PennDOT RECYCLING MATERIAL FACT SHEET

Coal Combustion By-Products (CCP)

Bottom Ash/Boiler Slag

Introduction and Background

Coal Bottom Ash and Boiler Slag are produced from burning pulverized coal in a coal-fired boiler for the generation of steam and/or the production of electric power. Most of these coal combustion by-products (CCP) are produced at coal-fired electric utility generating stations and are collected from the bottom of coal-fired furnaces.(1) Coal bottom ash is a dark gray, granular, porous, predominantly sand size (minus 12.7mm…½ in) material and boiler slag, often referred to as "black beauty," is a coarse, hard, black, angular, glassy material. When pulverized coal is burned in a dry, bottom boiler, about 80 percent of the unburned material or ash is entrained in the flue gas and is captured and recovered as fly ash. The remaining 20 percent of the ash is dry bottom ash. When pulverized coal is burned in wet-bottom boilers (slag-tap boiler and the cyclone boiler), as much as 50 percent of the ash is retained in the slag-tap furnace as boiler slag. In a cyclone furnace, 70 to 80 percent of the ash is retained as boiler slag, with only 20 to 30 percent leaving the furnace in the form of fly ash.(1,3,4)

According to recent statistics compiled by the American Coal Ash Association (ACAA) on CCP utilization, 36.9 percent of all bottom ash and 68.6 percent of all boiler slag produced in 2011 were utilized.(2) Selected Construction related bottom ash applications include (see Table 3 below) raw feed material for production of Portland cement, as aggregate in lightweight concrete masonry units, and snow and ice control. Bottom ash has also been used as a road base and subbase aggregate, structural fill material, and as fine aggregate in asphalt paving and flowable fill. Boiler slag applications include use as aggregate in asphalt paving, structural fill, and in road base and subbase applications.(1,3)

Problems have been reported with paving mixtures containing pyrite contamination in the bottom ash. Pyrite particles weather despite being coated with asphalt cement, causing popouts and deep red stains in the pavement surface.(1) Shrinkage cracking of cement-stabilized granular materials has also been observed.

This fact sheet provides information on the recycling of Bottom Ash and Boiler Slag including the physical and mechanical properties, chemical composition, and applications for the Pennsylvania Department of Transportation (PennDOT) use in civil engineering applications. The fact sheet is divided into the following sections:

Material Properties – describes typical Bottom Ash and Boiler Slag properties
- Physical and Mechanical properties
- Chemical composition

Applications – Selected construction/highway Bottom Ash and Boiler Slag applications
Specifications – Present existing PennDOT specifications.
Conclusions – Presents conclusions and discusses implementation issues.

Material Properties

Table 1. Typical Physical/Mechanical Properties Bottom Ash and Boiler Slag[1,4]

Property	Bottom Ash	Boiler Slag
Specific Gravity[6]	2.1 - 2.7	2.3 - 2.9
Dry Unit Weight[6]	720 - 1600 kg/m^3 (45 - 100 lb/ft^3)	960 - 1440 kg/m^3 (60 - 90 lb/ft^3)
Plasticity[6]	None	None
Absorption[4]	0.8 - 2.0%	0.3 - 1.1%
Maximum Dry Density kg/m^3 (lb/ft^3)[7]	1210 - 1620 (75 - 100)	1330 - 1650 (82 - 102)
Optimum Moisture Content, %[7]	Usually <20 12 - 24 range	8 - 20
Los Angeles Abrasion Loss %(4)	30 - 50	24 - 48
Sodium Sulfate Soundness Loss %[4]	1.5 - 10	1 - 9
Shear Strength (Friction Angle)[6]	38 - 42° 32 - 45° (<9.5 mm size)	38 - 42° 36 - 46° (<9.5 mm size)
California Bearing Ratio (CBR) %[6]	40 - 70	40 - 70
Permeability Coefficient cm/sec[6]	10^{-2} - 10^{-3}	10^{-2} - 10^{-3}

References cited in table above are listed in Reference 1 of this document see link below
http://www.fhwa.dot.gov/publications/research/infrastructure/pavements/97148/012.cfm

Table 2. Chemical Composition of Selected Bottom Ash and bBiler Slag Samples[1] (percent by weight)								
Ash Type:	**Bottom Ash**					**Boiler Slag**		
Coal Type:	**Bituminous**			**Sub-bituminous**	**Lignite**	**Bituminous**		**Lignite**
Location	**West Virginia**		**Ohio**	**Texas**		**West Virginia**		**North Dakota**
SiO_2	53.6	45.9	47.1	45.4	70	48.9	53.6	40.5
Al_2O_3	28.3	25.1	28.3	19.3	15.9	21.9	22.7	13.8
Fe_sO_3	5.8	14.3	10.7	9.7	2	14.3	10.3	14.2
CaO	0.4	1.4	0.4	15.3	6	1.4	1.4	22.4
MgO	4.2	5.2	5.2	3.1	1.9	5.2	5.2	5.6
Na_2O	1	0.7	0.8	1	0.6	0.7	1.2	1.7
K_2O	0.3	0.2	0.2	-	0.1	0.1	0.1	1.1

Table 2.: After Moulton, Lyle K. "Bottom Ash and Boiler Slag US Bureau of Mines Circular No. 8640, 1973
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Applications

Table 3. Coal Bottom Ash/Boiler Slag Selected Construction-related Applications (2011)[2]						
	Bottom Ash			Boiler Slag		
	Million Metric Tons	Million Tons	Percent of Total Used	Metric Tons	Tons	Percent of Total Used
1. Concrete/Concrete Products /Grout	0.36	0.33	5.74%	0	0	0.00%
2. Blended Cement/ Raw Feed for Clinker	1.27	1.15	20.18%	0	0	0.00%
3. Flowable Fill	0.06	0.05	0.93%	0	0	0.00%
4. Structural Fills/Embankments	2.68	2.41	42.52%	2,611	2,352	6.66%
5. Road Base/Sub-base	0.53	0.48	8.47%	1,443	1,300	3.68%
6. Soil Modification/Stabilization	0.23	0.20	3.60%	0	0	0.00%
7. Snow and Ice Control	0.49	0.44	7.74%	28,049	25,269	71.51%
13. Aggregate	0.68	0.61	10.82%	7,123	6,417	18.16%
Approximate Total	6.30	5.67	1.00	39,225	35,338	1.00
Source: Selected data from American Coal Ash Association 2011 CCP Production & Use Survey[2]						

Selected construction related applications for Coal Bottom Ash and Boiler slag are listed in Table 3 above. Descriptions of Highway applications for Coal Bottom Ash and Boiler slag (follow document link below) include[1]:

- *Asphalt Concrete*
- *Granular Base*
- *Stabilized Base*

Specifications

Currently the Pennsylvania Department of Transportation uses Coal Bottom Ash/Boiler Slag in highway construction.

- Pennsylvania Department of Transportation Publication 408 2011[5]; (ftp://ftp.dot.state.pa.us/public/bureaus/design/pub408/pub%20408-2011.pdf)
  - Sections: 220, 703, and 901
- Pennsylvania Department of Transportation Standard Special Provisions[6] (http://www.dot14.state.pa.us/ECMS/SVSPPSearch?action=showResults)
- b03101 SECTION 310 - CRUSHED AGGREGATE BASE COURSE (SU)
- b03121 SECTION 312 - CRUSHED AGGREGATE BASE COURSE, TYPE DG (SU)
- b07031 SECTION 703.4 ANTI-SKID MATERIAL

Unresolved Issues[1]

Asphalt Concrete:

Some bottom ash sources may contain pyrite particles and/or soluble iron sulfate particles. These particles, if not separated and removed prior to mixing with asphalt, will eventually weather in the pavement, producing popouts and cause staining. A more direct test method is needed to identify these undesirable particles, particularly the pyrites, so they can be removed from the bottom ash before being incorporated into a paving mix. Bottom ash may also contain friable, porous "popcorn" particles. Such bottom ashes should be precrushed before being mixed with asphalt.

Some standard test methods are not appropriate for evaluating bottom ash and boiler slag and can result in the rejection of otherwise acceptable materials. Bottom ash and boiler slag possess unique physical and engineering properties that are different from conventional aggregate materials, for which the standard test methods have been developed. Some new or modified test methods are needed to provide a more complete evaluation of bottom ash and/or boiler slag properties.

Granular Base:

Bottom ash and/or boiler slag aggregates have unique engineering properties and characteristics when compared to conventional (natural) sources of aggregate materials. For example, bottom ash may contain some particles that may crush or degrade easily, and boiler slag is uniformly graded. Standard test methods and specifications have been developed to evaluate conventional (natural) aggregate materials. Some sources of bottom ash and/or boiler slag provide satisfactory performance as an aggregate in granular base material applications, however, they do not satisfy all test criteria and/or specification requirements for such aggregates. This is particularly the case as far as particle size distribution specifications and abrasion loss requirements for graded base courses are concerned.

Stabilized Base:

As noted above, control of shrinkage cracking has been long considered by many state transportation agencies as a prime concern associated with stabilized base mixtures, especially cement-stabilized mixtures. Additional mix designs with reduced potential for shrinkage cracking need to be developed.

Pyrites must be removed before bottom ash or boiler slag can be used. Soluble sulfates in bottom ash may warrant removal if found in sufficient quantity to be considered detrimental. Improved techniques for timely removal of these detrimental constituents are needed.

Conclusions

Bottom Ash/Boiler Slag, Coal Combustion By-Products (CCP), have been used in numerous roadway construction projects throughout the U.S. The use of CCP has shown significant costs savings, environmental benefits, and has demonstrated performance comparable to conventional aggregates and earth material.

References: Ref (1) – Ref (6)