[Asphalt Concrete] [Granular Base] [Stabilized Base]

COAL BOTTOM ASH/ BOILER SLAG

Material Description

ORIGIN

Coal bottom ash and boiler slag are the coarse, granular, incombustible by-products that are collected from the bottom of furnaces that burn coal for the generation of steam, the production of electric power, or both. The majority of these coal by-products are produced at coal-fired electric utility generating stations, although considerable bottom ash and/or boiler slag are also produced from many smaller industrial or institutional coal-fired boilers and from coal-burning independent power production facilities. The type of by-product (i.e., bottom ash or boiler slag) produced depends on the type of furnace used to burn the coal.

Bottom Ash

The most common type of coal-burning furnace in the electric utility industry is the dry, bottom pulverized coal boiler. 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, a dark gray, granular, porous, predominantly sand size minus 12.7mm (½ in) material that is collected in a water-filled hopper at the bottom of the furnace.[(1)] When a sufficient amount of bottom ash drops into the hopper, it is removed by means of high-pressure water jets and conveyed by sluiceways either to a disposal pond or to a decant basin for dewatering, crushing, and stockpiling for disposal or use.[(2)] During 1996, the utility industry generated 14.5 million metric tons (16.1 million tons) of bottom ash.[(3)]

Boiler Slag

There are two types of wet-bottom boilers: the slag-tap boiler and the cyclone boiler. The slag-tap boiler burns pulverized coal and the cyclone boiler burns crushed coal. In each type, the bottom ash is kept in a molten state and tapped off as a liquid. Both boiler types have a solid base with an orifice that can be opened to permit the molten ash that has collected at the base to flow into the ash hopper below. The ash hopper in wet-bottom furnaces contains quenching water. When the molten slag comes in contact with the quenching water, it fractures instantly, crystallizes, and forms pellets. The resulting boiler slag, often referred to as "black beauty," is a coarse, hard, black, angular, glassy material.

When pulverized coal is burned in a slag-tap furnace, as much as 50 percent of the ash is retained in the furnace as boiler slag. In a cyclone furnace, which burns crushed coal, some 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)]

Wet-bottom boiler slag is a term that describes the molten condition of the ash as it is drawn from the bottom of the slag-tap or cyclone furnaces. At intervals, high-pressure water jets wash the boiler slag from the hopper pit into a sluiceway which is then conveys it to a collection basin for dewatering, possible crushing or screening, and either disposal or reuse.[(4)] During 1995, the utility industry in the United States generated 2.3 million metric tons (2.6 million tons) of boiler slag.[(1)]

A general diagram depicting the production and processing operations associated with bottom ash and boiler slag management is presented in Figure 4-1.

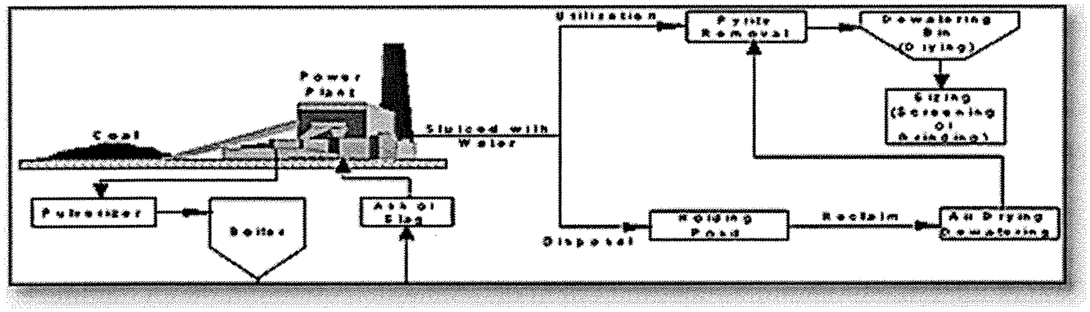

Figure 4-1. Production and processing of bottom ash or boiler slag.

Additional information on the use of bottom ash and/or boiler slag can be obtained from:

American Coal Ash Association (ACAA)
2760 Eisenhower Avenue, Suite 304
Alexandria, Virginia 22314

Electric Power Research Institute
3412 Hillview Road
Palo Alto, California 94304

CURRENT MANAGEMENT OPTIONS

Recycling

According to recent statistics on coal combustion by-product utilization, 30.3 percent of all bottom ash and 93.3 percent of all boiler slag produced in 1996 were utilized. Leading bottom ash applications are snow and ice control, as aggregate in lightweight concrete masonry units, and raw feed material for production of Portland cement. Bottom ash has also been used as a road base and subbase aggregate, structural fill material(5), and as fine aggregate in asphalt paving and flowable fill. Leading boiler slag applications are blasting grit, roofing shingle granules, and snow and ice control. Boiler slag has also been used as an aggregate in asphalt paving, as a structural fill,(5)and in road base and subbase applications.(2)

The U.S. EPA is presently undertaking a study of power plant wastes prior to disposal by the utility. It is possible that EPA's study on mixed power plant wastes could have a regulatory impact on beneficial use or reuse of any mixed materials. It is anticipated that this investigation will be completed in 1998.

Disposal

Discarded bottom ash and boiler slag are either landfilled or sluiced to storage lagoons. When sluiced to storage lagoons, the bottom ash or boiler slag is usually combined with fly ash. This blended fly ash and bottom ash or boiler slag are referred to as ponded ash. Approximately 30 percent of all coal ash is handled wet and disposed of as ponded ash.(3)

Ponded ash is potentially useable, but variable in its characteristics because of its manner of disposal. Because of differences in the unit weight of fly ash and bottom ash or boiler slag, the coarser bottom ash or boiler slag particles settle first and the finer fly ash remains in suspension longer. Ponded ash can be reclaimed and stockpiled, during which time it can be dewatered. Under favorable drying conditions, ponded ash may be dewatered into a range of moisture that will be within the vicinity of its optimum moisture content. The higher the percentage of bottom ash or boiler slag there is in ponded ash, the easier it is to dewater and the greater its potential for reuse. Reclaimed ponded ash has been used in stabilized base or subbase mixes and in embankment construction, and can also be used as fine aggregate or filler material in flowable fill.

MARKET SOURCES

Although electric utility companies produce ash at their coal-fired power plants, most utilities do not handle, dispose of, or sell the ash that they produce. For the most part, management of bottom ash or boiler slag is contracted out to ash marketing firms or to local hauling contractors. There are approximately 50 commercial ash marketing firms operating throughout the United States, in all states except Hawaii. In addition to commercial ash marketing organizations, certain coal-burning electric utility companies have a formal ash marketing program of their own. Most coal-burning electric utility companies currently employ an ash marketing specialist, who is responsible for monitoring ash generation, quality, use or disposal, and for interfacing with the ash marketers or brokers who are under contract to the utility companies.

HIGHWAY USES AND PROCESSING REQUIREMENTS

Asphalt Concrete Aggregate (Bottom Ash and Boiler Slag)

Both bottom ash and boiler slag have been used as fine aggregate substitute in hot mix asphalt wearing surfaces and base courses, and emulsified asphalt cold mix wearing surfaces and base courses. Because of the "popcorn," clinkerlike low durability nature of some bottom ash particles, bottom ash has been used more frequently in base courses than wearing surfaces. Boiler slag has been used in wearing surfaces, base courses and asphalt surface treatment or seal coat applications. There are no known uses of bottom ash in asphalt surface treatment or seal coat applications.

Screening of oversized particles and blending with other aggregates will typically be required to use bottom ash and boiler slag in paving applications. Pyrites that may be present in the bottom ash should also be removed (with electromagnets) prior to use. Pyrites (iron sulfide) are volumetrically unstable, expansive, and produce a reddish stain when exposed to water over an extended time period.

Granular Base (Bottom Ash and Boiler Slag)

Both bottom ash and boiler slag have occasionally been used as unbound aggregate or granular base material for pavement construction. Bottom ash and boiler slag are considered fine aggregates in this use. To meet required specifications, the bottom ash or slag may need to be blended with other natural aggregates prior to its use as a base or subbase material. Screening or grinding may also be necessary prior to use, particularly for the bottom ash, where large particle sizes, typically greater than 19 mm (3/4 in), are present in the ash.

Stabilized Base Aggregate (Bottom Ash and Boiler Slag)

Bottom ash and boiler slag have been used in stabilized base applications. Stabilized base or subbase mixtures contain a blend of an aggregate and cementitious materials that bind the aggregates, providing the mixture with greater bearing strength. Types of cementitious materials typically used include Portland cement, cement kiln dust, or pozzolans with activators, such as lime, cement kiln dusts, and lime kiln dusts. When constructing a stabilized base using either bottom ash or boiler slag, both moisture control and proper sizing are required. Deleterious materials such as pyrites should also be removed.

Embankment or Backfill Material (Mainly Bottom Ash)

Bottom ash and ponded ash have been used as structural fill materials for the construction of highway embankments and/or the backfilling of abutments, retaining walls, or trenches. These materials may also be used as pipe bedding in lieu of sand or pea gravel. To be suitable for these applications, the bottom ash or ponded ash must be at or reasonably close to its optimum moisture content, free of pyrites and/or "popcorn" like particles, and must be non-corrosive. Reclaimed ponded ash must be stockpiled and adequately dewatered prior to use. Bottom ash may require screening or grinding to remove or reduce oversize materials (greater than 19 mm (3/4 in) in size.

Flowable Fill Aggregate (Mainly Bottom Ash)

Bottom ash has been used as an aggregate material in flowable fill mixes. Ponded ash also has the potential for being reclaimed and used in flowable fill. Since most flowable fill mixes involve the development of comparatively low compressive strength (in order to be able to be excavated at a later time, if necessary), no advance processing of bottom ash or ponded ash is needed. Neither bottom ash nor ponded ash needs to be at any particular moisture content to be used in flowable fill mixes because the amount of water in the mix can be adjusted in order to provide the desired flowability.

MATERIAL PROPERTIES

Physical Properties

Bottom ashes have angular particles with a very porous surface texture. Bottom ash particles range in size from a fine gravel to a fine sand with very low percentages of silt-clay sized particles. The ash is usually a well-graded material, although variations in particle size distribution may be encountered in ash samples taken from the same power plant at different times. Bottom ash is predominantly sand-sized, usually with 50 to 90 percent passing a 4.75 mm (No. 4) sieve, 10 to 60 percent passing a 0.42 mm (No. 40) sieve, 0 to 10 percent passing a 0.075 mm (No. 200) sieve, and a top size usually ranging from 19 mm (3/4 in) to 38.1 mm (1-1/2 in). Table 4-1 compares the typical gradations of bottom ash and boiler slag.

Table 4-1. Particle size distribution of bottom ash and boiler slag.[4]
(percent by weight passing)

	Bottom Ash			Boiler Slag		
Sieve Size	Glasgow, WV	New Haven, WV	Moundsville, WV	Willow Island, WV	Rockdale, TX	Moundsville, WV
38 mm (1-1/2 in)	100	99	100	100	100	100
19 mm (3/4 in)	100	95	100	100	100	100
9.5 mm (3/8 in)	100	87	73	99	100	97
4.75 mm (No. 4)	90	77	52	97	99	90
2.36 mm (No. 8)	80	57	32	85	88	62
1.18 mm (No. 16)	72	42	17	46	42	16
0.60 mm (No. 30)	65	29	10	23	10	4
0.30 mm (No. 50)	56	19	5	12	5	2
0.15 mm (No. 100)	35	15	2	6	2	1
0.075 mm (No. 200)	9	4	1	4	1	0.5

Boiler slags are predominantly single-sized and within a range of 5.0 to 0.5 mm (No. 4 to No. 40 sieve). Ordinarily, boiler slags have a smooth surface texture, but if gases are trapped in the slag as it is tapped from the furnace, the quenched slag will become somewhat vesicular or porous. Boiler slag from the burning of lignite or subbituminous coal tends to be more porous than that of the eastern bituminous coals.[6] Boiler slag is essentially a coarse to medium sand with 90 to 100 percent passing a 4.75 mm (No. 4) sieve, 40 to 60 percent passing a 2.0 mm (No. 10) sieve, 10 percent or less passing a 0.42 mm (No. 40) sieve, and 5 percent or less passing a 0.075 mm (No. 200) sieve.[4] The specific gravity of the dry bottom ash is a function of chemical composition, with higher carbon content resulting in lower specific gravity. Bottom ash with a low specific gravity has a porous or vesicular texture, a characteristic of popcorn particles that readily degrade under loading or compaction.[7] Table 4-2 lists some typical physical properties of bottom ash and boiler slags.

Table 4-2. Typical physical properties of bottom ash and boiler slag.

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%

Chemical Properties

Bottom ash and boiler slag are composed principally of silica, alumina, and iron, with smaller percentages of calcium, magnesium, sulfates, and other compounds. The composition of the bottom ash or boiler slag particles is controlled primarily by the source of the coal and not by the type of furnace. Table4-3 presents a chemical analysis of selected samples of bottom ash and boiler slag from different coal types and different regions.

Table 4-3. Chemical composition of selected bottom ash and boiler slag samples (percent by weight).[4]

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	70.0	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	2.0	14.3	10.3	14.2
CaO	0.4	1.4	0.4	15.3	6.0	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	0.7	0.8	1.0	0.6	0.7	1.2	1.7
K_2O	0.3	0.2	0.2	-	0.1	0.1	0.1	1.1

Bottom ash or boiler slag derived from lignite or sub-bituminous coals has a higher percentage of calcium than the bottom ash or boiler slag from anthracite or bituminous coals. Although sulfate is not shown in Table 4-2, it is usually very low (less than 1.0 percent), unless pyrites have not been removed from the bottom ash or boiler slag.

Due to the salt content and, in some cases, the low pH of bottom ash and boiler slag, these materials could exhibit corrosive properties. When using bottom ash or boiler slag in an embankment, backfill, subbase, or even possibly in a base course, the potential for corrosion of metal structures that may come in contact with the material is of concern and should be investigated prior to use.

Corrosivity indicator tests normally used to evaluate bottom ash or boiler slag are pH, electrical resistivity, soluble chloride content, and soluble sulfate content. Materials are judged to be noncorrosive if the pH exceeds 5.5, the electrical resistivity is greater than 1,500 ohm-centimeters, the soluble chloride content is less than 200 parts per million (ppm), or the soluble sulfate content is less than 1,000 parts per million (ppm).[8]

Mechanical Properties

Table 4-4 lists some typical values for bottom ash and boiler slag compaction characteristics (maximum dry density and optimum moisture), durability characteristics (Los Angeles abrasion and sodium soundness), shear strength and bearing strength characteristics (friction angle and), and permeability.

The maximum dry density values of bottom ash and boiler slag are usually from 10 to 25 percent lower than that of naturally occurring granular materials. The optimum moisture content values of bottom ash and boiler slag are both higher than those of naturally occurring granular materials, with bottom ash being considerably higher in optimum moisture content than boiler slag.

Boiler slag usually exhibits less abrasion loss and soundness loss than bottom ash because of its glassy surface texture and lower porosity.[9] In some power plants, coal pyrites are disposed of with the bottom ash or boiler slag. In such cases, some pyrite or soluble sulfate is contained in the bottom ash or boiler slag,[9] which may be reflected in higher sodium sulfate soundness loss values. Reported friction angle values are within the same range as those for sand and other conventional fine aggregate sources.[7]

Table 4-4. Typical mechanical properties of bottom ash and boiler slag.

Property	Bottom Ash	Boiler Slag
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}

California Bearing Ratio values are comparable to those of high-quality gravel base materials. Dry bottom ash and boiler slag can both be expected to have permeability coefficients that are within approximately the same range[7] The permeability is related to the percent fines (minus 0.075 mm or No. 200 sieve) of the material.

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[Asphalt Concrete] [Granular Base] [Stabilized Base]

[Granular Base] [Stabilized Base] [Material Description]

COAL BOTTOM ASH/ BOILER SLAG **User Guideline**

Asphalt Concrete

INTRODUCTION

Bottom ash and boiler slag can be used as aggregates in hot mix asphalt base courses or wearing surfaces, emulsified asphalt cold mix bases or surfaces, and asphalt surface treatments or seal coats.

Bottom ash, produced in dry bottom boilers, is usually sufficiently well-graded that it does not need to be blended with other fine aggregates to meet gradation requirements. However, bottom ash particles are less durable than conventional aggregates. Consequently, bottom ash is better suited for use in base course and shoulder mixtures or in cold mix applications, as opposed to wearing surface mixtures. Most of the previous use of bottom ash has been in cold mix projects on low-volume secondary roadways.

Boiler slag is produced in wet bottom boilers, is uniformly sized, and consists of hard, durable, glassy particles. Boiler slag has to be blended with other fine aggregates to meet gradation requirements, but has been used more frequently in asphalt paving than bottom ash. Boiler slag has been used mainly in hot mix wearing surfaces, where it has been found to enhance skid resistance, and, to a lesser extent, in surface treatment or seal coat applications.

PERFORMANCE RECORD

Bottom ash and boiler slag have been used with considerable success as fine aggregates in asphalt paving mixtures for at least the past 25 years in different sections of the United States. The American Coal Ash Association recently reported that during 1996 more than 75,000 metric tons (83,000 tons) of boiler slag and nearly 14,400 metric tons (16,000 tons) of bottom ash were used in asphalt paving.(1)

A 1994 survey of all 50 state transportation agencies indicated that five states have made some recent use of bottom ash and/or boiler slag as an aggregate in asphalt paving on state roadways. These five states are Arkansas, Missouri, Texas, West Virginia, and Wyoming.(2) Previous surveys have reported bottom ash and boiler slag usage in up to as many as 11 different states, although such usage includes some projects on nonstate roadways.(3)

Bottom Ash

Bottom ash is a somewhat variable material that may sometimes contain pyrites or lightweight, porous "popcorn" particles. As a result, it is not frequently used as an aggregate source in hot mix asphalt paving mixes, especially wearing surfaces. Bottom ash has been used more frequently in cold mix emulsified asphalt mixtures, hot mix base course mixtures, or in shoulder construction, where gradation requirements and durability considerations are not as critical as in hot mix wearing surface mixtures.(4)

The most extensive use of bottom ash in bituminous paving has been in West Virginia, where, during the 1970's and 1980's, bottom ash was cold mixed with 6 to 7 percent by weight of emulsified asphalt and used in the paving of secondary roads where traffic volumes are lower and durability concerns are reduced. In some cases, the bottom ash was also blended with boiler slag. Similar applications have also been made in eastern Ohio.(5)

Bottom ash has been used occasionally as an aggregate in hot mix asphalt, but usually only when blended with conventional aggregates. There have been periodic indications of problems with paving mixtures in West Virginia containing bottom ash, in which pyrite contamination in the bottom ash had not been considered. Pyrite particles will weather in service, despite being coated with asphalt cement, causing popouts and deep red stains in the pavement surface.(8) Bottom ash has also been used in hot mix asphalt in some western states.

Boiler Slag

Boiler slag has been used more frequently in hot mix asphalt than bottom ash because of its hard, durable particles and resistance to surface wear. Boiler slag has also been used in hot mix asphalt wearing surface mixtures because of its affinity for asphalt and its dust-free surface, which aids in asphalt adhesion and resistance to stripping.(6) Another of the properties of boiler slag that enhances its value as an aggregate in bituminous paving is its permanent black color, which is not affected by sun or weather. The black color also aids in the melting of snow from the road surface during the winter.(7)

Since boiler slag has a uniform particle sizing, it is commonly blended with other aggregates for use in asphalt mixtures. As a rule of thumb, paving mixture stability is likely to suffer if the percentage of boiler slag exceeds 50 percent. (8)

Boiler slag was first used in asphalt paving many years ago in Hammond, Indiana, where, on an experimental basis, it was blended with conventional aggregate to help solve the problem of aggregate polishing. The success of that and several other demonstration projects in Indiana led to its acceptance and use in that state and several others, including Ohio, Michigan, Missouri, and West Virginia. Boiler slag has also been used as an aggregate in hot mix asphalt paving in a number of cities such as Cincinnati and Columbus, Ohio, as well as in Tampa, Florida.(9)

In West Virginia, boiler slag has been blended with graded river sand for resurfacing applications, where thin overlays are used. Typical sections range in thickness from 12.7 to 50.8 mm (1/2 to 2 in) and are composed of 50 percent by weight boiler slag, 39 percent river sand, 3 percent fly ash, and 8 percent asphalt cement. Some of these sections were able to provide more than 10 years of service with little change in texture, despite being subjected to heavy truck traffic.(6)

Some 10,000 tons of boiler slag were used to construct the wearing surface and shoulders of a portion of Interstate Route 94 near the Detroit Airport. This section of roadway was placed during the late 1970's and reportedly performed well into the mid 1980's.(10)

Boiler slag from lignite coal was successfully used for street resurfacing work in parts of southern Texas for many years. The paving mixes consisted of a blend of 75 percent by weight of lignite boiler slag and 25 percent limestone screenings, with an asphalt content of 6 to 7 percent by weight of aggregate. These pavements have reportedly held up well with no signs of shoving or raveling, despite heavy truck traffic, while maintaining a dark, black texture, nonskid properties and smooth riding quality. (11)

The City of Sioux City, Iowa, has incorporated optimum amounts of boiler slag and fly ash mineral filler in an asphalt hot mix surface course called "Carpet Coat." The mix consists of 56 percent by weight boiler slag, 17 percent quartzite, 14 percent sand, 7 percent fly ash, and 6 percent asphalt cement.(12)

Boiler slag has also been used very successfully as a seal coat aggregate for bituminous surface treatments in a number of states, especially in municipal road construction projects. The boiler slag provided better coverage per mile than limestone chips and retained its rich black color, while the surface of the stone chip gradually acquired a faded, gray appearance. Significant cost savings using boiler slag in this application during the mid 1980's have been documented.(13)

The use of power plant aggregates in surface treatment or seal coat applications is believed to be confined almost exclusively to boiler slag. There are no known uses of bottom ash as a seal coat aggregate in asphalt surface treatments.

MATERIAL PROCESSING REQUIREMENTS

Cleaning

Pyrites present in the coal before burning should be removed during the pulverizing step and should not be allowed to be collected together with the bottom ash or boiler slag. If pyrites are present in the bottom ash or boiler slag, they should be removed by electromagnets, media separation, or other means.

Screening

Oversize or agglomerated popcorn particles may be present in some bottom ash sources and should be removed by screening or scalping the material over a 19 mm (3/4 in) or 12.7 mm (1/2 in) screen.

Blending

Boiler slag will almost always require blending with other aggregate sources to meet applicable gradation specifications. Bottom ash may require blending with other aggregates, although it is considerably more well-graded than boiler slag.

Drying

Since aggregates used to produce hot mix asphalt are dried before blending with asphalt cement, moisture that may be present in bottom ash can be removed. Excessive moisture in the aggregates, however, will reduce the production rate of the paving material. Both bottom ash and boiler slag are relatively easy to dewater, particularly boiler slag, which consists of glassy particles. Ponded ash, which is usually a mixture of fly ash and bottom ash or boiler slag, must be stockpiled and allowed to drain sufficiently prior to use, preferably to a surface dry condition.

When used in a cold mix application, the bottom ash should be at least surface dry so that moisture does not interfere with the coating of the ash particles by the emulsified asphalt. Boiler slag should also be in a surface dry condition when used as a seal coat aggregate.

ENGINEERING PROPERTIES

Both bottom ash and boiler slag are used as fine aggregates in asphalt paving applications. Properties of bottom ash and boiler slag that are of particular interest when they are used in asphalt concrete include gradation, specific gravity, absorption, and durability. Table 1 shows some of the engineering properties of bottom ash and boiler slag from power plants in West Virginia.(15)

Table 4-5. Engineering properties of selected bottom ashes and boiler slags

Power Plant Source	Boiler Type	Bulk Sp. Gravity	% Water Absorption	L.A. Abrasion	MgSO4 Soundness	Friable Particles
Fort Martin	Dry bottom	2.31	2.0	40	6	Yes
Mitchell	Dry bottom	2.68	0.8	37	10	None
Hatfield	Dry bottom	2.39	1.7	39	-	Yes
Harrison	Dry bottom	2.66	1.0	38	-	Some
Kammer	Wet bottom	2.76	0.3	37	10	None
Willow Island	Wet bottom	2.72	0.3	33	15M	None
Limestone Sand	Wet bottom	2.65	1.1	-	-	-

Gradation: ASTM D1073 defines a fine aggregate in asphalt paving mixtures as an aggregate that passes the 9.5 mm (3/8 inch) sieve.(14) Boiler slag, with few exceptions, meets this size requirement and most bottom ash sources, with minimal screening of oversize material, will satisfy this definition of a fine aggregate. Bottom ash is predominantly sand-sized, usually with 50 to 90 percent passing a 4.75

mm (No. 4) sieve.

Specific Gravity and Absorption: Bottom ash generally has lower specific gravity and higher absorption values than limestone sand, while boiler slag is comparable in specific gravity with lower absorption than limestone sand.(15)

Durability: Bottom ash and boiler slag exhibit marginal durability as measured by the Los Angeles abrasion test, with bottom ash percent loss values between 30 and 50 and boiler slag somewhat lower. Most bottom ash samples have some friable particles, while boiler slag normally does not.

Soundness: Soundness values are generally found to be within ASTM D1073 weight loss specifications of not more than 15 percent after five cycles when sodium sulfate is used, or not more than 20 percent after five cycles when magnesium sulfate is used. Values for both boiler slag and bottom ash are generally found to be less than 10 percent.(15)

DESIGN CONSIDERATIONS

Mix Design

Bottom Ash

Dry bottom ash has received much less usage than boiler slag in asphalt paving and most of the experience in using bottom ash for this purpose has been in cold mixes. A serious consideration with some sources of dry bottom ash is the presence of friable popcorn particles, which can break down under compaction. For this reason, bottom ash is more appropriate for use in base course rather than surface mixtures.(16)

Because many bottom ashes contain friable popcorn particles that are also absorptive, the asphalt contents of hot mixes or cold mixes containing some percentage of bottom ash will be higher than those of mixes with conventional aggregates. Although the asphalt contents of mixes containing bottom ash will be greater than the asphalt contents of conventional asphalt paving mixes, the total amount of asphalt cement used should not be significantly greater because of the reduced unit weight of the mixes containing bottom ash. Bottom ash mixes are also likely to have relatively high air void contents. The high air voids are attributable to the high angle of internal friction and the rough surface texture of the bottom ash particles.(16)

Because of comparatively high optimum asphalt contents of mixtures using bottom ash as the only aggregate, combining bottom ash with conventional aggregates is recommended. Increased percentages of conventional aggregate result in a reduction in the optimum asphalt content. The primary benefit to be realized from blending with conventional aggregates is an improvement in the durability of the paving mix.

The addition of bottom ash can alter Marshall stability values, and stability must be examined in each mix design. Immersion-compression testing(17) indicates that moisture damage potential does not appear to be critical in paving mixtures containing bottom ash.(18) However, this test is too short in duration to detect particle degradation due to pyrites in the bottom ash.(16) It has been reported that kneading compaction(19) more closely approximates field compaction conditions than Marshall drop hammer compaction(18)

Boiler Slag

The uniform gradation and smooth surface texture commonly associated with most boiler slags require that these materials be blended with other aggregates for use in asphalt paving mixtures. The blend proportions of boiler slag and conventional aggregate(s) will be dictated mainly by the size distribution of the materials and the requirements of the gradation specifications. Percentages of boiler slag ranging from 40 to 50 percent by weight of the total mix have been successfully used on a number of past projects. The best use of boiler slag is as a partial replacement for the sand fraction of hot mix base and surface course mixtures. The type of aggregate used and the relative proportions of the boiler slag and aggregate have a significant influence on the properties of the paving mixture.[8]

Marshall stability and flow values have been found to decrease as the percentage of boiler slag is increased for a given compactive effort. Mixes blended with rounded siliceous aggregates, such as uncrushed river sand, result in lower quality mixtures than blends containing crushed stone, which possess more desirable angularity and surface texture. Blending crushed stone aggregates with boiler slag is recommended because most boiler slags lack microtexture, which increases the ability of aggregate to retain its asphalt coating and to provide skid resistance.[15]

Optimum skid resistance using boiler slag is best found in open graded sand mixes using boiler slag as the top-sized aggregate. However, such mixes should limit the percentage of boiler slag in the mix and avoid low filler content. Rounded river sands should also be avoided. Boiler slag does not appear to be as helpful in terms of skid resistance in coarse graded mixtures, especially if the coarse aggregate is polish susceptible.[8]

The effect of compaction method on mixture properties is quite pronounced with blends of boiler slag and sand. Kneading compaction improves the stability and flow of such mixes, compared with Marshall drop hammer compaction. Obtaining adequate compaction is essential with boiler slag mixtures. The best mixtures are produced by blending boiler slag with well-graded, angular, rough-textured aggregate and limiting the percentage of boiler slag to 50 percent or less.[17]

It is possible that some of the more vesicular (porous) boiler slag sources could be used in greater percentages, but excessively vesicular slags tend to be weak and lack crushing resistance.[16] These types of boiler slag may also be more absorptive than typical boiler slag sources and require a higher percentage of asphalt cement.

Boiler slag asphalt mixtures have performed well with respect to their retention of stability in the presence of water. When evaluated using the Marshall immersion-compression test,[17] boiler slag mixtures yielded acceptable stability retention values.[8]

Structural Design

Conventional AASHTO pavement structural design methods are appropriate for asphalt pavements incorporating bottom ash/boiler slag in the mix.[20

Similarly, pavement thickness design procedures for cold mix overlays containing bottom ash or boiler slag, or a blend of the two, should not be any different from the thickness design procedures normally used for cold mix overlays using conventional aggregates. Modified structural numbers (SN) for cold mix overlays containing bottom ash and/or boiler slag should be the same as those normally used by the local jurisdiction for conventional cold mix overlays.

CONSTRUCTION PROCEDURES

Bottom Ash

Material Handling and Storage

Bottom ash can be handled and stored or stockpiled using the same methods and equipment that are normally used for handling and storage of conventional aggregates. However, as noted previously, prospective users of bottom ash must be aware of the possible presence of pyrites in the bottom ash and, if such pyrites were not removed prior to burning the coal, they must be removed from the bottom ash prior to its use in asphalt paving. *Mixing, Placing, and Compacting*

The same methods and equipment used for mixing, placing, and compacting conventional pavements are applicable to asphalt pavements containing bottom ash.

When bottom ash is used in hot mix applications, it usually must be blended with other aggregates. However, dry bottom ash used in cold mix applications may not have to be blended with other aggregate. Such mixes can be prepared cold by mixing with emulsified asphalt at a central pugmill mixing plant and can usually be stockpiled for 10 days or more.

Cold mixes containing bottom ash can be placed with a paver or a spreader box, or, in some cases, can even be dumped and leveled with a grader. Adequate compaction is usually achieved from three to four passes with a pneumatic roller, followed by one or two passes from a steel-wheeled roller.[15]

Laydown characteristics of dry bottom ash cold mixes have been found to be excellent with the use of either a spreader box or a conventional paving machine. Lifts of up to 200 mm (8 in) loose were attempted in a spreader box with good results. It is believed that lifts greater than 200 mm (8 in) in loose thickness would probably be difficult to compact.[15]

Boiler Slag

Material Handling and Storage

Boiler slag can be handled and stored or stockpiled using the same methods and equipment that are normally used for handling and storage of conventional aggregates.

Mixtures with acceptable skid resistance that use boiler slag as the top size aggregate can be designed by limiting the percentage of boiler slag in the mix and by avoiding open-graded mixtures with low filler content.[18]

Mixing, Placing and Compacting

The same methods and equipment used for mixing, placing and compacting conventional pavements are applicable to asphalt pavements containing boiler slag.

size>**UNRESOLVED ISSUES**

Some, but not all, 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 causing unsightly staining. These particles are usually associated with low pH values, which are indicative of the presence of excessive sulfate. 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. If so, such bottom ashes should not be used in asphalt surface mixes unless precrushed before being mixed with asphalt. The performance of wearing surface mixes with precrushed bottom ash aggregate should be evaluated in comparison with more conventional asphalt paving mixes.

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 construction 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. This is especially the case with respect to abrasion loss characteristics and particle size degradation during compaction for bottom ash.

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[Granular Base] [Stabilized Base] [Material Description]

COAL BOTTOM ASH/ BOILER SLAG **User Guideline**

Stabilized Base

INTRODUCTION

Bottom ash and/or boiler slag can be used as either the fine aggregate fraction or, in some cases, as the entire aggregate in either Portland cement or pozzolan-stabilized base and subbase mixtures. A blend of bottom ash and boiler slag may comprise the entire aggregate portion of the mix if both materials are available. If only bottom ash is available, it may be used as the entire source of aggregate, or it may be blended with a coarse aggregate to meet a specified range of gradation. If only boiler slag is available, it must be blended with sand or other well-graded fine aggregate to produce an aggregate with a suitable particle size distribution. If a broader range of particle sizes is specified, further blending with a coarse aggregate may also be necessary.

PERFORMANCE RECORD

Bottom ash and, in particular, boiler slag have been used as aggregate sources in stabilized base or subbase applications since as far back as 40 years ago. Most of these installations have not been well documented, but their service record is believed to have been from fair to very good.

A recent survey reported that in 1996, 0.6 million metric tons (0.7 million tons) of bottom ash and/or boiler slag (predominantly bottom ash) were used as road base or subbase materials. The category for road base or subbase includes stabilized base or subbase, as well as granular or unbound base or subbase installations. The exact percentage used in stabilized base applications was not reported.

According to a 1992 survey of all state highway and transportation agencies, at least five states indicated that they were currently making use of bottom ash or boiler slag in some type of stabilized base or subbase applications. These states include Arkansas, Kentucky, Mississippi, Texas, and Utah. A sixth state, Wyoming, indicated some use of bottom ash as a granular base, but cited instability of the material as the reason for discontinuing the use of bottom ash. Although the nature of the instability was not explained, it is believed to be due to a lack of cohesion in the base, possibly because of the material becoming too dry.

Bottom ash and boiler slag have been used in the past as an aggregate for stabilized base and subbase mixtures in other states, although not necessarily on state highway projects. These states include, but are not limited to, Georgia, Illinois, Michigan, North Dakota, Ohio, and West Virginia. There are currently no state specifications for the use of bottom ash or boiler slag as an aggregate in stabilized base or subbase mixtures. Table 4-8 presents a listing of pertinent data on some selected applications.

Table 4-8. Pozzolanic stabilized base general design and construction data.

Project (Date)	Type	Constituents	Compressive Strength Data	
State Rt. 195[4] Montgomery County, Illinois (1976)	5.6 km (3.5 mi) 250 mm (10 in) Lime-Fly Ash Base Course	Lime - 3% Class F Fly Ash - 32.5% Boiler Slag - 64.5% (minus 4.75 mm (No. 4) sieve)	Lab Cores	>6900 kPa ($1000\ lb/in^2$) 9700 kPa ($1400\ lb/in^2$)
Route 2[5] Wheeling, West Virginia (1971-1972)	Portland Cement, Boiler Ash, Bottom Ash Base Course	Aggregate Boiler Slag - 54% Bottom Ash - 46% Portland Cement - 5% (wt of aggregate)	No data	

Route 34[6] Charleston, West Virginia	Portland Cement Bottom Ash	No Data	Cores (2 yr)	>9000 kPa (1300 lb/in^2)
Rome, Georgia[7] (early 1980's)	305 mm (12 in) Lime Bottom Ash Base Course	Lime - 6 - 8%	Cores (6 wk)	>4800 kPa (700 lb/in^2)
Route 22[8] Georgia (1985)	305 m (1000 ft) 216 mm (8-1/2 in) Portland Cement Pond Ash Base Course	No Data	Lab (7 day)	3400 kPa (494 lb/in^2)
Route 15 Stone County Mississippi (1987)	Lime Stabilized Base and Portland Cement Stabilized Base with Class C Pond Ash	Lime - 2 - 7% Cement - 7.5%	7% Lime Base Cores Cement Base Cores	4500 - 8700 kPa (650 - 1260 lb/in^2) 15900 kPa (2300 lb/in^2)

Pozzolan-stabilized base compositions consisting of lime, fly ash, and aggregates (LFA) were originally patented in the early 1950's under the trade name Poz-O-Pac. Some of the first LFA compositions in the Chicago area were mixed in place and used boiler slag as the aggregate. These early mixtures contained an average of 5 percent by weight hydrated lime, 35 percent Class F fly ash, and 60 percent boiler slag. Pavements using such mixtures provided many years of satisfactory service, and cores taken from these pavements have developed compressive strengths well in excess of 6900 kPa (1,000 lb/in^2)

Typical of these early boiler slag mixes was a 5.6 km (3.5 mile) service road built from State Route 195 to the Coffeen power station near Coffeen, Illinois, during the mid-1970's. General design and construction data are presented in Table 4-8. The pavement reportedly performed without distress, even though the roadway was constantly subjected to heavy truck traffic.

The first known large-scale use of a cement stabilized bottom ash base course in the United States was in the relocation of West Virginia Route 2 during the 1971-72 construction season. The aggregate used was a blend of bottom ash and boiler slag from American Electric Power Company's Mitchell and Kammer plants, respectively. General design and construction data are presented in Table 4-8. The blend was necessary in order to meet the West Virginia Department of Highway gradation specifications for cement-treated base course. The roadway provided excellent service for over 10 years at a substantial reduction in cost compared with the use of conventional aggregates.

Since 1984 several hundred miles of low-volume secondary roads in West Virginia have been reconstructed using cement-stabilized bottom ash. Most of these roads were primarily gravel subbase with traffic ranging from 150 to 1,500 vehicles per day. A typical section, presented in Table 4-8, is Route 34 in Putnam County, near Charleston, where a 150 mm (6 in) thick bottom ash subbase was placed and compacted. Successive 150 mm (6 in) thick lifts of cement-treated bottom ash were placed on top of the subbase.

During the early 1980's, Georgia Power Company successfully constructed a lime-stabilized bottom ash base with a 38 mm (1-1/2 in) asphalt wearing surface near Rome, Georgia. In 1985, the Georgia Department of Transportation successfully constructed a 305 m (1,000 ft) section of cement stabilized pond ash base on State Route 22.

In 1987, pond ash from subbituminous coal was used to reconstruct approximately 2.4 km (1.5 miles) of State Route 15 in Stone County, Mississippi. The reconstruction involved five different sections, four with lime-stabilized ash and one with cement-stabilized ash. A 1.36 km (0.85 mile) control section of mechanically stabilized sand-clay subbase was also constructed. All sections were mixed in place and had a double bituminous surface treatment as a wearing surface. Stabilized base design data are presented in Table 4-8.

Deflection measurements were taken each year after construction through 1990. The sections with 6 and 7 percent lime and 7.5 percent cement all had much lower deflection readings than the control section and the section with only 2 percent lime. After 3 years of service, the control section and the section with 2 percent lime had no observed cracking, while the cement stabilized section had the most cracking. The shrinkage cracking of cement-stabilized granular materials is a fairly common occurrence, especially in soil-cement mixtures. The cracking in traditional soil-cement mixtures is attributable to the hydration of Portland cement. None of the cracking that was observed was considered structural in nature.

MATERIAL PROCESSING REQUIREMENTS

Bottom ash and/or boiler slag are both well-drained materials that can be readily dewatered in 1 or 2 days. Ponded ash reclaimed from a lagoon for use as a base course aggregate should be stockpiled and allowed to drain prior to use. Ponded ash will require a longer dewatering period because it usually includes some fly ash. The higher the percentage of fly ash in the ponded ash, the longer will be the time required for dewatering.

Crushing or Screening

Well-graded aggregates normally require less activator or reagent than poorly graded aggregates in order to produce a well-compacted mixture. Bottom ash is generally a more well-graded aggregate than boiler slag, which is normally more uniformly graded between the 4.75 mm (No. 4) and 0.42 mm (No. 40) sieve sizes. Pond ash may be a blend of bottom ash and fly ash, and will vary in gradation, depending on its location in the pond relative to the discharge pipe. Bottom ash may contain some agglomerations or popcorn-like particles. These agglomerations should either be reduced in size by clinker grinders at the power plant or removed by scalping or screening at the 12.7 mm (1/2 in) or 19 mm (3/4 in) screen.

Blending

When necessary to achieve a specified gradation, bottom ash or boiler slag may need to be blended with other aggregates. This is normally not necessary with bottom ash, but may be necessary with boiler slag.

Removal of Deleterious Materials

Deleterious materials, especially coal pyrites, should be removed at the power plant prior to use of bottom ash or boiler slag as an aggregate. The pyrites oxidize (or weather) over time, causing expansion and possible popouts of individual particles from the matrix. Soluble sulfates also occur in some bottom ashes. Low pH values are often used as an indicator for the presence of sulfates.

ENGINEERING PROPERTIES

Some of the engineering properties of bottom ash and/or boiler slag that are of particular interest when used as aggregates in stabilized base or subbase mixtures are gradation, specific gravity and unit weight, durability, and soundness.

Gradation: The size limits in Table 4-9 are recommended for cement-treated aggregate base by the Portland Cement Association and are applicable to bottom ash and/or boiler slag use in cement-treated base course mixes.

Table 4-9. Recommended gradation for cement stabilized base.

Sieve Size	Percent Passing

19 mm (3/4 in)	100
9.5 mm (3/8 in)	70-90
4.75 mm (No. 4)	55-90
3.35 mm (No. 8)	40-70
1.18 mm (No. 16)	30-60
0.075 mm (No. 200)	0-30

Specific Gravity and Unit Weight: The specific gravity of bottom ash usually ranges from 2.1 to 2.7, with dry unit weights ranging from 720 to 1600 kg/m^3 (45 to 100 lb/ft^3). The specific gravity of boiler slag usually ranges from 2.3 to 2.9, with dry unit weights ranging from 960 to 1440 kg/m^3 (60 to 90 lb/ft^3). With bottom ash, lower specific gravity is usually indicative of the presence of porous, popcorn-like particles, which readily degrade under compaction.

Durability: In ASTM C131 (Los Angeles Abrasion) tests, bottom ash has had loss values between 30 and 50 percent. Boiler slag has had loss values between 24 and 48 percent. Most bottom ashes have loss values less than 45 percent, enabling them to meet ASTM requirements for soil-aggregate base and subbase materials.

Soundness: The durability of an aggregate for possible use in stabilized bases or subbases can be evaluated by the sodium sulfate soundness test. Bottom ash has had sodium sulfate soundness loss values that normally range from 1.5 to 10.5 percent. Boiler slag has had sodium sulfate soundness loss values of between 1 and 9 percent. The lower the specific gravity, the higher the probable percentage of deleterious material in the ash, which will likely be reflected in a higher value for soundness loss.

DESIGN CONSIDERATIONS

Mix Design

For pozzolan-stabilized base (PSB) mixtures containing coal fly ash (along with either lime, Portland cement, or kiln dust as an activator), the initial step in determining mix design proportions is to find the optimum fines content. This is done by progressively increasing the percentage of fines and determining the compacted density of each blend. Fly ash alone can be used to represent the total fines. A Proctor mold and standard compaction procedures are used for each blend of bottom ash and/or boiler slag and fines. Fly ash percentages ranging from 25 to 45 percent by dry weight of the total blend are suggested for the initial trial mixes.

At least three different fly ash additions are needed to establish the optimum fines content, which is the percentage of fines that results in the highest compacted dry density. The dry density for each fly ash percentage is then plotted to identify the optimum fines content. An optimum moisture content must then be determined for the selected mix design proportions.

Once the design fly ash percentage and optimum moisture content have been determined, the activator (lime, Portland cement, kiln dust, etc.) percentage must also be established. Trial mixtures using a gradual increase in the activator percentage are recommended. Final mix proportions are selected based on the results of compressive strength and durability testing, using ASTM C593 procedures. The objective is to meet strength and durability criteria with the most economical mix design.

For cement-stabilized bottom ash and/or boiler slag mixtures, the only mix design consideration is a determination of the percentage of Portland cement to be added to the mixture. As with the PSB mixtures, trial mixtures using several increasing percentages of cement will be necessary. Usually between 5 and 12 percent Portland cement will be needed to properly stabilize bottom ash and/or boiler slag for use as a roller-compacted base course. The results of ASTM C593 compressive strength and durability testing should be the basis for selection of final mix proportions.

The compacted unit weight of bottom ash and/or boiler slag mixes is usually considerably lower than the compacted unit weight of stabilized base mixtures containing conventional aggregates. Consequently, a cement content of 10 percent by weight for a base course mix containing bottom ash and/or boiler slag may be the equivalent of a 7 percent by weight cement content for a similar mix containing a normal weight aggregate.

In general, the trial mixture with the lowest percentage of cement (or activator plus fly ash in PSB mixtures) that satisfies both the compressive strength and the durability criteria is considered the most economical mixture. To ensure an adequate factor of safety for field placement, it is recommended that the stabilized base or subbase mixture used in the field have an activator content that is at least 0.5 percent higher (1.0 percent higher if using kiln dust) than that of the most economical mixture.(18)

Structural Design

The thickness design of stabilized base or subbase mixtures containing bottom ash or boiler slag can be undertaken using the standard structural equivalency design method for flexible pavements described in the AASHTO Design Guide.(19) This method uses an empirical structural number (SN) that relates pavement layer thickness to performance.

Table 4-10 lists recommended structural coefficient values based on studies of pozzolanic and crushed stone base materials(19) for stabilized base or subbase mixtures. The values are for stabilized base or subbase materials that attain a given range of compressive strength, regardless of the source of aggregate used or the type of reagent(s) in the design mix. These coefficient values are based on the use of a_1 = 0.44 (used for a bituminous wearing surface) and a value of a_3 = 0.15 (used for a crushed stone base).

Table 4-10. Recommended structural layer coefficient values for stabilized base and subbase materials.

Quality	Compressive Strength, psi (7 days @ 37.7° C)	Recommended Structural Layer Coefficient
High	Greater than 1,000	a_2 = 0.34
Average	650 to 1,000	a_2 = 0.28
Low	400 to 650	a_2 = 0.20

The main factors influencing the selection of the structural layer coefficient are the compressive strength and modulus of elasticity of the stabilized base material. The value of compressive strength recommended for determination of the structural layer coefficient is the field design compressive strength, which is the compressive strength developed in the laboratory after 56 days of moist curing at 73° F (23° C).(18) However, other time and temperature curing conditions may be required by various specifying agencies.

When a Portland cement concrete (PCC) roadway surface is to be designed with a stabilized base or subbase, the AASHTO structural design method for rigid pavements can be used.(19)

CONSTRUCTION PROCEDURES

Material Handling and Storage

Both bottom ash and boiler slag can be handled and stored using the same methods and equipment that are normally used for handling and storage of conventional aggregates.

Mixing, Placing, and Compacting

The blending or mixing of bottom ash or boiler slag in stabilized base mixtures can be done either in a mixing plant or in place. Plant mixing is recommended because it provides greater control over the quantities of materials batched and also results in the production of a more uniform mixture. Although mixing in place does not usually result in as accurate a proportioning of mix components as plant mixing, it is probably used more frequently with mixes involving bottom ash or boiler slag and will still produce a satisfactory stabilized base material.

Stabilized base materials should not be placed in layers that are less than 100 mm (4 in) or greater than 200 to 225 mm (8 to 9 in) in compacted thickness. These materials should be spread in loose layers that are approximately 50 mm (2 in) greater in thickness prior to compaction than the desired compacted thickness. The top surface of an underlying layer should be scarified prior to placing the next layer. For granular or coarse graded mixtures, steel-wheeled vibratory rollers are most frequently used for compaction. For more fine-grained mixtures, a vibratory sheepsfoot roller, followed by a pneumatic roller, is often employed.(18)

To develop the design strength of a stabilized base mixture, the material must be well-compacted and must be as close as possible to its optimum moisture content when placed. Plant-mixed materials should be delivered to the job site as soon as possible after mixing and should be compacted within a reasonable time after placement.

When self-cementing fly ashes are used as a cementitious material in stabilized base mixtures, compaction should be accomplished as soon as possible after mixing. Otherwise, delays between placement and compaction of such mixtures may be accompanied by a significant decrease in the strength of the compacted stabilized base material, unless a retarder is used. A commercial retarder, such as gypsum or borax, may be added at the mixing plant in low percentages (approximately 1 percent by weight) without adversely affecting the strength development of the stabilized base material. (18)

Curing

After placement and compaction, the stabilized base material must be properly cured to protect against drying and to assist in the development of in-place strength. An asphalt emulsion seal coat should be applied to the top surface of the stabilized base or subbase material within 24 hours after placement. The same practice is applicable if a PCC pavement is to be constructed above the stabilized base or subbase material. Placement of asphalt paving over the stabilized base is recommended within 7 days after the base has been installed. Unless an asphalt binder and/or surface course has been placed over the stabilized base material, it is recommended that vehicles should not be permitted to drive over the material until it has achieved an in-place compressive strength of at least 2400 kPa (350 lb/in^2).(18)

Special Considerations

Cold Weather Construction: Stabilized base materials containing bottom ash and/or boiler slag that are subjected to freezing and thawing conditions must be able to develop a certain level of cementing action and in-place strength prior to the first freeze-thaw cycle in order to withstand the disruptive forces of such cycles. For northern states, many state transportation agencies have established construction cutoff dates for stabilized base materials. These cutoff dates ordinarily range from September 15 to October 15, depending on the state, or the location within a particular state, as well as the ability of the stabilized base mixture to develop a minimum desired compressive strength within a specified time period.(19)

Crack Control Techniques: Stabilized base materials, especially those in which Portland cement is used as the activator, are subject to cracking. The cracks are almost always shrinkage related and are not the result of any structural weakness or defects in the stabilized base material. The cracks also do not appear to be related to the type of aggregate used in the base mix. Unfortunately, shrinkage cracks eventually reflect through the overlying asphalt pavement and must be sealed at the pavement surface to prevent water intrusion and subsequent damage due to freezing and thawing.

One approach to controlling or minimizing reflective cracking associated with shrinkage cracks in stabilized base materials is to saw cut transverse joints in the asphalt surface that extend into the stabilized base material to a depth of 75 mm (3 in) to 100 mm (4 in). Joint spacings of 9 m (30 ft) have been suggested.(18) The joints should all be sealed using a hot poured asphaltic joint sealant.

UNRESOLVED ISSUES

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. Since most mixtures that include bottom ash and/or boiler slag as the aggregate have been placed on secondary roads, haul roads, and parking lots, as opposed to higher-type highway facilities, the issue of crack control has not been as great a concern to the owners or administrators of these installations. However, additional mix designs with reduced potential for shrinkage cracking need to be developed, especially if these materials are someday to be used on higher-type facilities.

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 quatity to be considered detrimental. Improved techniques for timely removal of these detrimental constituents are needed.

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[Material Description] [Asphalt Concrete] [Granular Base]