



## Case Study 21

# High-Volume Use of High-Carbon Fly Ash for Highway Construction

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Sponsored by the U.S. Department of Energy (DOE) and in cooperation with the Minnesota Department of Transportation (Mn/DOT), a team consisting of Washington State University, University of Wisconsin at Madison, and Bloom Companies, LLC tested the real-world use of high-carbon fly ash in stabilized road base course. This application has the potential to be a high-volume use for a material that would otherwise be landfilled or used for a lower-value application. Compared to untreated-RPM (reclaimed pavement materials), carbon-fly-ash-treated RPM has lower energy consumption, fewer greenhouse gas emissions, and greater durability in rainstorms. This new application could benefit both coal and road developers.

### What is happening to fly ash?

Many power plants in the United States are eagerly looking for ways of utilizing their fly ash to avoid landfilling. Each year, over 900 million tons of coal are used for electricity generation in the United States. The combustion of coal, however, produces a large volume of byproducts, including fly ash, flue gas desulfurization (FGD), and bottom ash. According to American Coal Ash Association (ACAA) surveys, in 2006 about 72 million tons of fly ash were produced. Due to the increasingly stringent environmental policies of the U.S. Environmental Protection Agency (EPA) and/or local and state authorities, the power generation industry must take measures to reduce the emission of nitrogen oxides ( $\text{NO}_x$ ), sulfur oxides ( $\text{SO}_x$ ), and mercury (Hg). Low- $\text{NO}_x$  burners reduce  $\text{NO}_x$  emissions by changing the combustion characteristics of coal boilers, but they increase the amount of residual unburned carbon in ash. Additionally, activated carbon is injected to reduce mercury emissions, which also increase the carbon level in fly ash. In 2006, 40 million tons of fly ash were placed in landfills, resulting in significant tipping fees and energy use, and potential environmental issues. Increased carbon levels make air-entrained concrete production more difficult when fly ash is used as a cement replacement. For affected power plants, these issues could transform ash from a revenue-generating commodity to the third-greatest operating cost (behind fuel and labor). The issues could also take commercial products away from those who rely on low-carbon fly ash (Class C or Class F fly ash), including ash marketers, concrete producers, cement manufacturers, and construction contractors. Consumption of fly ash, especially off-spec fly ash (e.g. high-carbon fly ash), will greatly relieve the pressure on the power industry by beneficially utilizing the fly ash.

### Solution to high-volume high-carbon fly ash utilization

In general, within-spec fly ashes are classified as Class C or Class F fly ash. Combustion of bituminous or anthracite coal produces Class F (low calcium) fly ash and combustion of lignite or sub-bituminous coal produces Class C (high calcium) fly ash. Class F fly ash is pozzolanic while Class C fly ash is both self-cementitious and pozzolanic. The upper limit of loss on ignition (LOI) for both Class C and F fly ash, mostly due to carbon, is 6% and 5% according to the ASTM C-618 and AASHTO M295 standards, respectively.

Richard Meininger, a highway research engineer at the Federal Highway Administration, explained the types of fly ash and the problems associated with high-carbon ash: "Currently, most specification fly ash can be used as a supplementary cementitious material (SCM) in concrete to improve durability and economy as well as to meet environmental goals," he said. "Cementitious high-calcium, high-carbon fly ashes can have self-hardening properties in the presence of moisture, like some Class C fly ashes. However, the high carbon content often eliminates it from being used, because the carbon in fly ash absorbs air-entraining admixture in freshly-mixed concrete, making it very difficult to control entrained air. We need to find ways to use these non-specification fly ashes, such as high-carbon fly ash, for highway construction. Fly ash is an already heat-treated cementitious material that needs to be used in a beneficial way—environmentally and economically."



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Unlike concrete, which needs air-entrainment (generally 6% air by volume), extra voids are not desirable in a base course under an asphalt pavement. A base course with maximum density and minimal void content will last longer than a loose base course. Therefore, the high-carbon content in fly ash presumably will not affect the performance of a base course. At the same time, the cementitious properties of high-calcium high-carbon fly ash will produce a stronger base course to support loads, compared to untreated base course. Stabilization of pulverized cold in-place recycled asphalt pavement materials with cementitious high-carbon fly ash will create a strong base course, which improves the long term performance of asphalt pavement and beneficially utilizes the high-carbon fly ash, which would otherwise be landfilled.

### Construction Demonstration

“While there are many potential benefits of using fly ash stabilization, some questions still remain. The most important question is whether or not the fly ash used in the base course has any harmful effects on the environment,” says Tim Clyne, a Mn/DOT engineer. “Another question that pavement designers are trying to answer is what is the actual stiffness or strength of the stabilized layer. They will then be able to use more accurate values in future pavement designs and compare it to that of more traditional base materials.”

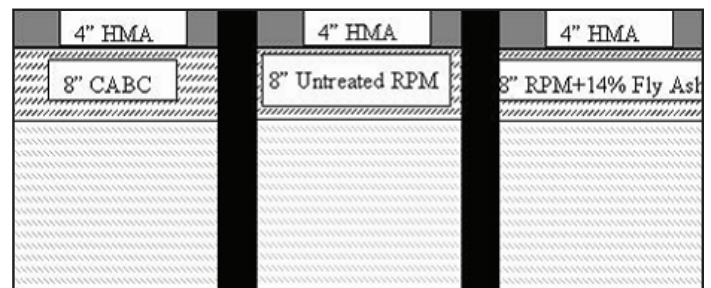
The U.S. Department of Energy sponsored a study to build test sections at the Minnesota Road Research Project (MnROAD) accelerated testing facility, which is Mn/DOT’s cold weather road research facility. To expedite the performance evaluation, three test sections were built at the MnROAD test road. MnROAD provides an exceptional opportunity to evaluate this new material and technology under real-world conditions in a timely fashion. MnROAD is 3.5 miles long and is divided into numerous test sections, which represent varying combinations of road-building materials and designs. Each section is about 500 feet long. The three sections used for this test

consisted of identical asphalt surface, subbase, and subgrade layers, with three different base course materials: conventional crushed aggregates, full depth reclaimed pavement materials (RPM), and fly ash stabilized RPM materials. A single heavily loaded truck continuously drives on the sections, providing a direct comparison of the performance between the sections. MnROAD is equipped with a great number of sensors in the pavement to detect traffic volume, stress and strain under loading, moisture, and temperature. The real-time data are collected by a computer and stored on a server for subsequent analysis.

Fly ash obtained from Unit 8 of the Riverside Power Plant in Minneapolis, MN (operated by Xcel Energy) was used to stabilize the RPM. This fly ash has a calcium oxide (CaO) content of 22.37% and a carbon content of 16.35%. Riverside Unit 8 fly ash is a cementitious high-carbon fly ash. It is considered a non-



Aerial Photo of MnROAD Site (Courtesy of Mn/DOT)



Pavement Structures of Test Sections at MnROAD





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compliant material by the Minnesota Pollution Control Agency and a special permit was applied for this construction demonstration project.

Xcel Energy was an eager partner in the test project. “Xcel Energy is excited about this demonstration project,” says Mike Thomes, the Combustion Products Coordinator of Xcel Energy. “We have plenty of anecdotal information indicating that, when responsibly used in soil stabilization applications, these relatively high-carbon fly ashes will provide good geotechnical and environmental performance. But this project provides an excellent opportunity to express that performance in rigorous engineering terms -- which should expand confidence and value in this use of fly ash.”

By October 30, 2007, construction of the experimental road sections was completed. The fall of 2007 saw tremendous rainfalls in Minnesota. The precipitation infiltrated into the base courses. The untreated-RPM and crushed-aggregate sections were too wet for the construction equipments and trucks to drive on them in order to lay down the asphalt surface paving. However, the fly-ash-treated RPM base was not affected by the precipitation and was paved with asphalt successfully. For the other two sections, the wet base materials never dried and eventually had to be removed. Wet subgrade soils were also removed. The new subgrade and bases were replaced and paved with asphalt. The asphalt layers were compacted using an intelligent compactor which can indicate to the driver of compactor if the compaction is sufficient.

“The construction process itself went quite smoothly,” says Tim Clyne. “A vibratory padfoot roller is necessary for compaction, and the motor grader needs to be on top of things to get the material bladed quickly. MnROAD experienced an extraordinary amount of rain over the summer, and the fly ash stabilized section was able to support the hot mix trucks during paving operations while the non-stabilized sections were not.”

### Environmental monitoring

The fly ash used for construction contains small amounts of mercury and other heavy metals. Lysimeters were constructed to collect and monitor leachate generated by water percolating through the pavement. The leachate water in the storage tanks was sampled and the amount of leaching water was recorded. As of June 2008, these lab results were being compared to field test results.



*Fly Ash Stabilization: before mixing with RPM (right of Caterpillar) and after mixing (Behind the Caterpillar)*



*Robert Patton of U.S. DOE (left) and Jonathon O'Donnell, a graduate student at University of Wisconsin at Madison, sample leachate on site.*



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### Comparison of Initial Construction Costs, Energy Consumption, and Greenhouse Gas Emissions

Upon the completion of construction, the initial construction costs were available for comparison between different technologies. As shown in Figure 1, crushed aggregate has the highest total construction costs. Some of the costs for crushed aggregate and untreated RPM are associated with the second base work, due to the rainfall during the construction. At the end, the fly-ash-treated RPM base course had the lowest construction costs.

The initial energy consumption and greenhouse gas emissions were also compared. Again, the high-carbon-fly-ash-treated RPM has the lowest energy consumption and greenhouse gas emissions, as shown in Figure 2 and Figure 3. However, it should be noted that these comparisons are based on initial construction data. Life-cycle costs, energy consumption, and greenhouse gas emissions would be needed for a full comparison, as the pavement performance affects maintenance and rehabilitation activities.

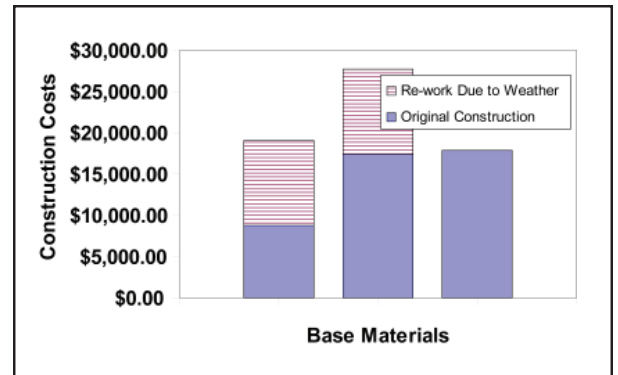


Figure 1: Comparison of Initial Construction Costs

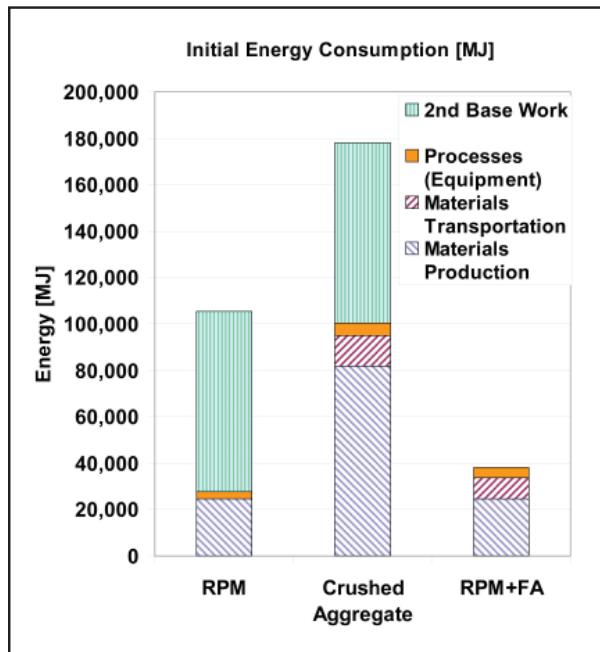


Figure 2: Comparison of Initial Energy Consumption

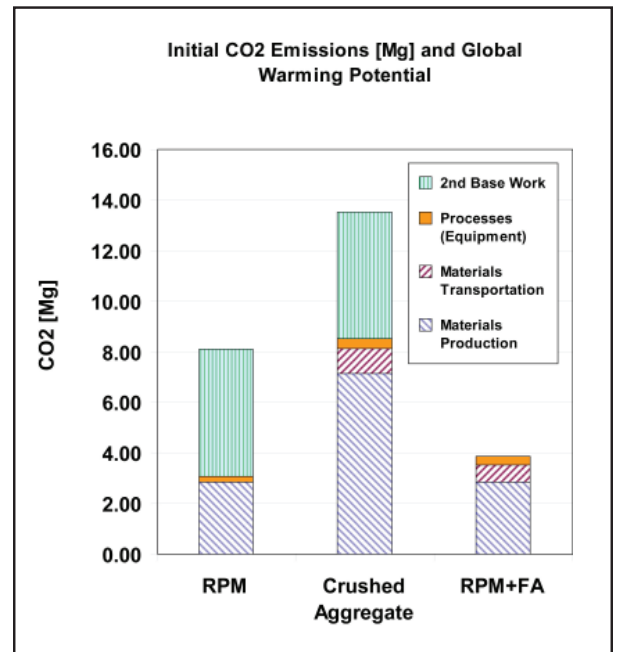


Figure 3: Comparison of Initial Greenhouse Gas Emission



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