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Standard Guide for Use of Coal Combustion Products (CCPs) for Surface Mine Reclamation: Revegetation and Mitigation of Acid Mine Drainage[1]

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1. Scope

1.1 This guide covers the beneficial use of coal combustion products (CCPs) for abatement of acid mine drainage and revegetation for surface mine reclamation applications related to area mining, contour mining, and mountaintop removal mining. It does not apply to underground mine reclamation applications. There are many important differences in physical and chemical characteristics that exist among the various types of CCPs available for use in mine reclamation. CCPs proposed for each project must be investigated thoroughly to design CCP placement activities to meet the project objectives. This guide provides procedures for consideration of engineering, economic, and environmental factors in the development of such applications.

1.2 The utilization of CCPs under this guide is a component of a pollution prevention program; Guide E1609 describes pollution prevention activities in more detail. Utilization of CCPs in this manner conserves land, natural resources, and energy.

1.3 This guide applies to CCPs produced primarily from the combustion of coal.

1.4 The testing, engineering, and construction practices for using CCPs in mine reclamation are similar to generally accepted practices for using other materials, including cement and soils, in mine reclamation.

1.5 Regulations governing the use of CCPs vary by state. The user of this guide has the responsibility to determine and comply with applicable regulations.

1.6 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C188 Test Method for Density of Hydraulic Cement
C311 Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
C400 Test Methods for Quicklime and Hydrated Lime for Neutralization of Waste Acid
D75 Practice for Sampling Aggregates
D420 Guide to Site Characterization for Engineering Design and Construction Purposes (Withdrawn 2011)[3]
D422 Test Method for Particle-Size Analysis of Soils
D653 Terminology Relating to Soil, Rock, and Contained Fluids
D698 Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3 (600 kN-m/m^3))
D854 Test Methods for Specific Gravity of Soil Solids by Water Pycnometer
D1195 Test Method for Repetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements
D1452 Practice for Soil Exploration and Sampling by Auger Borings
D1557 Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft^3 (2,700 kN-m/m^3))
D1586 Test Method for Penetration Test (SPT) and Split-Barrel Sampling of Soils

[1] This guide is under the jurisdiction of ASTM Committee E50 on Environmental Assessment, Risk Management and Corrective Action and is the direct responsibility of Subcommittee E50.03 on Pollution Prevention/Beneficial Use.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] The last approved version of this historical standard is referenced on www.astm.org.

D1883 Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils
D2166 Test Method for Unconfined Compressive Strength of Cohesive Soil
D2216 Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass
D2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading
D3080 Test Method for Direct Shear Test of Soils Under Consolidated Drained Conditions
D3550 Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils
D3877 Test Methods for One-Dimensional Expansion, Shrinkage, and Uplift Pressure of Soil-Lime Mixtures
D3987 Practice for Shake Extraction of Solid Waste with Water
D4253 Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table
D4254 Test Methods for Minimum Index Density and Unit Weight of Soils and Calculation of Relative Density
D4448 Guide for Sampling Ground-Water Monitoring Wells
D4767 Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils
D4972 Test Method for pH of Soils
D5084 Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter
D5092 Practice for Design and Installation of Groundwater Monitoring Wells
D5239 Practice for Characterizing Fly Ash for Use in Soil Stabilization
D5759 Guide for Characterization of Coal Fly Ash and Clean Coal Combustion Fly Ash for Potential Uses
D5851 Guide for Planning and Implementing a Water Monitoring Program
E1527 Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process
E1609 Guide for Development and Implementation of a Pollution Prevention Program (Withdrawn 2010)[3]
E2201 Terminology for Coal Combustion Products

2.2 *Other Methods:*
EPA Method 1312 Synthetic Precipitation Leaching Procedure (SPLP)(**1**)[4]
EPA Method 1320 Multiple Extraction Procedure (MEP)(**2**)
EPA Method Monofill Waste Extraction Procedure (MWEP)(**3**)
Synthetic Ground Water Leaching Procedure (SGLP)(**4**)
Long-Term Leaching Procedure (LTL)(**4**)

3. Terminology

3.1 *Definitions*—For definitions related to coal combustion products, see Terminology E2201. For definitions related to geotechnical properties see Terminology D653.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *acid-forming materials*—earth materials that contain sulfide mineral or other materials, which, if exposed to air, water, or weathering processes, will produce acids that may result in acid drainage.

3.2.2 *basicity factor*—a measure of alkalinity which can be used for comparing relative neutralization power of materials. It is determined as grams of calcium oxide equivalents per kilogram of material.

3.2.3 *bench*—a ledge, shelf or terrace formed in the contour method of strip mining or formed in surface operations of underground coal mining.

3.2.4 *disturbed area*—those lands that have been affected by surface mining and reclamation operations, or by surface operations of underground coal mining.

3.2.5 *final grade*—the finished elevation of any surface disturbance prior to replacement of topsoil.

3.2.6 *internal erosion*—piping; the progressive removal of soil particles from a mass by percolating water, leading to the development of channels.

3.2.7 *overburden*—all of the earth and other materials, excluding topsoil, which lie above a natural deposit of coal and also means such earth and other material after removal from their natural state in the process of strip mining.

3.2.8 *permeability, n*—the capacity to conduct liquid or gas. It is measured as the proportionality constant, k, between flow velocity, v, and hydraulic gradient, i; $v = ki$.

3.2.9 *productivity*—the vegetative yield produced by a unit area for a unit of time.

3.2.10 *recharge capacity*—the ability of the soils and underlying materials to allow precipitation and run-off to infiltrate and reach the zone of saturation.

3.2.11 *soil horizons*—contrasting layers of soil lying one below the other, parallel or nearly parallel to the land surface. Soil horizons are differentiated on the basis of field characteristics and laboratory data. The three major soil horizons are:

3.2.11.1 *A horizon*—the uppermost layer in the soil profile often called the surface soil. It is the part of the soil in which organic matter is most abundant, and where leaching of soluble or suspended particles is the greatest.

3.2.11.2 *B horizon*—the layer immediately beneath the A-horizon and often called the subsoil. This middle layer commonly contains more clay, iron, or aluminum than the A or C-horizons.

3.2.11.3 *C horizon*—the deepest layer of the soil profile. It consists of loose material or weathered rock that is relatively unaffected by biologic activity.

3.2.12 *spoil*—overburden that has been removed during surface mining.

3.2.13 *stabilize*—any method used to control movement of soil, spoil piles, or areas of disturbed earth and includes increasing bearing capacity, increasing shear strength, draining, compacting, or revegetating.

3.2.14 *water table*—the upper surface of saturation, where the body of ground water is not confined by an overlying

[4] The boldface numbers in parentheses refer to the list of references at the end of this standard.

impermeable zone. The seasonal high water table is the highest elevation that ground water reaches within the year.

4. Significance and Use

4.1 *General*—CCPs can effectively be used to reclaim surface mines (**5-10**). First, CCPs are ideally suited for use in numerous reclamation applications. Any type of CCP may be evaluated for use in mine reclamation. Project specific testing is necessary to ensure that the CCPs selected for use on a given project will meet the project objectives. Second, the use of CCPs can save money because they are available in bulk quantities and reduce expenditures for the manufacture and purchase of Portland cement or quicklime. Third, large-scale use of CCPs for mine reclamation conserves valuable landfill space by recycling a valuable product to abate acid mine drainage and reduce the potential for mine subsidence, provided that the CCP is environmentally and technically suitable for the desired use. The availability of CCPs makes it possible to reclaim abandoned mineland that could not otherwise be reclaimed. The potential for leaching constituents contained in CCPs should be evaluated to ensure that there is no adverse environmental impact.

4.2 *Physical and Chemical Properties and Behavior of CCPs*—Fly ash, bottom ash, boiler slag, FGD material and FBC ash, or combinations thereof, can be used for mine reclamation. Each of these materials typically exhibits general physical and chemical properties that must be considered in the design of a mine reclamation project using CCPs. The specific properties of these materials vary from source to source so environmental and engineering performance testing is recommended for the material(s) or combinations to be used in mine reclamation projects.

4.2.1 *Physical Properties:*

4.2.1.1 *Unit Weight*—Unit weight is the weight per unit volume of material. Fly ash has a low dry unit weight, typically about 50 to 100 pcf (8 to 16 kN/m^3). Bottom ash is also typically lighter than coarse grained soils of similar gradation. Stabilized FGD material from a wet scrubber and FGD material from a dry scrubber are also relatively lightweight, with unit weights similar to fly ash.

4.2.1.2 *Strength*—Shear strength is the maximum resistance of a material to shearing stresses. The relatively high shear strength of fly ash is beneficial for CCP flowable fill formulations requiring strengths sufficient to prevent mine subsidence. The shear strength of non-self-hardening fly ash is primarily the result of internal friction. Cementitious CCPs experience a cementing action that is measured as cohesion and increases over time, which results in high compressive strength. Unconfined compressive strengths in excess of 1000 psi can be achieved for cementitious CCPs.

4.2.1.3 *Specific Gravity*—Specific gravity is the ratio of the weight in air of a given volume of solids at a stated temperature to the weight in air of an equal volume of distilled water at a stated temperature. The particle specific gravity of fly ash is relatively low compared to that of natural materials, and generally ranges from 2.1 to 2.6.

4.2.1.4 *Grain-Size Distribution*—Grain-size distribution describes the proportion of various particle sizes present in a material. Fly ash is a uniformly-graded product with spherical, very fine grained particles.

4.2.1.5 *Moisture Content*—Moisture content is the ratio of the mass of water contained in the pore spaces of soil or rock material to the solid mass of particles in that material, expressed as a percentage. CCPs have almost no moisture when first collected after the combustion of coal. Power plant operators sometimes add moisture to facilitate transport and handling, a process termed "conditioning."

4.2.1.6 *Coefficient of Permeability*—Permeability is the capacity of a material to transmit a liquid. When compacted to its maximum dry density, fly ash can have permeabilities ranging from 10 to 10^{-3} gpd/ft^2 (10^{-4} to 10^{-7} cm/s). These permeabilities are comparable to natural silty soils.

4.2.2 *Chemical Properties:*

4.2.2.1 *Elemental Composition*—The major elemental components of CCPs are silica, aluminum, iron, calcium, magnesium, sodium, potassium, and sulfur. These elements are present in various amounts and combinations dependent primarily on the coal and type of CCP. The elements combine to form amorphous (glassy) or crystalline phases. Trace constituents may include elements such as arsenic, boron, cadmium, chromium, copper, chlorine, mercury, manganese, molybdenum, selenium, or zinc.

4.2.2.2 *Phase Associations*—The primary elemental constituents of CCPs are present either as amorphous (glassy) phases or crystalline phases. Coal combustion fly ash is typically 70+ % amorphous material. FGD and FBC products are primarily crystalline, and the crystalline phases typically include lime (CaO), portlandite ($Ca(OH)_2$), hannebachite ($CaSO_3 \cdot \frac{1}{2} H_2O$), and forms of calcium sulfate.

4.2.2.3 *Free Lime Content*—Free lime content varies among CCP sources and other potential activators (for example, lime kiln dust, cement kiln dust, quicklime, or Portland cement). Variability of free lime content in CCP sources is due to the type and efficiency of the emissions control technology that is used. FBC products typically contain up to 10 % free lime, while most Class F fly ash has no free lime content. The free lime content of other potential activators is also variable. For example, cement kiln dust typically ranges from 20 to 30 % free lime whereas quicklime contains 100 % free lime.

4.2.2.4 *Pozzolanic Activity*—Most CCPs, with the exception of FGD material, are characterized as pozzolans due to the presence of siliceous or siliceous and aluminous materials that in themselves possess little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

4.2.2.5 *Buffer Capacity*—The buffer capacity of the CCP is important in maintaining the high pH that generally is a requirement for neutralizing acidic materials such as acid mine drainage or for minimizing acid formation from acid forming materials. The CCP must have enough buffer capacity to maintain the pH of the treated areas so the area remains stable over time and under environmental stresses. Test Methods C400 can be applied to evaluate the buffer capacity of the CCP. Determine the basicity factor for the CCP as noted in Test Method B of Test Methods C400.

4.3 *Environmental Considerations:*

4.3.1 *Regulatory Framework:*

4.3.1.1 *Federal*—The U.S. Department of the Interior Office of Surface Mining (OSM) is charged with the responsibility of ensuring that the national requirements for protecting the environment during coal mining are met and making sure the land is reclaimed after it is mined. When the use of CCPs happens at surface coal mines, state or federal coal-mining regulators are involved to the extent that SMCRA (Surface Mining Control and Reclamation Act) requires the mine operator to ensure that:

(1) All toxic materials are treated, buried, and compacted, or otherwise disposed of, in a manner designed to prevent contamination of ground or surface water (30 CFR 816/817.41).

(2) The proposed land use does not present any actual or probable threat of water pollution (30 CFR 816/817.133).

(3) The permit application contains a detailed description of the measures to be taken during mining and reclamation to ensure the protection of the quality and quantity of surface and ground water systems, both on- and off-site, from adverse effects of the mining and reclamation process (30 CFR 780.21 and Sections 401.402, or 404 of the Clean Water Act).

(4) The rights of present users of such water are protected (30 CFR 816/817.41).

(5) Any disposal of CCPs at mine sites must be in accordance with those standards and with applicable solid waste disposal requirements (30 CFR 816/817.89).

SMCRA gives primary responsibility for regulating surface coal mine reclamation to the states, and 24 coal-producing states have chosen to exercise that responsibility. On federal lands and Indian reservations (Navajo, Hopi, and Crow) and in the coal states that have not set up their own regulatory programs (Tennessee and Washington), OSM issues the coal mine permits, conducts the inspections, and handles the enforcement responsibilities. As a result of the activities associated with the SMCRA, coal mine operators now reclaim as they mine, and mined lands are no longer abandoned without proper reclamation. OSM also collects and distributes funds from a tax on coal production to reclaim mined lands that were abandoned without being reclaimed before 1977. OSM has a Coal Combustion Residues Management Program that focuses on providing expert technical information on the use of CCPs in mine reclamation for the mining industry, regulatory agencies, and other stakeholders. Use of CCPS in reclamation procedures should be proposed in the mining permit application if possible, detailing the type and characteristics of the proposed CCP and the specific beneficial use for the location proposed. In 1999, U.S. Environmental Protection Agency (EPA) completed a two-phased study of CCPs for the U.S. Congress as required by the Bevill Amendment to RCRA. At the conclusion of the first phase in 1993, EPA issued a formal regulatory determination that the characteristics and management of the four large-volume fossil fuel combustion waste streams (that is, fly ash, bottom ash, boiler slag, and flue gas emission control waste) do not warrant hazardous waste regulation under RCRA and that utilization practices for CCPs appear to be safe. In addition, EPA "encourage[d] the utilization of coal combustion by-products and support[ed] state efforts to promote utilization in an environmentally beneficial manner." In the second phase of the study, EPA focused on the by-products generated from FBC boiler units and the use of CCPs from FBC and conventional boiler units for mine reclamation, among other things. Following completion of the study, EPA issued a regulatory determination that again concluded that hazardous waste regulation of these combustion residues was not warranted. However, EPA also decided to develop national solid waste regulatory standards for CCPs, including standards for placement of CCPs in surface or underground mines, either under RCRA, SMCRA, or a combination of the two programs (65 CFR 32214, May 22, 2000).

4.3.1.2 *State and Local*—There is considerable variation in state-mandated permitting and other regulatory requirements for CCP utilization. Some states have specific beneficial use policies, while other states have no regulations or guidance addressing beneficial use. Although the NEPA (National Environmental Policy Act) strictly applies only to federally funded projects, many states have similar mechanisms for assessing the environmental impacts of non-Federal projects. These mechanisms may require state permits that address any or all of the following issues: wetlands/waterways, National Pollutant Discharge Elimination System (NPDES) discharge, underground injection, erosion and sediment control, air quality considerations, and storm water management.

4.3.2 *Water Quality*—When planning to use CCPs for mine reclamation, one should consider the potential impacts on ground water and surface water to ensure protection of human health and the environment.

4.3.2.1 *Ground Water*—The design and implementation of a mine reclamation project should consider the potential ground water impacts of CCPs to ensure the protection of human health and the environment. Considerable research has been conducted to assess and predict the potential impacts of CCP utilization on ground water quality. An assessment of ground water quality impacts should be performed by a qualified professional and should take into account project-specific considerations such as composition of CCPs, the typical leachability of CCPs, presence of acid forming materials or acid mine drainage, placement of CCPs relative to the ground water table, rates of infiltration, the type of placement used for the CCP, and constituent migration, attenuation in ground water, and location of sensitive receptors (that is, wells). Where protection of ground water is a special concern, the leaching characteristics of the CCP should be evaluated as part of the assessment of constituent migration and attenuation. Consideration should be given to the leachability of the CCP in the presence of AMD.

NOTE 1—It is highly recommended that up-gradient and down-gradient wells be installed to determine background groundwater conditions prior to CCP placement. Then, following placement of CCPs, periodic monitoring of these wells should be done to determine any potential groundwater impact.]

4.3.2.2 *Surface Water*—CCPs may affect surface water bodies during and after placement activities as a result of erosion and sediment transport. The engineering and construction practices recommended to minimize these effects on surface