

Corrosivity of Indiana Bottom Ash

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Current studies of the engineering properties of bottom ash have justified its use in many kinds of highway construction, such as backfill, embankment, subbase, and even base courses. However, the electrochemical characteristics of bottom ash are still not well known, and neither is its corrosivity to the metal structures that are commonly included in highway construction. A simple corrosivity test and corrosivity evaluation results are presented for Indiana bottom ashes to clarify the extent of this problem. Four corrosivity parameters were used to estimate the corrosivity of bottom ash: minimum electrical resistivity (r), pH, soluble chloride content (Cl^-), and soluble sulfate content (SO_4^{2-}). The corresponding noncorrosive limits are proposed to be a minimum resistivity of 1,500 ohm-cm, a minimum pH of 5.5, a maximum soluble chloride of 200 ppm, and a maximum soluble sulfate of 1,000 ppm. Eleven bottom ashes collected from 10 power plants in Indiana were tested. The r varied from 200 to 7,000 ohm-cm, the pH from 3 to 10, the Cl^- from 0.4 to 16 ppm, and the SO_4^{2-} from 50 to 1,100 ppm. At least 7 of the 11 bottom ashes tested were therefore classified as corrosive. Most Indiana bottom ashes are potentially corrosive. If the same holds true for bottom ashes produced in other states, the following actions are recommended before use in the vicinity of the metal structure in highway construction: (a) thoroughly examine the corrosion potential of the bottom ashes proposed for use; (b) pretreat the potentially corrosive bottom ashes, either at the power plant source or on the site of use; and (c) use corrosion-resistant metal members or plastic substitutes.

The corrosivity of bottom ash may limit its extensive use in highway construction. Simple corrosivity tests and corrosivity evaluation results of bottom ash samples collected in Indiana are presented.

Every year a huge quantity of solid waste is produced by industry. The disposal of this waste is costly and may cause environmental problems. If this material were to be reused, not only could a solid waste disposal problem be solved but an alternative material could be provided for the construction market.

Recently, bottom ash has become one of the solid wastes most actively considered for reuse. Bottom ash is one kind of coal ash, a slag material that builds up on the heat-absorbing surface of a coal furnace and subsequently falls through the furnace bottom to the ash hopper below (see Figure 1). Either wet or dry bottom ash may be produced (1). Wet bottom ash particles are generally black, hard, and look much like crushed glass, since they derive from the quenching of the molten ash from the furnace into water. In contrast, during its sedimentation through the furnace bottom, dry bottom ash directly solidifies and agglomerates into coarse particles, which are gray and more porous ("popcorn"

like). Recent studies on the engineering properties of bottom ash (1,2) have recommended the use of bottom ash in many kinds of highway construction, such as backfill, embankment, subbase, and even base courses.

In highway construction, metal structures such as steel culverts, rebars in concrete, steel piles as retaining walls, and reinforcing steel strips in reinforced earth are often involved. Since the electrochemical characteristics of bottom ash are not well defined, potential interactions between the bottom ash and such metal structures are of concern. Accordingly, the corrosivity of bottom ash needs to be examined to clarify the extent of this problem. That was the objective of the study reported herein.

Corrosivity tests selected for routine highway use must be simple and inexpensive. In this study, a set of electrochemical characteristics was chosen to estimate the corrosivity of bottom ash. They are minimum resistivity (r), pH, soluble chloride content (Cl^-), and soluble sulfate content (SO_4^{2-}). Accordingly, the testing program in this study was limited to the determination of these four characteristics, which mostly followed the test methods used by the California Department of Transportation. Thereafter, the corrosivity of bottom ash samples was evaluated by comparing the testing results with the proposed evaluation criteria. The reliability of the testing methods used in this study and the validity of the proposed evaluation criteria need to be justified by future field burial tests.

LITERATURE REVIEW

Studies on the corrosion tendency of metals in a bottom ash environment are limited. Most investigators [Headon and Chan (3), Jablonski and Aliff (4), and Reinforced Earth Company (5)] have transferred knowledge of metal corrosion in soils to the case of bottom ashes. This section briefly covers definition, significance, mechanism, and test methods for corrosivity. Most of the contents of this section are extracted from Ke (6).

Definition

Corrosion is the deterioration of a metal, usually caused by chemical or electrochemical interaction with the surrounding environment or media. Corrosivity is the characteristics of a material (or an environment) that indicate the likelihood of its causing the corrosion of a contacted metal. In a metal/medium system where corrosion is severe, either the metal is denoted as easily corroded or the medium is denoted as very corrosive.

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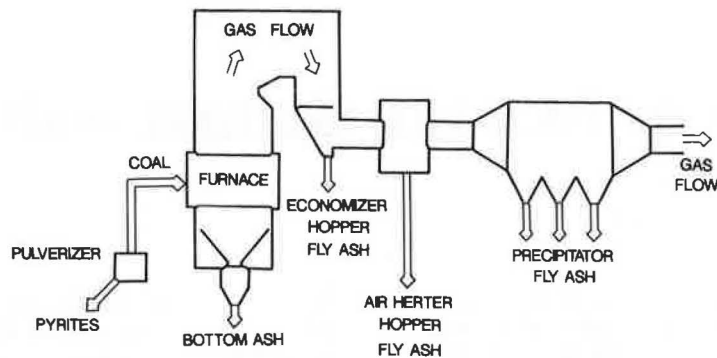


FIGURE 1 Ash collection system.

Significance

Corrosion may result in mechanical failure of metal members or leakage of metal pipes. This leads to high maintenance costs or required replacement of corroded metal members. The annual direct losses due to corrosion in the United States were reported to be \$70 billion (7). The combination of direct and indirect losses is forcing engineers and scientists to further study and understand complicated corrosion mechanisms and to find effective solutions. In highway construction, attention is often directed to the selection of noncorrosive engineering materials to be used in the vicinity of metal structures.

Underground Corrosion

Corrosion environments include atmospheric, aqueous, and underground environments. Because of the proposed use of bottom ash (like soils), only underground corrosion is of interest. Understanding of the underground corrosion mechanism has been developed through experience with soils. Escalante (8) characterized four types of underground corrosion: corrosion by stray current, bacteria corrosion, corrosion in undisturbed soils, and corrosion in disturbed soils. Corrosion in disturbed soils is the most complex, relating to a variety of soil characteristics and site conditions. Ke (6) presented the possible correlations between them, as given in Table 1. Furthermore, he considered the nature of bottom ash and the site conditions after construction and concluded that the parameters best related to the corrosivity of bottom ash are as follows: minimum resistivity, pH, soluble chloride content, and soluble sulfate (in order of decreasing significance), along with site variations in water content, alien inclusions, and so forth. A material with lower values of minimum resistivity and pH and higher values of soluble chloride and soluble sulfate is, generally, more corrosive.

Test Methods

Three methods have been used to investigate the corrosion resistance of a metal or the corrosivity of a surrounding medium. They consist of burial methods (a direct method by measuring metal losses), electrochemical techniques (mainly

measuring the corrosion potential or current followed by converting it to metal loss), and correlation between medium parameters and corrosivity (multivariate regression analyses). Burial methods are the most reliable but are costly (time-consuming) and destructive, whereas electrochemical techniques are reliable and nondestructive. The cost and reliability of the correlation methods depend on the number of parameters to be used.

In this study, because of the limitation of funding and time, the correlation method with the aforementioned four electrochemical characteristics was selected to estimate the corrosivity of bottom ash. On the basis of several available evaluation criteria for soil corrosivity (with respect to these four parameters) (9–13), the approximate noncorrosive limits for bottom ash to general metal structures are proposed as follows [see Ke (6) for details]: $r > 1,500$ ohm-cm, $\text{pH} > 5.5$, $\text{Cl}^- < 200$ ppm, and $\text{SO}_4^{2-} < 1,000$ ppm.

The more sophisticated criteria of this kind should also depend on metal type, functional use, structure size, and so forth. Ke (6) also collected information from previous studies and provided the approximate service life of several metal members corresponding to the preceding criteria and that for other values of the four parameters.

EXPERIMENTAL PROGRAM

In the sources from which the preceding criteria were extracted (9–13), California test methods were specified in determining the four parameters. Therefore, the testing program (laboratory) of this study basically followed these methods to readily apply the criteria to testing results. Field tests of pH and resistivity were also performed on the ash deposits of several power plants. Data are available in Ke (6).

Selection of Samples

A total of 11 bottom ashes from 10 power plants in Indiana were sampled for testing. Consideration was given to furnace type, coal source, geographic distribution, and ash storage method. Figure 2 shows the approximate locations of the power plants. All ash samples except the Schahfer 14 ash were dry bottom ashes.

TABLE 1 CORRELATIONS BETWEEN UNDERGROUND CORROSION TYPES AND ELEMENTS OF CORROSION IN DISTURBED SOILS (6)

+: positively-related -: negatively-related	Disturbed Soils (DS)													
	SC	SRB	US	R	W	RE	pH	SS	Cl	SO ₃	SO	Fe	AE	ID
Stray Current (SC)	+			-	+			+						+
Sulfate-Reducing Bacteria (SRB)		+	+			-				+	+	+	-	-
Undisturbed Soils (US)			+	+									-	-
Resistivity (R)	-			+	-			-	-	+	+	+	-	-
Moisture (W)	+			+	+		+	+	+	+	+	+	-	-
Redox Pot. (RE)		-				+	+						+	
pH						+	+							±
Soluble Salts (SS)	+			-	+			+					+	+
Cl ⁻ (Cl)				-	+			+					+	+
SO ₃		+			+				+				+	+
DS SO ₄ ²⁻ (SO)		+			+		-			+			+	+
Fe ₂ (Fe)		+			+						+		+	+
Aeration (AE)		-	-		-	+						+	+	+
Internal Drainage (ID)								+	+	+	+	+	+	+
Temperature (T)	+			-	-			+	+	+	+	+	+	+
Change of Water Table (WT)			-										+	+
Water Movement (WM)				+				-	-	-	-	-		+
Inhomogeneity (IN)				±									+	+
Alien Inclusion (AI)				±				±	±	±	±	±	±	+



FIGURE 2 Approximate locations of 10 power plants in Indiana.

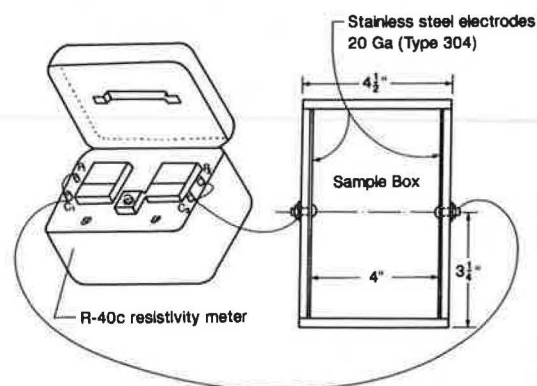


FIGURE 3 Connection of R-40C meter with sample box.

Determination of Minimum Resistivity

The configuration of the sample box (in a plan view) and its connection with a SOILTEST R-40C resistivity meter is shown in Figure 3. The determination of minimum resistivity was mainly conducted as specified in California Test 532 (9), except for one testing procedure modified by the authors. Since this test method specifies the maximum size of particles used for testing to be the opening of the No. 8 sieve (related to the dimension of the sample box), it does not take into account the contribution of the coarser particles to the measured resistivity. A crushing method was hence used to crush the ash

sample into particles smaller than the aforementioned maximum size, followed by the other operational procedures described in the method. "Crushing" would increase the total surface area of ash particles that water can access and the intensity of ion diffusion from ash to water, probably leading to a lower resistivity value (a more critical point). Indeed, lower resistivity values were observed in some dry bottom ash samples after crushing than in the same samples with larger particles sieved out (6). The minimum resistivity is usually obtained when the ash sample is fully saturated.

Determination of pH Values

The laboratory determination of pH was also made in accordance with California Test 532 (9). First, 2 teaspoons of bottom ash were mixed with 2 teaspoons of deionized water in a cup (with an ash:water ratio near unity), and the pH values were

then measured using a Corning meter 125, with a reading precision of two decimal places. The suggested crushing procedure was also performed on the samples before measuring to obtain a pH value more representative of all the ash particles. The effects of particle size, ash:water ratio, and stirring time on pH value can be found in Ke (6).

Determination of Soluble Chloride Content

The determination of the soluble chloride content present in the ash sample was basically accomplished following the California Test 422 (14). However, instead of a potassium chromate indicator, an Orion combination chloride electrode (Cat. No. 961700) was used to measure the endpoint of titration of soluble chloride (in the ash-water suspension) and silver nitrate (added), from which the soluble chloride content was calculated. The effect of stirring/suspending time on Cl^- can be found in Ke (6).

Determination of Soluble Sulfate Content

The determination of soluble sulfate content was performed in accordance with the California Test 417 (15), except that a filtration method was used to determine the amount of BaSO_4 instead of a turbidimeter (not available in the laboratory). The effect of stirring/suspending time on SO_4^{2-} can be found in Ke (6).

TEST RESULTS AND CORROSIVITY EVALUATION

Test Results

Table 2 summarizes the test results of the 11 ashes examined. Because of the time constraint, determinations of soluble chloride and sulfate contents were only conducted on the first four bottom ashes in the table. The r varied from 200 to 7,000 ohm-cm, the pH from 3 to 10, the Cl^- from 0.4 to 16 ppm (μg of Cl^- per gram of dried ash), and the SO_4^{2-} from 50 to 1,110 ppm (μg of SO_4^{2-} per gram of dried ash).

Corrosivity Evaluation

The results of corrosivity evaluations of Indiana bottom ashes are summarized in Table 3. A bottom ash is classified as noncorrosive if all four parameters meet the corresponding noncorrosive limits; otherwise, it is corrosive. For the seven ash samples lacking data on Cl^- and SO_4^{2-} , meeting the limits of both r and pH led to a tentative classification of noncorrosive. (This is not conservative.) Therefore, at least 7 of the 11 bottom ashes (about 64 percent) were classified as corrosive. The comparison of the results of the Schahfer 14 ash and those of the others in Table 3 indicates that wet bottom ash seems to be much less corrosive than dry bottom ash. Moreover, comparing the data in Table 3 with those of natural soils (16) and those of backfills used by the Reinforced Earth

Company (17), Indiana bottom ashes appeared to be more corrosive.

CONCLUSIONS AND RECOMMENDATIONS

Most Indiana bottom ashes are potentially corrosive, on the basis of the four ash characteristics and the proposed evaluation criteria. The reliability of the test methods used and the validity of the proposed evaluation criteria need to be verified by future field tests. If the same conclusion holds true for bottom ashes produced in other states, note of this should be taken by all state highway agencies before selecting bottom ash as an alternative highway construction material in the vicinity of metal structures.

To avoid possible corrosion failure of the adjacent metal structures in highway construction, the following actions are recommended:

1. Thoroughly examine the corrosivity of the bottom ashes proposed for use;
2. Pretreat the potentially corrosive bottom ashes before their use, either at the power plant or on the site of use; and
3. Use corrosion-resistant steel structures or plastic substitutes.

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TABLE 2 CORROSIVITY PARAMETERS OF INDIANA BOTTOM ASHES

Ash Name	r (ohm-cm)	pH	Cl^- (ppm)	SO_4^{2-} (ppm)
Perry K.	980	4.8	15.5	598
Gibson	2201	7.6	7.3	1127
Schahfer 14 ^a	>6663	9.6	0.4	50
Schahfer 17	3082	8.6	6.1	383
Gallegher	335	9.1	- ^b	-
Mitchell	1771	8.0	-	-
Wabash	1051	5.7	-	-
Richmond	247	8.2	-	-
Stout	4249	6.6	-	-
Culley	486	8.5	-	-
Brown	213	3.2	-	-

^a wet bottom ash

^b not determined

TABLE 3 CORROSIVITY EVALUATION OF INDIANA BOTTOM ASHES

Ash Name	Acceptance				Overall Corrosivity
	r	pH	Cl ⁻	SO ₄ ²⁻	
Perry K.	NA ^a	NA	A ^b	A	C ^c
Gibson	A	A	A	NA	C
Schahfer 14 ^e	A	A	A	A	NC ^d
Schahfer 17	A	A	A	A	NC
Gallegher	NA	A	- ^f	-	C
Mitchell	A	A	-	-	NC
Wabash	NA	A	-	-	C
Richmond	NA	A	-	-	C
Stout	A	A	-	-	NC
Culley	NA	A	-	-	C
Brown	NA	NA	-	-	C

^a not meeting the limit of the proposed criteria^b meeting the limit of the proposed criteria^c denoting "corrosive", if at one "NA" exists^d denoting "noncorrosive", if no "NA" exists^e wet bottom ash^f not determined

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