the fly ash that may prove to create a more environmentally benign product than that from cold bonded processes;
- h. sintered/rotary kiln fired lightweight aggregates typically have a higher market value than cold bonded lightweight aggregates because of higher strength and lower density;
- i. sintered/rotary kiln fired lightweight aggregates has a proven track record from operating plants in Europe and are, therefore, generally better accepted than cold bonded lightweight aggregates;
- j. residual carbon is burned up in a properly sintered/rotary kiln fired aggregate while it is retained as a contaminant in cold bonded aggregates. LOI content in mixes must be controlled in order to meet ASTM C-330 (Structural Lightweight Concrete) and C-331 (Lightweight Concrete for Masonry Units); and,
- k. sintered/rotary kiln fired lightweight aggregate tends to be more consistent in color than cold bonded aggregates because of the variability of carbon content retained.

Advantage of Cold Bonded Process

Based on experiences to date:

- a. cold bonded process plants tend to have lower capital costs than sintering/rotary kiln firing plants;
- b. cold bonded processes tend to have lower operating costs than sintering/rotary kiln firing;
- c. cold bonded process plants have less environmental impact than sintering/rotary kiln firing plants (no exhaust gases). Both processes require particulate emission controls and may have waste water streams; and,
- d. finished material costs tend to be lower for cold bonded material than for sintered material.

Process Challenges

From the reference material it appears that all fly ash lightweight aggregate plants

that have operated in North America and in Europe produced material that found acceptance in the market. However, problems were encountered with plant operations. There appeared to be a general reluctance or inability to allocate adequate funds to implement improvements. However, with the increasing cost of by-products disposal and, increasing cost and difficulty of siting landfills, the level of commitment for improvements should increase.

Process problems are normal during maturation of the industry. There were many ad-hoc improvements made in the plant processes. However, the greatest problems were caused by the inherent variability of the fly ash feed stock with respect to parameters such as fineness, gradation, chemical composition, and carbon content. These properties affect the basic process including agglomeration and sintering, or curing. Depending on the type of plant, a carbon content in the 4 to 8 percent LOI range was found to be desired for optimum product quality. There are also many production parameters that impact the quality of the final product including additives, moisture content during agglomeration (initial and final), pellet size, green pellet density, agglomeration and sintering time.

CONCLUSIONS

- a. Both processes (sintering/rotary kiln firing and cold bonded) require controlled inputs of fly ash and additives for the process to operate successfully.
- b. The sintered/rotary kiln fired fly ash lightweight aggregates tend to be stronger and generally of a higher quality than cold bonded lightweight aggregate.
- c. Sintered/rotary kiln fired fly ash lightweight aggregate should gain a wider market than cold bonded lightweight aggregates because of their higher strength and lower density.
- d. The potentially higher production cost of sintered/rotary kiln fired fly ash lightweight aggregate may be offset by its higher quality, which should in turn command a better price.
- e. A lightweight aggregate should meet the requirements of ASTM C330 (used in structural concrete), and ASTM C-331 (used in masonry blocks) to provide wide acceptance.

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