Continued Performance and Economic Issues for the Polk County Minnesota
Bituminous County Road Constructed with Municipal Solid Waste Combustor Ash

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Abstract
This paper is a follow up to previous installments presenting environmental, construction, performance and economic issues associated with Polk County CSAH 13. The CSAH 13 project was a demonstration of the use of municipal waste combustor (MWC) ash in bituminous. New structural and cost data is presented.

The incorporation of MWC ash into bituminous pavements has been investigated in the United States since the middle 1970s. Thus far, most, if not all of these projects, have attempted to answer the questions: Is it safe? Is it feasible? Or does it provide an acceptable product? The presented project answers these questions on a new level.

MWC ash amended bituminous was used to construct a portion of 2.25 miles of road in Northwest Minnesota. Significant environmental and structural testing was performed prior to, during and after construction.

Environmental testing on this project has shown that the use of MWC ash in bituminous pavement, as performed, is safe. In addition, economic analysis shows important financial advantages by using ash-amended bituminous. Structural testing showed a 36% increase in stability, 19% increase in flow and a 17% increase in spring season axle load capacity. Improvement in resistance to freeze-thaw cracking was also shown.

1.0 Introduction
The Polk County Solid Waste Department, located in Polk County Minnesota, participates in a complete integrated solid waste management program that includes four other counties in northwest Minnesota. One component of the integrated solid waste management program includes the operation of a municipal waste combustor (MWC) that combusts approximately 65 tons per day of processed solid waste. The starved air design of the combustor causes low turbulence in the primary burning chamber minimizing particulate carryover through the system. This results in generation of approximately 12 tons per day of combined ash comprised of 98 to 99 percent bottom ash and 1 to 2 percent fly ash, by weight.

In 1996 the facility installed an up-front separation facility, or materials recovery facility (MRF), that removes recyclable materials as well as non-processible or objectionable materials prior to combustion. The ash generated by combustion prior to the 1996 installation of the MRF is referred to as "old ash" and was landfilled in a lined MWC ash monofill permitted by the Minnesota Pollution Control Agency (MPCA). The ash generated since installation of the MRF is referred to as "new ash", and is also placed in the permitted landfill. The chemical and physical differences between the new and old ash are important enough to warrant the two ashes being addressed separately for purposes of this utilization demonstration project.

In 2000 and 2001, Polk County performed a demonstration of the feasibility of utilizing combined MWC ash as a partial replacement of aggregate in bituminous paving materials. The project consisted of building and evaluating a section of county road using the MWC ash-amended bituminous.
The results of that demonstration were published at NAWTEC8 in 2000i, NAWTEC9ii and A&WMA in 2001iii, and at NAWTEC10 in 200iv. This paper presents the updates to performance and economics issues associated with this demonstration. In order to minimize the redundancy with the previous papers on this project, direct references and summaries will be used when appropriate.

2.0 Background

Significant up-front environmental evaluations were performed as part of this demonstration as previously presented by Lucido and Wilson at NAWTEC9v. These comprehensive evaluations resulted in the only outstanding environmental issue being stack emissions from the asphalt plant. Since this continued project has not yet provided a solution to asphalt plant stack emissions, this will be a topic for further discussion in this paper.

The project was approved by the MPCA and supported by the Minnesota Resource Recovery Association, the Association of Minnesota Counties, the Minnesota Office of Environmental Assistance, the Minnesota State Representative for District 1B (previously 2A), the four partner counties adjacent to Polk County, the Polk County Board, the Polk County Highway Department, and the citizens of Polk County.

NATIONAL

In 2002, there were 98 MWCs in operation in the United States, serving the disposal needs of more than 2.26 million homes. These facilities generated about 2500 MW of electricity from the combustion of 29 million tons of MSW. In the process, nearly 7 million tons of ash was produced. Most was used as landfill daily cover, as roadbed, or was disposed of in landfillsvi. Enabling the beneficial use of ash will assure the continued operation of MWCs, promote landfill abatement and decrease the use of more valuable resources such as natural aggregates.

The ash from MWCs is an excellent resource material that has proved to be of particular benefit in the construction of roads and highways. Field tests and demonstration projects show that processed ash can be successfully used in road base, bituminous paving, and concrete products. Substituting ash for rock aggregate in bituminous pavement, also called asphalt concrete, has proven to be a straightforward procedure in many field demonstrations. The literature describes many demonstrations of the use of MWC ash. A comprehensive resource document, Beneficial Use and Recycling of Municipal Waste Combustion Residuesvii, identifies and describes many of the uses of MWC ash. Environmental testing in this project, as well as many other demonstrations around the United States, has shown that the use of MWC ash in pavement construction can be safe.

WORLDWIDE

The United States boasts some success stories in ash utilization, but the European countries have led the way in the successful practice of using the benefits of ash in roadways. Germany uses 60 percent of WTE bottom ash as material for road paving and similar projects.viii The Netherlands uses more than 90 percent of the bottom ash in road base and road embankmentsix. In 1994, France put about 45 percent of its bottom ash to beneficial use in civil engineering projects.x

POLK COUNTY, MINNESOTA

The topic of this paper is a section of County State Aid Highway (CSAH) 13 located in near Crookston Minnesota (see Figure 1). The Polk County Highway Department constructed a 2.25-mile section of road in the fall of 2000 and spring of 2001. The road was constructed with a 5.2-inch thick bituminous base course 25 feet wide, overlain by a 2-inch thick bituminous binder course 24 feet wide, overlain by a 1.5-inch thick bituminous wear course 24 feet wide.

For this demonstration project, ash-amended bituminous was incorporated into the bituminous base course and the bituminous binder course. As a conservative measure, no ash was placed in the wear course. The 2.25-mile road section was constructed as follows:

- 0.75 miles with no ash as a control section.
- 0.75 miles, replacing 10 percent of the aggregate with old ash in the bituminous base and binder courses for a total of 416 tons of new ash in 4,000 tons of bituminous.
0.75 miles, replacing 10 percent of the aggregate with new ash in the bituminous base and binder courses for a total of 463 tons of old ash in 4,000 tons of bituminous.

In addition, about 8 tons of new ash was utilized in bituminous pavement at the Polk County Landfill. This was intended to assess the health effects of recycling the bituminous. A 10-percent replacement was used.

Standard bituminous production, placement equipment, and procedures were used.

The old ash and new ash have sufficiently distinct characteristics so that Polk County evaluated the two ashes independently. In addition, the bituminous material produced utilized old ash and new ash independently. The old ash was mined from previously landfilled areas, thus freeing up landfill space for future use, while the new ash was from current generation. Independent evaluation of the two ash types makes the demonstration project results applicable to a wider range of combustors within and outside the State of Minnesota.

The ashes used in the bituminous were combined ash (1-2% fly ash and 98-99% bottom ash). Combined ash provided the appropriate particle size gradation to meet the MnDOT mix design once the ash was screened to remove oversized (0.75") and deleterious materials. This removal of 0.75" material had the effect of slightly decreasing the ratio of bottom ash to fly ash. Therefore, the percentage of fly ash was slightly more than 1-2% and the percentage of bottom ash was slightly less than 98-99%.

Initial trial mix designs showed that 40% old ash and 20% new ash could be used for replacement of aggregate in bituminous. However, in order to maintain the most efficient bituminous plant operation, it was necessary to reduce the percentage of ash to 10 percent of each old and new. The replacement rate of 10 percent for each ash was used throughout the project.

Bituminous production and placement issues were previously detailed by Lucido and Wilson.\textsuperscript{11}
3.0 Previous Issues and Results

Significant issues and results from the demonstration are summarized in this section.

ENVIRONMENTAL
As previously stated the only outstanding environmental issue is stack emissions from the asphalt plant. Environmental issues that were addressed are summarized in Table 1.

STRUCTURAL
Structural issues were detailed by Lucido and Wilson and are summarized as follows. Bituminous trial mix designs were prepared with natural aggregate and with old and new ash. The relevant results are summarized in Table 2. As shown, the Marshall stability of the bituminous mix without ash was about 1,771 pounds. The stability of the bituminous with 10 percent old or new ash was about 2,400 pounds, which represents a 36 percent increase in stability. Stability is a measure of the amount of force required to "break" a compacted sample of the bituminous.

Also as shown in Table 2, the use of ash had an impact on bituminous flow. Flow is a measure of the amount of deformation, or flex, the bituminous sample will undergo before it breaks in the stability test. Flow is measured in hundredths of an inch.

A significant increase in stability often raises a concern with increased "brittleness". However, the ash-amended bituminous not only had an increase in stability, but it also had a 19 percent increase in flow. The lab flow for the bituminous without ash was 0.070 inches, while the lab flow for the bituminous with new or old ash was about 0.083 inches.

The last column in Table 2 shows the mix design requirement for asphaltic cement or AC. As shown, the AC for the bituminous without ash was 5.0 percent while the use of ash required an additional 1.1 percent AC. The MnDOT lab supervisor suggested that the higher porosity of ash particles resulted in an increased surface absorbency. This more absorbent surface required more AC. However, it is reasonable to expect that the more absorbent particles and higher AC resulted in greater adhesion between the particles. This increased adhesion probably improved stability, while the increased AC content increased flow.

Other Structural Considerations
Due to construction schedules, the production and placement of bituminous did not begin until late in the fall of 2000. This late start resulted in only one 2-inch lift of unamended bituminous, one 2-inch lift of old-ash-amended bituminous and a partial lift of new-ash-amended bituminous being placed prior to the winter end-of-construction. The subsequent lifts and construction completion occurred in the spring of 2001. However, this unintended timing provided some very valuable information. After the winter of 2000/2001 and immediately prior to the resumption of bituminous placement, the previously placed lift of bituminous was inspected.

During that inspection, pronounced cold-temperature-transverse-cracking observed in the unamended and old-ash-amended bituminous sections. However, it was also observed that there was a significant disparity in the relative number of cracks in each section. The 0.75-mile section of unamended bituminous had 50 full-width transverse cracks, while the 0.75-mile section of old-ash-amended bituminous had only 6 full-width transverse cracks. With only one lift in place prior to the 2000/2001 winter, the thin layer of bituminous was highly susceptible to cold-temperature-cracking. This high susceptibility may have allowed accelerated evidence of the resistance of the bituminous to this cracking mechanism. The combination of increased stability and flow with the incorporation of ash and additional AC may provide for the increased resistance to cold-temperature cracking.
Table 1: Polk County MWC Ash in Bituminous Environmental Testing

<table>
<thead>
<tr>
<th>Lab Evaluations Prior to Construction</th>
<th>Standards Used</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recoverable metals in ash and amended bituminous</td>
<td>MPCA Soil Reference Values (SRVs), EPA Preliminary Remediation Goals (PRGs), unamended bituminous</td>
<td>All relevant standards were met.</td>
</tr>
<tr>
<td>Leachable metals in amended bituminous</td>
<td>Minnesota Department of Health HRLs, EPA MCLs, unamended bituminous</td>
<td>All relevant standards were met.</td>
</tr>
<tr>
<td>2,3,7,8 TCDD in ash and amended bituminous</td>
<td>MPCA Industrial SRVs</td>
<td>All relevant standards were met.</td>
</tr>
<tr>
<td>Longterm cumulative effects</td>
<td>MPCA Industrial Scenario Risk Evaluation (1999 version)</td>
<td>All relevant standards were met.</td>
</tr>
</tbody>
</table>

**Evaluations During and Post Construction**

<table>
<thead>
<tr>
<th>Test Performed</th>
<th>Standards Used</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pavement infiltration water</td>
<td>Minnesota Department of Health HRLs, EPA MCLs, un unamended bituminous</td>
<td>No infiltration observed after more than 1 year.</td>
</tr>
<tr>
<td>Surface water from amended bituminous</td>
<td>Minnesota Department of Health HRLs, EPA MCLs, unamended bituminous</td>
<td>All relevant standards were met.</td>
</tr>
<tr>
<td>Metals in adjacent soil</td>
<td>Unamended bituminous</td>
<td>All relevant standards were met.</td>
</tr>
<tr>
<td>Operator breathing space for:</td>
<td>OSHA Permissible Exposure Limits, American Conference of Governmental Industrial Hygienists (ACGIH Threshold Limit Values (TLVs), Minnesota Department of Health/MPCA Health Risk Values (HRVs)</td>
<td>All relevant standards were met.</td>
</tr>
<tr>
<td>Total particulate, 2,3,7,8 TCDD, Asphalt fume</td>
<td>MPCA stack testing rules MR 7017.2001 – 7017.2060, EPA Methods 1, 2, 3B, 4, 5, 9, 29.</td>
<td>Particulate emissions and concentrations were higher for the ash amended products. This was expected because of the dusty nature of the ash. However, higher opacities were not observed while producing ash-amended*.</td>
</tr>
</tbody>
</table>

* It should be noted that, in this demonstration, the particulate emissions with and without ash would have exceeded the federal Standards of Performance for Hot Mix Asphalt Facilities.

Table 2: Summary of Trial Mix Design Results

<table>
<thead>
<tr>
<th></th>
<th>Lab stability (lbs.)</th>
<th>Lab flow (in.)</th>
<th>AC (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No ash</td>
<td>1,771</td>
<td>0.070</td>
<td>5.0</td>
</tr>
<tr>
<td>New ash</td>
<td>2,439</td>
<td>0.081</td>
<td>6.1</td>
</tr>
<tr>
<td>Old ash</td>
<td>2,397</td>
<td>0.085</td>
<td>6.1</td>
</tr>
</tbody>
</table>

**PRODUCTION**

Bituminous plant production issues were detailed by Lucido and Wilson. The average production rates were 251 tons per hour (TPH) for new-ash-amended bituminous, 254 TPH for old-ash-amended bituminous, and 229 TPH for unamended bituminous. This data by itself indicates that the use of ash did not lower production rate. However, information provided by the operator suggests that, under ideal conditions, the use of ash would have reduced...
production. The rate of bituminous production is an important factor in the economics of a project. Therefore, the impacts of ash utilization on production rate must be carefully evaluated.

ECONOMICS
Economic issues are obviously a critical component in the consideration to utilize MWC ash in bituminous. If a potential user does not realize a financial benefit, there is not much incentive to use the ash. Components that must be considered in the financial equation include:

- The avoidance of ash landfilling or disposal costs,
- The costs to utilize the ash,
- Avoidance of use of traditional bituminous components, as well as
- Implications on pavement performance.

The costs associated with the above components were detailed by Lucido and Wilson, and are summarized below.

Landfilling or Disposal Costs
Disposal cost savings from the use of ash were estimated at $2.25 per ton of bituminous produced.

Costs of Utilization
The costs for utilization of MWC ash is less clearly defined than landfilling costs since utilization has a less established history in the United States. Based on the Polk County demonstration, several cost factors were identified. These factors were previously detailed and are summarized below.

Dewatering, Screening and Drying
Polk County staff dewatered the ash by mechanically working the pile at the landfill. This cost was estimated at $0.22 per ton of ash-amended bituminous produced. Additional costs were incurred for screening.

Hauling
Hauling was estimated at $1.00 per ton of ash-amended bituminous.

Asphaltic Cement
As previously identified, the use of ash required an additional 1.1 percent asphaltic cement, or AC. This resulted in an increase of about $1.60 per ton of bituminous.

Fuel
The fuel used to run the burner for drying and heating the aggregate, ash and AC was used motor oil. Production data maintained during the air emissions stack testing showed a fuel usage of 0.35 gallons more fuel per ton of ash-amended bituminous. This resulted in an average cost of $0.23 more for fuel to produce a ton of ash-amended bituminous.

Environmental Protection
The results of environmental evaluations performed in this demonstration indicate that very little environmental protection should be needed for future projects that are performed under similar conditions. The one environmental cost that may be needed is for replacement of baghouse bags in the plant air pollution control system. For a 10 percent ash replacement, we estimated a potential bag replacement cost of $0.61 per ton of bituminous.

Reduced Bituminous Production
An important cost implication to consider is the impact of the use of ash on the rate of bituminous production. Modifications to the 2000/2001 process should be pursued to reduce the baghouse fouling rate and improve production. These efforts should be able to reduce this cost by at least 50 percent to a cost of less than $4.16 per ton.

Longterm Performance
The longterm performance of ash-amended bituminous must be considered as part of an economics evaluation. Information cited by Wiles indicated that the bituminous pavements are safe and long lasting. Data from the Polk County project suggested that ash-amended bituminous may be more durable and long lasting than unamended bituminous. Potential cost savings due to improved longterm performance were estimated at $2.25 per ton of bituminous. Longterm performance implications are further discussed in the Updates and Discussion Sections of this paper.
Avoidance of Use of Traditional Aggregate
By using MWC ash, less traditional aggregate is needed. In some parts of Minnesota, natural aggregates are in increasingly short supply. Assuming an aggregate cost of $3.00 per ton, a 10 percent savings would be $0.30 per ton of bituminous. Reducing the rate of depletion of this resource is an important consideration. The use of MWC ash does not require any damage to the environment, while excavation of natural aggregates does cause environmental damage and necessitates repair.

Implications of Bituminous Performance
As previously described, it appears that the ash-amended bituminous may demonstrate higher stability and flow characteristics. These characteristics were not originally intended as performance enhancements in this project, since the unamended bituminous met the required specifications. However, such characteristics have the potential for increased bituminous performance. In addition, the appearance of improved freeze/thaw crack resistance has important implications for increased bituminous performance. This will be further discussed in the Updates and Discussion Sections of this paper.

Total Additional Cost
The previously identified and estimated component costs result in a total additional cost of about $3 per ton of ash-amended bituminous. This additional cost is an issue that needs to be addressed and clarified. Cost is further addressed in the Discussion Section of this paper.

4.0 Updates
Updates to the Polk County project are provided in this Section. These updates include:
- Post-construction structural testing.
- Additional Polk County projects

POST-CONSTRUCTION STRUCTURAL TESTING
In the summer of 2002, the Polk County Highway Department performed falling weight deflectometer (FWD) testing on the CSAH 13 sections. The FWD testing was performed to provide a measurement of the Spring Season Axle-Load (SSAL) capacity of the roadway. The SSAL was evaluated to be 15.9 tons on the road section that was not amended with ash, 18.6 tons on the road section that was amended with 10 percent old ash, and 18.5 tons on the road section that was amended with 10 percent new ash. Since the posted road restriction is 9 tons, the SSALs well exceeded the requirement. However, the sections that were amended with ash were 16% stronger than the sections without ash. The potential ramifications of this evaluation are discussed in the Discussion Section of this paper.

ADDITIONAL POLK COUNTY PROJECTS
As identified in this paper and in previous installments, important factors that are in need of additional investigation include:
- Bituminous plant production rate,
- Bituminous plant stack emissions,

In addition, in the 2000/2001 demonstration, a section of ash-amended bituminous was installed at the Polk County landfill. The objective of this installation was to evaluate the effects of recycling the ash-amended material.

Polk County intends to perform another demonstration in 2003 and/or 2004 to address these outstanding issues. If a project is performed in 2003 it will be at the entrance road to the Polk County. A project in 2004 would be jointly performed with the Polk County Highway Department on CSAH 44, which is a gravel road leading from a state highway to the entrance of the landfill.

A 2003 and/or 2004 project would consider modifications to the 2000/2001 procedures in the hopes of improving both production rate and stack emissions. The modifications considered are the pre-screening of ash to remove the smaller particles, pre-drying the ash and a change in the location of injection of the ash into the bituminous plant drum drier. The modifications should reduce the amount of fine particles that are carried into the plant's air pollution control (APC) equipment. This should improve production rate and reduce stack emissions.

In the 2000/2001 project, the ash was introduced at the beginning of the bituminous plant drum drier along with the other aggregates. It is suspected that this may have resulted in the ash being partially pulverized by the other harder aggregate. In the 2003/2004 projects the ash may be introduced from the recycled asphalt (RAP) bin, as shown in Figure 2. This would reduce the amount of time that the ash is tumbled with the
other aggregates, thus reducing the pulverizing effect. It would also introduce the ash much closer to the point of AC injection. This would coat the ash particles with AC early on and minimize the carryover into the APC equipment. However, in order to introduce the ash from the RAP bin the ash may have to be pre-dried.

5.0 Discussion and Recommendations

Environmental Issues
Upon resolution of stack emission issues, the environmental impacts of the project will have been addressed. We anticipate that stack emissions can be addressed by pre-qualifying the plant APC equipment, modifying the ash injection location, and/or pre-screening the ash.

Cost and Performance Issues
The original quoted cost of bituminous for this project was $22.50 per ton. The potential adjustments to the components of this cost were identified in Section 3.0. Several of these components need to be better identified and clarified. Ways to improve the cost of ash-amended bituminous are discussed here.

Individual component costs for ash screening and dewatering and drying, hauling, AC and heating fuel do not seem to be subject to significant changes. Additional effort put into ash dewatering and drying could result in cost savings in fuel. However, this may be a trade off. Something as simple as tarping the ash and aggregate piles to prevent impacts from precipitation may reduce the heating fuel requirement. While additional cost for AC was identified, this additional AC may be responsible for structural improvements, which are discussed below.

Significant cost components that should be addressed include: environmental protection, bituminous production rate and bituminous performance. The only cost identified for environmental protection was $0.61 per ton of bituminous for baghouse bag replacement. If the dust generation can be reduced by ash pre-screening, and/or modifying the ash injection point, this cost may be eliminated. These same efforts could also improve the plant production rate. This could have a dramatic impact on the $4.16 per ton associated with this component.

Cost implications associated with bituminous performance may be significant. Performance variables such as cold-temperature crack resistance and load bearing capacity, as measured by FWD testing, may provide pavements that are more durable and stronger. This could result in less frequent repair or replacement of pavements. In Section 3.0 of this paper it was identified that a 10 percent improvement in pavement life could result in a cost savings of $2.25 per ton of bituminous. The actual improvement in pavement life has yet to be identified.

In Section 4.0 it was identified that FWD testing showed a 16 percent improvement in pavement strength. This could translate to either an additional improvement in pavement life or it could indicate that the pavement thickness may be reduced while achieving the required performance. The opportunity to reduce the thickness of the class 5 base and/or bituminous thickness could save significant material costs. If the bituminous requirement was reduced by 16% this would save $3.60 per ton (at $22.50 per ton).

The potential cost savings identified above will result in a bituminous that is cheaper, stronger and more durable than that produced without ash.

Recommendations
Concluding recommendations of this paper are as follows:

- Methods to address production rate and plant stack emissions should be investigated. Some of these potential methods were described in Section 4.0.
- Better measurements of cost implications should be developed. This would include lifecycle cost of ash-amended versus unamended bituminous.
- Performance impacts should be further quantified.
- Future demonstrations should investigate the potential to increase the replacement rate of ash in bituminous.
- The impacts of ash amendment on the recyclability of bituminous should be investigated.

All of these recommendations will be implemented in future Polk County demonstration projects.
References


v Lucido and Wilson (NAWTEC9)


xi Lucido and Wilson (NAWTEC10)

xii Ibid

xiii Ibid

xiv Ibid

xv Wiles, 1999
Figure 2: Typical Hot Mix Asphalt Plant Parallel Flow Drum Mix