Coventry University and
The University of Wisconsin Milwaukee Centre for By-products Utilization,
Second International Conference on Sustainable Construction Materials and Technologies
June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.
Special Technical Proceedings ed. P Claisse, E Ganjian, F Canpolat and T Naik
ISBN 978-1-4507-1488-4 http://www.claisse.info/Proceedings.htm

Green Benefits of Using Coal Ashes in Pavement Construction

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ABSTRACT

Quantifying the benefits of using green materials is a key factor influencing growth in green-construction of public infrastructure. This paper quantifies benefits of using coal ash in road construction using life cycle assessment techniques. Energy and water consumption and CO_2 emissions are evaluated in a quantitative framework and the benefits are expressed as financial savings. The combined benefits obtained using coal ashes annually is equivalent to the energy consumed by 8,650 homes, the water used by 2,800 persons, the CO_2 equivalent associated with 11,200 automobiles, and cost savings equivalent to the annual salary of 610 average Americans realized with the modest use of coal ashes in pavement construction that occurs today. The methodology presented can be extended to other beneficial use applications of coal combustion products (CCPs) to get a more complete picture of overall savings. With more widespread use of CCPs, much greater savings could be achieved.

INTRODUCTION

Coal burning accounted for 42% of all US fossil fuel consumed for energy production in 2007 and is expected to play a bigger role in the future [EIA 2009]. Consequently, greater volumes of coal combustion products (CCPs) will be produced and available for beneficial use. According to the 2007 Survey Report of the American Coal Ash Association [ACAA 2008], 114 million Mg of CCPs were produced in the United States, the majority being fly ash (64.5 million Mg) and bottom ash (16.4 million Mg). Approximately 44% (35 million Mg) of fly ash and bottom ash is used beneficially, whereas the remaining 56% (45.7 million Mg) is disposed in impoundments or landfills.

Road construction accounts for only 3% of beneficial use of CCPs. The study described in this paper was conducted to quantify the environmental and economic benefits of using CCPs to encourage greater use of CCPs in road construction.

METHODOLOGIES AND PROCEDURE

The environmental and economic benefits of CCPs use in road construction were quantified by evaluating the differences in energy expenditure, water consumption, and global warming potential associated with virgin material and CCPs (fly ash or bottom ash) in road construction. The economic benefits were calculated based on the monetary value of the environmental benefits. Unit impacts, i.e., the environmental impacts per Mg of CCP used in construction per year, were modeled independently using the life cycle assessment (LCA) program *PaLATE* [RMRC 2004]. *PaLATE* is a spreadsheet program designed to carry out LCAs for road construction. A variety of recycled material uses can be simulated in *PaLATE*, e.g., coal ashes, foundry sand, etc. Global warming potential and energy use are the key outputs of the program.

In road construction applications, the *PaLATE* model considers consumption of energy and water and emission of greenhouse gases associated with material transportation and placement as well as mining/processing of conventional aggregates. Unit impacts for energy, water, and greenhouse gases were multiplied by the most recent CCP beneficial consumption (in Mg) provided by ACAA [2008] to quantify the annual benefits and savings obtained by using CCPs for pavement construction. A flow chart showing the procedure is presented in Figure 1.

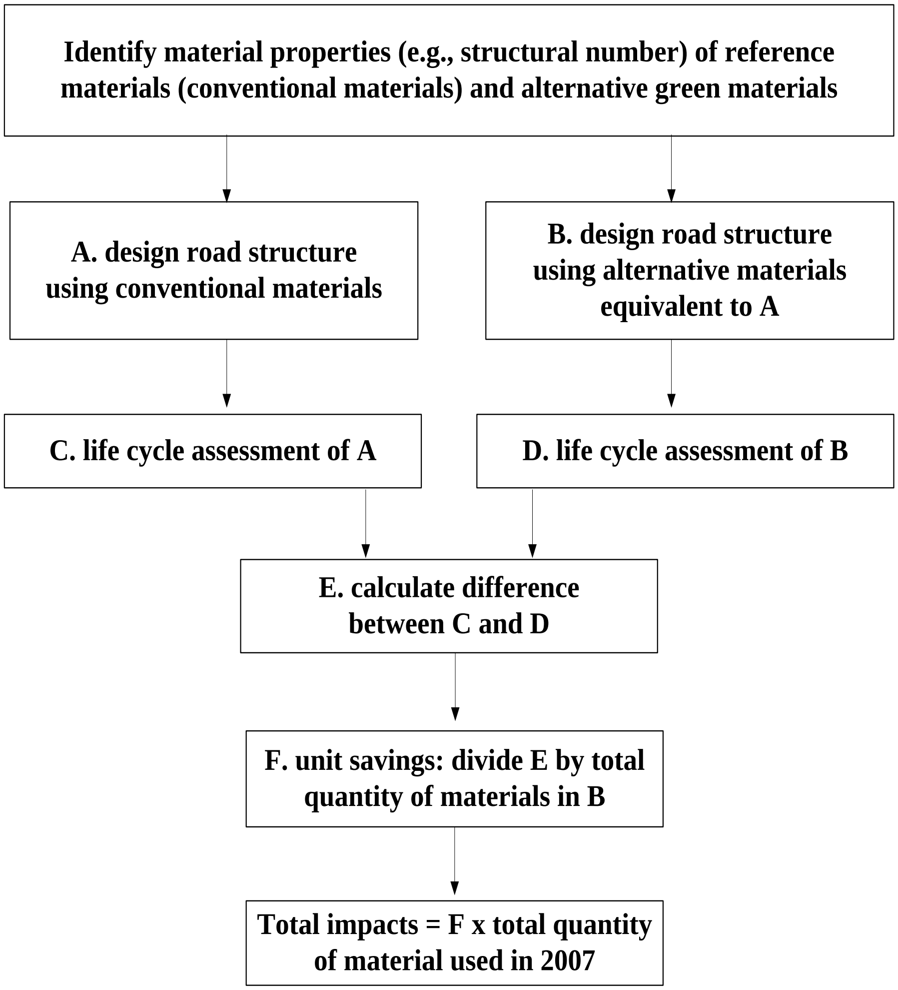

Fig. 1. Flow Chart of Procedure to Quantify Benefits

The first application involves stabilization of a soft subgrade using 10% cementitious fly ash to form a working platform for construction over soft subgrade [Edil et al. 2002]. Unit impacts for energy consumption, water consumption, and greenhouse gas emissions were computed for subgrade stabilization using fly ash and compared to the conventional construction technique, where the soft subgrade is replaced with crushed rock. The two subgrade stabilization methods were designed to generate the same structural number (i.e., 2.8) using layer coefficients of 0.18 and 0.13, respectively, for crushed rock and fly ash stabilized subgrade as suggested by Geo Engineering Consulting [2009]. The equivalent thicknesses are 0.41 and 0.56 m for crushed rock and fly ash, respectively.

Since fly ash needs to be mixed into the subgrade, the model includes a comparison of energies needed for mixing relative to placement of crushed rock. The final model inputs includes 62.5 m^3 of subgrade stabilized with 10% fly ash or 45 m^3 of crushed aggregate along a 3.65-m wide and 30.5-m long road. Impacts for this road segment are in Table 1. Unit impacts are converted to "per Mg" fly ash using an average maximum dry density for fly ash stabilized subgrade as suggested by Edil et al. [2002] (1.64 Mg/m^3) and are summarized in Table 2. Average costs of energy and water were obtained from EPA [2008] and the market price of CO_2 was obtained from CCX [2009].

Table 1. Life Cycle Comparison of Fly Ash Stabilization vs. Crushed Rock

	Crushed rock	Fly ash stabilized subgrade	Difference
Energy (MJ)	20,483	640	19,843
Water (kg)	2.86	0.03	2.83
CO_2 (Mg)	1.46	0.05	1.41

Table 2. Savings Profile for Fly Ash Stabilization vs. Crushed Rock

Areas of impact		Savings per 1 Mg of fly ash
Energy	Savings (MJ/Mg fly ash)	2,134
	Financial savings (US$/Mg fly ash)	60
Water use	Savings (L/Mg fly ash)	0.3
	Financial savings (US$/Mg fly ash)	0.0002
GHG emission	CO_2 e (Mg/Mg fly ash)	0.15
	Financial savings (US$/Mg fly ash)	0.6

The second application involved using bottom ash as a granular subbase on top of subgrade instead of a natural granular backfill. Impacts were derived in a similar manner employed for the case where fly ash was used for stabilization. The two granular layers were designed to generate the same structural number (i.e., 1.6) using layer coefficients of 0.08 and 0.06, respectively, for granular backfill and bottom ash as suggested by Geo Engineering Consulting [2009]. The equivalent thicknesses are 0.51 and 0.68 m, respectively.

The equipment used to place and compact granular backfill material and bottom ash was assumed to be the same. Impacts for a 3.65-m wide and 30.5-m long road segment are given in Table 3. The difference in model unit impact outputs were converted to “per Mg” bottom ash by using an average maximum dry density for bottom ash suggested by Tanyu et al. [2004] (1.48 Mg/m^3). The unit impacts of replacing granular backfill with bottom ash subbase in savings/Mg of bottom ash are summarized in Table 4.

Table 3. Life Cycle Environmental Comparison of Using Granular Backfill vs. Bottom Ash

	Granular Backfill	Bottom Ash	Difference
Energy (MJ)	24,388	1,908	22,480
Water (kg)	3.42	0.28	3.14
CO_2 (Mg)	1.74	0.14	1.60

Table 4. Unit Impacts Profile Using Bottom Ash vs. Granular Backfill

Areas of impact		Savings per 1 Mg of bottom ash
Energy	Savings (MJ/Mg bottom ash)	201
	Financial savings (US$/Mg bottom ash)	5.6
Water use	Savings (L/Mg bottom ash)	0.03

	Financial savings (US$/Mg bottom ash)	0.00002
GHG emission	CO_2 e (Mg/Mg bottom ash)	0.01
	Financial savings (US$/Mg bottom ash)	0.04

TOTAL BENEFITS

Impacts of using fly ash and bottom ash in road construction across the US were evaluated by extrapolating the unit impacts described previously using national data from 2007 on CCP use in pavement construction available from ACAA [2008]. The ACAA data indicate that 0.3 million Mg of fly ash and 0.7 million Mg of bottom ash are used each year in road base/subbase applications.

These benefits are summarized in Table 5 for fly ash and Table 6 for bottom ash. The combined benefits obtained using fly ash and bottom ash is equivalent to the energy consumed by 8,650 homes [EIA 2009], the water used by 2,800 persons, the CO_2 equivalent associated with 11,200 automobiles, and cost savings equivalent to the annual salary of 610 average Americans. This savings are accrued with the modest use of fly ash and bottom ash in pavement construction that occurs today. With more widespread use, much greater savings could be achieved.

Table 5. Annual Savings Using Fly Ash to Stabilize Subgrades

Point of Impact	Annual saving	Equivalent to
Energy (TJ)	724.8	Annual energy use of 7,200 households (2005)
Water (L)	101,904	2,300 persons daily water use for shower (43.9 L/capita)
CO_2e (Mg)	50,952	Equivalent to the removal of 9,800 passenger cars per year from roadways
Financial* (million US$)	20.5	Provides 510 full-time average Americans with annual salary (US $39,500/yr; US Census Bureau 2006)

*Financial benefits are only from the environmental benefits and do not include savings due to savings in material cost.

Table 6. Annual Savings Using Bottom Ash as Subbase

Point of Impact	Annual Saving	Equivalent to
Energy (TJ)	144.8	Annual energy use of 1,450 households (2005)
Water (L)	21,656	500 persons daily water use for shower (43.9 L/capita)
CO_2e (Mg)	7,219	Equivalent to the removal of 1,400 passenger cars per year from roadways
Financial* (million US$)	4.1	Provides 100 full-time average Americans with annual salary (US$39,500/yr)

*Financial benefits are only from the environmental benefits and do not include savings due to savings in material cost.

SUMMARY AND CONCLUSION

Environmental and economic savings from the application of fly ash and bottom ash in road construction have been analyzed. The steps of material production and placement are identified as the drivers of environmental and economic impacts. These savings are accrued with the modest use of fly ash and bottom ash in pavement construction that occurs today. The methodology presented can be extended to other beneficial use applications of coal combustion products to get a more complete picture of overall savings. There are also additional savings that have not been included such as arising from the difference in cost of materials and avoidance of landfilling fly ash and bottom ash as solid waste. With more widespread use of coal combustion products, much greater savings could be achieved.

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