# Optimizing Flyash for New Architectural Uses

## Experimental Research to Explore Possibilities

**This current project is being funded by the Unniversity of Kansas New Faculty Research Grant program, and the University of Kansas General Research Fund. It is scheduled to be complete in May 2005. Jerry Wright, John Schlueter and Branden Warden are student collaborators helping with the project.**

**This text is from the original grant proposal.**

### Abstract

Flyash is a naturally-cementitious coal combustion by-product. It is extracted by the precipitators in the smokestacks of coal-burning power plants to reduce pollution. In the U.S., about 57 million tons of flyash are generated per year. Overall, only about 33% of the flyash produced by the combustion of coal is currently reused or recycled, while the remainder is disposed of in landfills.[1] Since the flyash disposal problem emerged with the advent of pollution control systems in the 1960's and 1970's, extensive research has been done to understand how it performs in its orthodox capacity—as a soils stabilizer and structural concrete admixture. But from what I can tell[2], there has been little published research attempting to understand flyash's qualities and capacities as a basic cementitious material, in uses outside of its orthodox, heavy-construction uses.

Though use of flyash in orthodox concrete construction—as a low-volume admixture—is fairly common, widespread acceptance in high-volume applications has still not been achieved, nor has it been used as a cementitious binder in applications outside of the traditional concrete ready-mix establishment.[3]

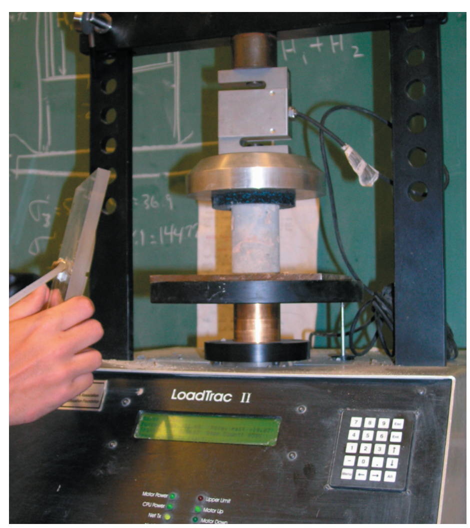
This proposed research project is intended to provide the background data necessary to seek future funding for the development of factory-produced architectural products such as tiles, panels, shingles, furniture, countertops or other items using high volumes of flyash as a cementitious binder, along with other waste materials (e.g. ground glass, sawdust, shredded tires) as aggregate.

Cylinders and slabs made using flyash as the primary cementitious binder, along with a variety of aggregates.

The objectives of the project are as follows:

1. Compile information on the "state of the art" of flyash in cementitous building materials applications: collect research reports, patents and patent applications, and articles concerning use of high-volume flyash concrete mixtures.

2. Develop a matrix of sample mixes with the goal of identifying desirable material properties by means of subjecting a series of uniform samples to a series of engineering tests (compressive strength, tensile strength, abrasion resistance, water retention, water resistance, porosity, texture, setting times). The overall goal of this phase of work is to arrive at optimum mixes for different characteristics.




Testing cylinders for compressive strength in Learned Hall.

## Budget

**Personnel:**

| | |
|---|---|
| Principal Investigator (Nils Gore), salary requested* | $ 5000.00 |
| Undergraduate Research Assistant(s) | $ 2000.00 |
| **Fringe Benefits** | |
| 28% x PI salary= (5000 x .28) | $ 1400.00 |
| 4% x assistant salary= (2000 x .04) | $ 80.00 |
| **Consumable Materials** | $ 680.00 |
| **Other Costs:** | |
| In-state travel to visit flyash producers and consumers. | $400.00 |
| **Total New Faculty Funds** | **$ 9560.00** |

## Project Description and Objectives:

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## Why this Project is Unique:

Since the flyash disposal problem emerged with the advent of pollution control systems in the 1960’s and 1970’s, extensive research has been done to understand how it performs in its orthodox capacity—as a soils stabilizer and structural concrete admixture. But from what I can tell[4], there has been little published research attempting to understand flyash’s qualities and capacities as a basic cementitious material, in uses outside of its orthodox, heavy-construction uses. The abstract of a current research project by the Electric Power Research Institute (EPRI) helps to confirm this thinking: “EPRI will seek products with concrete-like or rock-like properties and try to develop alternatives that could be produced using fly ash. If preliminary estimates of the costs of such products are promising, EPRI will recommend projects for future years to produce and test prototype replacement materials in the laboratory, followed by field demonstrations."[5]

This project will explore flyash's fundamental qualities as a cementitious material, and then will speculate on the types of products which would benefit from those qualities, in the interest of spurring development of flyash products.

### Flyash Waste Problem:

Flyash is a naturally-cementitious coal combustion by-product. It is extracted by the precipitators in the smokestacks of coal-burning power plants to reduce pollution.

In the U.S., about 57 million tons of flyash are generated per year. Overall, only about 33% of the flyash produced by the combustion of coal is currently reused or recycled, while the remainder is disposed in landfills.[6] Some have estimated this to be approximately 26 cubic miles of landfill space.[7] Accordingly, the supply of flyash is plentiful, and with continually more power being consumed in the US, is expected to increase.

Locally, Mr. Bryce Stehman, Director of ash disposal at Kansas City Power and Light (KCPL), reports that 3 KCPL plants produce in excess of 300,000 tons of flyash annually[8]. Though it has a higher ash-recycling rate than the norm, KCPL still is forced to landfill over 100,000 tons of flyash each year.

In addition to taking up space, landfilled flyash leaches heavy metals and other deleterious elements into groundwater, and is carried beyond the landfill, into the air, by wind.

### Orthodox Flyash Uses:

Today, flyash primarily is used in the concrete and heavy construction industries as a concrete additive, in paving and structural concrete, and as a soil stabilizer under building pads and for road building. In concrete use, Portland cement is still the primary cementitious material with flyash generally comprising as much as 25% of the cementitious materials in structural concrete applications.[9] Recent research has investigated the use of higher volumes of flyash (58%) in air-entrained lightweight concrete mixtures, and has confirmed that the resultant mixtures have adequate compressive strength at 28 days and excellent long-term strength properties and durability characteristics.[10] Even more recent research finds that a concrete mix of 100% flyash is capable of producing compressive strength resistance of 10,787 psi (normal ready-mix Portland cement concrete is approximately 3,000 psi).[11]

Use of flyash in lieu of cement has multiple benefits. It removes material from the waste stream, it replaces a product (Portland cement) that takes enormous energy inputs—along with concomitant $CO_2$ emissions—to produce.[12] Tests have shown that flyash used in conjunction with cement results in concrete with higher long-term strength (56-90 days) than in concrete without flyash.[13]

Though use of flyash as a low-volume admixture in orthodox concrete construction is fairly common, widespread acceptance in high-volume applications is yet to be achieved; similarly, flyash remains to be used as a cementitious binder in applications outside of the traditional structural concrete ready-mix establishment.[14]

### Obstacles to Expanded Flyash Use:

**Habit**: The heavy-construction industries are slow to change. They have survived by specializing in discrete disciplines, and profit by developing procedures that are repeatable from project to project. There is little incentive to innovate. At the design level, projects are defined by conservatively-written specifications, instituted by conservative clients.

**Seasonal Fluctuations**: Construction is a seasonal industry. Construction material usage intensifies in the summer months and wanes in mid-winter. Flyash, as an additive in (primarily) road-building and ready-mix applications is subject to the same demand curve. As stated above, KCPL currently is forced to dispose of approximately 100,000 tons a year, all during the winter months.

**Low Cost:** Though end-users do pay for it when they need it, the price ($10-$15/ton) will not justify the development of storage facilities to house it in the winter months. Thus, the flyash that doesn't find immediate use is landfilled.

**Geography and Transportation:** As a low-cost material it is not economically justifiable to ship it long distances. When flyash gets used, it tends to be used near to where it was produced. Additionally, the properties of the flyash are dependent on the coal it came from. So flyashes from different plants are going to differ to some degree.

### Opportunities for Expanded Flyash Use:

The obstacles listed above give a starting place for finding opportunities to expand flyash's use and keep it out of the waste stream.

**Habit**: Many industries welcome innovation: consumer-focused industries, for instance, thrive on innovation, and many businesses have a habit of continual innovation. Progressive businesses are continually seeking to expand product lines, and maximize production capacity. Portland cement is used for many factory-produced products: blocks, bricks, tiles, panels, pipes, etc. With slight modification and an appreciation of flyash's performance, the only obstacle preventing existing manufacturers from using flyash is a more fundamental knowledge of its properties vis-à-vis their needs.

**Seasonal Fluctuations:** The difficulties of seasonal use of flyash can be avoided by developing manufacturing processes for products using flyash that are housed under a roof or in a factory. The development of factory-produced goods with high volumes of flyash content would help alleviate the problem.

**Low Cost:** The problem of flyash's low cost can be addressed by developing products which have a higher end-value to consumers. A product—say a floor tile—which has a high relative cost (compared to soil stabilization), could be made of flyash, and priced competitively with ceramic tile.

**Geography and Transportation:** If the cost problem can be adjusted, it will be worthwhile to ship it to expanded markets beyond the customary shipping radius.

## Methodology/Timeline:

The project will proceed as follows:

**Phase I:** June 15, 2003 to July 15, 2003: I will conduct a literature search of the current "state of the art," consisting of published research reports, patents and patent applications, and technical articles concerning the use of fly-ash in high volume applications (a good bit of this has been collected already). Analysis will provide a sensible starting point for the second phase of work.

**Phase 2:** Academic Year 2003/2004: Based on the analysis of phase 1, we will make test samples of a matrix of mixes for a series of engineering tests, to understand how the various mixes perform in different conditions. These would include compressive strength, tensile strength, abrasion resistance, water retention, and porosity. Testing and analysis will reveal optimum mixes for different uses. (e.g. a floor tile would need to be optimized for abrasion resistance; a shingle for water resistance.) These data will be used for the development of future research proposals.

## Supplies:

Construction Materials: This project will be a hands-on materials research project. Funding is sought to purchase construction materials to build molds (lumber, steel, plywood, latex, plaster, resin), and for ingredients in the various mixes (portland cement, aggregates, admixtures). Mr. Brady Prior, of Fly Ash Management, Inc. in Topeka, Kansas, has offered me an unlimited supply of Class C flyash, Economizer Ash and Bottom Ash for use during this project.

## Personnel/Facilities:

Nils Gore (Project Investigator) is an Assistant Professor of Architecture at the University of Kansas. He is a registered architect, and received his professional education at Kansas State University (BArch.) and Harvard University (MArch.) Specializing in Materials Research and Construction Technology, he has successfully managed numerous funded research projects ranging from $2,227 to $87,000 while on the Architecture faculty at Mississippi State University. (CV Attached)

I am requesting hourly funding for an undergraduate assistant(s) to help me with this project. I plan to employ an architectural engineering student with experience using the testing equipment in Learned Hall, and with experience conducting rigorous experimentation. The School has a number of qualified applicants.

The workshop facilities of the School of Architecture at University of Kansas will be utilized during the project. Dr. Bob Parsons of the KU School of Engineering has offered the lab facilities in his department—at no cost—for the testing portion of the project.

**Future Research:**

Existing research has shown flyash to be a highly durable and useful material. This project will explore the potential of expanding the use of flyash in building materials manufacturing, and then will give others the opportunity to see it in a new light—outside of its traditional use. Our research will explore specific mixes which yield desirable samples for a variety of material properties. Future research would focus on development of prototype objects that would benefit from, say, durability: floor tile, table top, wall panel. Similarly, if we find an optimum mix that exhibits water-resistant properties, we will use that mix to look at the design of such products as roof shingles and siding.

**Potential Future Funding Sources:**

1. Product Realization & Environmental Manufacturing Innovative Systems (PREMISE), National Science Foundation, Division of Design, Manufacture, & Industrial Innovation. Website: http://www.eng.nsf.gov/dmii/

PREMISE is aimed at developing integrated research thrusts between manufacturing technologies and systems and design methodologies that are directed towards the reduction of energy use and adverse environmental impact in product realization. Appropriate planning activities can include establishing interdisciplinary teams, identifying specific research issues, and developing comprehensive research plans appropriate to the complexity of the research. Education, economics, environment, and energy considerations are all necessary components of the PREMISE topic area.

2. Concrete Materials (GSL-14), US Department of Defense, U.S. Army Corps of Engineers, Engineering Research & Development Center. Deadline: continuous. Website: http://www.mvk.usace.army.mil/contract/other.asp

Research areas for this program include: nature of and potential for reactions between aggregates and alkalies; signifi cance of and techniques for regulating aggregate moisture content; importance of aggregate shape and size distributions; and contribution to concrete durability. Optimizing the use of marginal natural aggregates, such as those with high clay contents of low structural integrity, also could be investigated, as could use of man-made aggregates such as recycled concrete and lightweight aggregates. Use in concrete of by-products of other industrial processes, such as fly ash, silica fume, and ground granulated blast-furnace slag, is increasing with knowledge of the potential benefits to concrete properties.

These uses contribute to solutions of industrial waste disposal problems while enhancing potential for development of new types of concrete with properties tailored to special uses. Knowledge of the mechanisms by which these materi als interact with cement, aggregates, and other concrete ingredients is essential. Effects of these materials on concrete strength and durability is another area of particular research interest as is the use of cementitious materials other than portland cement, including some fly ashes and slags. (Contact: Dr. Paul Mlakar, 601-634-3251)

3. Electric Power Research Institute (EPRI) Combustion By-Product Use Research Program.

Website: http://www.epri.com/destinations/dynamic/dilbert.asp

Objective: Develop new, moderate-to-high-volume uses for combustion by-products, primarily fly ash, with sufficiently high value to compete in the market, considering transportation costs, in order to reduce or avoid the need for land disposal. Protect current uses of by-products impacted by NOx or mercury controls.

(Footnotes)

[1] Source: Rustu S. Kalyoncu, United States Geological Survey data sheet, "Coal Combustion Products-1999."

[2] In the development of this proposal, I have searched extensively on the Internet, in the KU engineering library, and in numerous academic journals to find research precedents.

[3] "There is an understandable resistance to adopting a technology many still consider unproven in the field, with the perceived risk of delays or cost overruns. At present, materials standards and building codes do not prohibit the use of flyash in concrete, but current specification practices effectively discourage it." EcoSmart Concrete Project Interim Report, Greater Vancouver Regional District, July, 2001, p. 2.

[4] In the development of this proposal, I have searched extensively on the Internet, in the KU engineering library, and in numerous academic journals to find research precedents.

[5] EPRI website. Project # P78.003 "Outreach to Promote Use of Combustion By-Products."

[6] Source: Rustu S. Kalyoncu, United States Geological Survey data sheet, "Coal Combustion Products-1999."

[7] Scott Shell, EHDD Architects, http://www.buildinggreen.com/features/flyash/shell.html

[8] Telephone Interview, January 2002.

[9] ISG Technical Bulletin #4.

[10] Electrical Power Research Institute, Technical Report TR-107685, January 1997.

[11] Charles W. Hedley, et. al. US Patent Application Publication # US2001/0039902A1

[12] "Using coal fly ash conserves energy by reducing the demand for typical pavement materials such as lime, cement and crushed stone, which take energy to produce. Each ton of fly ash used to replace a ton of cement, for example, saves the equivalent of nearly one barrel of imported oil. Also less greenhouse gases are produced that would otherwise contribute to global warming." The Flyash Resource Center (http://www.geocities.com/CapeCanaveral/Launchpad/2095/flyash.html) also: "Cement manufacturing operations are responsible for approximately 8% of the global emissions of $CO_2$, a significant greenhouse gas…. $CO_2$ emissions are a direct function of cement production volume: for every ton of cement manufactured, roughly one ton of $CO_2$ is generated." EcoSmart Report, p.1.

[13] ISG Technical Bulletin #3.

[14] "There is an understandable resistance to adopting a technology many still consider unproven in the field, with the perceived risk of delays or cost overruns. At present, materials standards and building codes do not prohibit the use of flyash