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

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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

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[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 waters (in accordance with the requirements of the 30 CFR 816.43 through 816–49 and any applicable federal or state permit) include storing the CCPs in stockpiles employing effective storm water management controls to maximize runoff and minimize run-on. Impacts could also be minimized by limiting size of active working face of area being reclaimed.

4.3.3 *Air Quality*—When planning to use CCPs for mine reclamation, one should consider the potential impacts to air quality including dusting and emissions.

4.3.3.1 *Dust Control*—Dusting must be controlled during the transport and handling of CCPs in order to avoid fugitive dust and to ensure worker safety. Dust control measures routinely used on earthwork projects are effective in minimizing airborne particulates at CCP storage sites. Typical controls include appropriate hauling methods, use of windbreaks, moisture conditioning of the CCPs, storage in bins or silos, covering the CCPs with large tarpaulins, wetting or covering exposed CCP surfaces, and paving or wetting unpaved high-traffic haul roads with coarse materials.

4.3.3.2 *Radionuclides*—Coal and fly ash are not significantly enriched in radioactive elements or in associated radioactivity compared to common soils or rocks (**11**). Certain radioactive elements including radium and uranium are known to occur naturally in CCPs (**12**) and other fill materials. The U.S. Department of Energy estimated the radium concentration of fly ash to be no more than 3.0 pCi/g (**13**). Radon emissions from the CCPs are not likely to exceed the naturally occurring ambient emissions.

4.4 *Economic Benefits*—The use of CCPs for mine reclamation can have economic benefits. These benefits are affected by local and regional factors, including production rates, processing and handling costs, transportation costs, availability and cost of competing materials, environmental concerns, and the experience of materials specifiers, design engineers, purchasing agents, contractors, legislators, regulators, and other professionals. CCPs are competing as manufactured materials and not as waste products. Since CCPs are produced in the process of manufacturing electricity, these materials can present an advantage when utilized as raw products for finished goods. This is primarily due to the low overheads involved with the material production cost and the fact that some, but not all coal-fired power plants have immediate access to low-cost transportation. The transport of coal to the power plant can provide an excellent opportunity to return CCPs to a mine site to aid in mine reclamation projects.

5. Site Characterization

5.1 *General*—The siting and design of a surface mine reclamation project requires the identification and resolution of site access and environmental issues and completion of a geologic and hydrogeologic investigation to characterize the subsurface and mine conditions. The degree to which these activities are needed to support the engineering design will vary for each mine site, depending upon whether the sites are abandoned or active. Practice E1527 may be applied whenever a real estate transaction is involved.

5.2 *Access*—In most cases, reclamation procedures will be included in the mining permit, and in active mining and associated reclamation, access to the site and associated areas of potential mining impact will be available for appropriate reclamation activities. Consideration of physical access to the area for reclamation with CCPs needs to include roads for hauling/delivering the CCP to the site and adequate area for placing, mixing, compacting, and otherwise handling the CCP and other materials at the site.

5.3 *Geologic and Hydrogeologic Investigation*—The site subsurface conditions must be understood. This typically involves a review of mine maps and other available information about the site; a site reconnaissance by a qualified professional, mapping of the site topography or geology, or both; implementation of exploratory drilling and survey techniques; and extraction of soil, rock, and ground water samples from the subsurface for classification and testing. Guides D420 and Practice D5092 offer guidance for conducting subsurface investigations by providing checklists of items related to site investigations and installation of ground water monitoring wells, respectively.

5.4 *Environmental Resources*—Many sensitive environmental resources, such as wetlands, floodplains, surface water bodies, rare and endangered species, and cultural resource areas are afforded protection by federal, state and local regulations and ordinances. Appropriate action should be taken to comply with the requirements of the regulatory agencies having jurisdiction at the mine site.

5.4.1 *Soil Resources:*

5.4.1.1 Adequate soil survey information for the area to be reclaimed should included:

(1) A map delineating different soils,
(2) Soil identification,
(3) Soil description,
(4) Present and potential productivity of existing soils, and
(5) Soil pH.

5.4.2 *Vegetation Resources:*

5.4.2.1 The pre-mine setting should be evaluated to facilitate development of a revegetation plan. Typical parameters to be evaluated and catalogued include:

(1) A prediction of the mine soil character based on overburden analysis, soil analysis, and other available information,
(2) The proposed treatment to neutralize acidity,
(3) The method of mechanical seed bed preparation,
(4) The application rates and analysis of fertilization, rates and types of mulch, species of perennial vegetation,
(5) The areas to be planted or seeded to trees and shrubs, and
(6) The land use objective.

5.4.2.2 Specific issues that may require specific consideration when CCPs are proposed for use in the revegetation plan are:

(1) Soil treatment and amendments,
(2) Fertilizer application based on state requirements or soil analysis, and
(3) Maximum or minimum soil pH based on the optimum pH for the revegetation species.

5.4.2.3 In implementing the revegetation plan, the operator shall take into consideration the character of the mine soil. Factors to be considered include the following:

(1) Fertility,
(2) Stoniness,
(3) Texture,
(4) Steepness of slope,
(5) Standard field and laboratory overburden analysis, and
(6) Premining overburden analysis.

5.5 *Mine Characterization*—Two key components of site characterization for mine reclamation applications are: *(1)* the identification of the mine configuration and geometry; and *(2)* the evaluation of mine hydrology.

5.5.1 *Mine Hydrology*—The hydrology of the mine must be understood so that reclamation can be optimized. The techniques used to characterize mine hydrology are similar to those presented for a geologic and hydrogeologic investigation (see 5.3). The chemical quality of mine discharge and mine pool water should be monitored.

5.6 *Environmental Monitoring*—Environmental monitoring provides a means of documenting whether reclamation activities have impacted the site or surrounding area. Baseline monitoring should be conducted during site characterization activities. At a minimum, the monitoring should include the collection of precipitation quantity; mine drainage and surrounding surface water quality and quantity; and ground water elevation and quality. Guides D5851 and D4448 discuss sampling techniques. All water quality samples should be submitted for laboratory analysis of those chemical parameters deemed appropriate to characterize the baseline water quality of the mine and surrounding site. Monitoring should be conducted at the appropriate frequency to ensure potential seasonal variations in water quality and flow are characterized.

6. Laboratory Test Procedures

6.1 *General*—Laboratory testing of the proposed CCPs is needed to determine and confirm material properties for design. Test results also provide documentation that may be requested or required by site owners and regulatory agencies. The tests to be conducted should be determined on the basis of site conditions, knowledge of the CCPs, end use, and local environmental considerations.

6.2 *Sampling and Handling*—Sampling CCPs for testing purposes should conform to Practice D75 or Test Methods C311, as appropriate. Guide D420 with sample extraction conducted in accordance with Practice D1452, Test Method D1586, or Practice D3550, as appropriate, should be considered. Proper laboratory protocols for handling fine-grained material should be followed.

6.3 *Physical and Engineering Characteristics*—Several standard test methods developed for soils may be used to determine CCP properties for use in surface mine applications. These test methods define physical and engineering parameters for use in design and construction control and for comparison to other materials. Because of the noncohesive nature of some CCPs, extra care in sample handling may be required. These tests or other tests, or both, may be warranted depending on the specific mine application for CCPs and should be selected based on the professional judgment of a qualified scientist or engineer.

6.3.1 *Grain-Size Distribution*—Test Method D422 is commonly used for determining the grain-size distribution of CCPs. For fly ash and FGD material, a substantial portion of the material will be finer than the No. 200 sieve, and hydrometer analyses will also be required. Distilled water is used in the hydrometer test, with a deflocculating agent added to prevent fly ash or FGD material from forming flocs. Self-hardening fly ash(es) and FGD material may require use of alcohol or another nonreactive solution in place of the standard solution. Fly ash often has a relatively uniform particle size, and precautions against overloading sieves are warranted. Specimen loss through dusting can also be a problem. Specific gravity may vary with particle size. Specific gravity values used in hydrometer analyses should be appropriate to the portion of the sample being tested. Test Method D422 is not applicable to fly ash with a specific gravity less than 1 unless a nonaqueous solvent is used. Grain-size or particle size distribution may also be determined by use of dry powder laser diffraction, retention of particles on sieves, or optical particle counters.

6.3.2 *Specific Gravity*—Test Method D854 is normally used for CCPs. For some fly ash and FGD samples, a significant portion of the particles may have a density less than water, and these will float. Agitation of the slurry may be needed to keep the particles in suspension so that the average specific gravity can be obtained. Alternately for this ash, self-hardening fly ash, and FGD material, Test Method C188, which uses kerosine as the fluid, may be used.

6.3.3 *Water Content*—Test Method D2216 is normally used for CCPs. For self-hardening fly ash and FGD material, lowering the drying temperature to 140°F (60°C) may be considered to avoid driving off the water of hydration.

6.3.4 *Compaction:*

6.3.4.1 *Fly Ash and FGD Material*—Test Methods D698 or D1557 may be used, depending on end use. For dry self-hardening fly ash and FGD material, the time interval between wetting and compaction in the laboratory should be similar to that anticipated during construction to account for the influence of the rate of hydration on compaction characteristics. Compaction criteria are not typically developed for FGD material that exhibits thixotropic properties, because excessive compaction may cause the material to liquefy.

6.3.4.2 *Bottom Ash and Boiler Slag*—Test Methods D4253 and D4254 may be used for the determination of maximum and minimum density of coarse-grained CCPs that do not exhibit a moisture-density relationship.

6.3.5 *Strength*—Material strength is defined by shear strength and compressive strength. Strength determinations may be performed to evaluate the behavior of a CCP for use as a barrier within the mine setting or mine reclamation process.

6.3.5.1 *Shear Strength*—Test Method D3080 can be used to determine the shear strength parameters of compacted CCP specimens under drained conditions. This test is preferred because it models the drained conditions that typically exist in a structural fill constructed of CCPs. When Test Method D3080 is used, the method is modified in that the shear box is not to be filled with water as required by Test Method D3080.

6.3.5.2 *Compressive Strength of Non-Self-Hardening CCPs*—Test Method D4767 can be used to predict the as-constructed compressive strength of the CCP fill and to design for specific site conditions, loading conditions, and final height. Specimens tested for strength parameters shall be compacted to the densities and water contents required by the project compaction specifications.

6.3.5.3 *Compressive Strength of Self-Hardening Fly Ash and FGD Material*—Test Method D2166 can be used to determine the unconfined compressive strength at various ages to evaluate short-term and long-term strength development.

6.3.6 *Hydraulic Conductivity*—Test Method D5084 is commonly used to determine the hydraulic conductivity of saturated CCPs. The hydraulic conductivity can provide information valuable in accessing the use of a CCP as a barrier in the mine setting or mine reclamation process.

6.3.7 *Compressibility*—Samples should be prepared at the degree of compaction specified for construction and at the optimum water content determined by the compaction test. This is because fly ash and FGD material tend to lose surface stability in the field when compacted at water contents greater than the optimum for compaction. Special considerations may be required for wet FGD material, which is typically produced at 15 to 20 % above optimum moisture. Test Method D2435 can be used to determine the compressibility of saturated or unsaturated samples.

6.3.8 *Swelling*—Test Method D3877 can be used to determine the swelling potential of self-hardening fly ash and FGD material. Reactions producing the expansive properties may not commence for a period of more than 30 days after initial ash hydration. The test procedures must address this delayed reaction. The procedure should be modified to extend the wetting and drying cycles to a frequency determined by a qualified design engineer.

6.4 *Chemical Characteristics*—Chemical analyses are routinely conducted by many CCP producers as a means of determining material variation. The mine reclamation designer(s) and other professionals should obtain or evaluate the chemical characteristics of candidate CCPs so they can be considered in design, particularly with regard to assessing chemical interaction between fill and other materials or structures. Tests for soluble species, generally accomplished through leaching tests, may also be required by local regulatory agencies.

6.4.1 *Chemical Composition*—Test Method C311 is often used to determine the major chemical constituents of CCP samples. Minor and trace constituents can be evaluated using appropriate ASTM or EPA methods, or both, or the equivalent.

6.4.2 *pH*—Test Method D4972 or Practice D5239 may be used to determine CCP pH. In assessing the test results, consideration should be given to the possibility that the pH of the CCP may vary with age, water content, and other conditions.

6.4.3 *Buffer Capacity*—The buffer capacity of the CCP is important in maintaining the high pH that generally is a requirement for the neutralization of acid from acid forming materials potentially present at mine sites when CCPs are used as neutralization agents. The CCP must have enough buffer capacity to maintain the pH in the appropriate range so neutralization of acid continues 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.

6.4.4 *Leaching Characterization*—Numerous leaching tests have been developed to evaluate the leaching behavior of materials. Commonly applied leaching tests are listed and referenced in Table 1, but the selection of the test procedure(s), leachate test parameters, and interpretation of leachate test results must be guided by professional judgment and the appropriate regulatory authority.

7. Use of CCPs in Revegetation and Other Near-Surface Applications

7.1 The use of CCPs for revegetation or near soil surfaces primarily refers to the uses as a soil substitute or a soil additive. The purposes of these uses are to replace soil that was previously available at the site, enhance soil properties, or enhance plant growth. This can be accomplished as noted in the following sections.

NOTE 2—Based on site specific conditions, it may be necessary to consider an effective cover cap between CCPs and cover material to be used

7.2 *Treatment of Acid Soils*—Acid mine soils could potentially be present in soil horizons A through C. These soils are generally removed either separately or in combination for replacement during the reclamation process. If any of these soils exhibit low pH or contain acid-forming materials, they may limit vegetative success. Some CCPS can be used to treat these soils to neutralize the soil pH or minimize or halt acid formation from acid-forming materials. Generally, the final top soil or horizon A soil should range in pH from ~6.5 to 8.0. All soils should be evaluated by a qualified professional for pH, acidity/alkalinity, and chemical composition. The chemical

TABLE 1 Leaching Methods Applicable to Stabilized Materials

	Leaching Solution	Liquid: Solid Ratio	Leaching Duration
MEP (**2**)	Multiple solutions (acetic acid, sulfuric acid, and nitric acid)	20:1	24 h/ extraction
MWEP (**3**)	Distilled/deionized water or other for specific silt	10:1	18 h/ extraction
Test Method D3987	Distilled/deionized water	20:1	24 h
SGLP (**4**)/ LTL (**4**)	Synthetic ground water dictated by site or distilled/deionized water	20:1	18 h/ 30, 60, 90 days
SPLP (**1**)	Sulfuric acid	20:1	18 h

composition analyses should follow state guidelines for mine reclamation or limits for land applied materials.

7.2.1 *Soil Reconstruction and Amendments*—Physical and chemical characteristics of reconstructed or amended soils are designed to be similar to the original soils from the area. The reconstructed or amended soils need to meet soil-horizon depths, soil densities, soil pH, and other specifications such that constructed or amended soils will have the capability of achieving levels of yield equal to, or higher than, those of premined land. Soil horizons must allow for root penetration and water supply to the root zone. CCPs can be used to adjust pH, add calcium, adjust the soil permeability, add micronutrients, add sulfate, and otherwise modify soils to improve tilth and lessen erosion potential.

7.2.2 *Top Soil Substitutes*—Topsoil or other approved substitute materials can be used as the final surface soil layer. This surface soil layer shall equal or exceed the thickness of the original surface soil layer, as determined by the soil survey. CCPs can be used to augment or supplement existing topsoil or to amend overburden for use as topsoil. CCPS can add tilth, calcium, sulfate, and micronutrients. CCPs can also be used to adjust the compaction of the topsoil.

7.3 *Identifying Appropriate CCPs*—Various CCPs may have appropriate characteristics to meet the requirements for soil reconstruction of amendment. The CCPs under consideration should be tested with an appropriate test as noted in Section 6.

7.4 *Evaluating Mixtures of Acid Mine Soils and CCPs*—The replacement soil mixture should be analyzed by a qualified soils laboratory. Chemical and physical analyses should consist of pH, acidity/alkalinity, phosphorus, potassium, other elements as dictated by state rules, texture and permeability. In some cases, greenhouse and field tests may be useful to evaluate the suitability of the CCP or CCP modified soil to support the vegetation planned for the site. If CCPs are combined with soils or other materials, the final mixture should be evaluated for appropriateness for the intended applications.

8. Use of CCPs in Remediating Acid Mine Drainage in Surface Mine Settings

8.1 Drainage from acid-forming materials into ground and surface water shall be avoided by identifying, burying, blending, segregating, or treating, or combination thereof, spoil or other materials that will be toxic to vegetation or that will adversely affect water quality. Many CCPs can be used to accomplish the activities required to avoid acid mine drainage from entering ground or surface water. The potential CCP applications include construction of low-permeability barriers to allow the neutralization of acid formed or to limit the infiltration of water or oxygen to limit acid formation, and combining the CCP and acid-forming materials to limit acid formation.

8.2 *Treatment of Acid-Forming Materials in Overburden*—CCPs exhibiting appropriate pH and buffereing capacity can be used to blend with overburden or other site materials to decrease or halt acid formation. These materials can be handled in similar fashion as CCPs used in soil reconstruction or amendment for near surface applications as noted in Section 7.

8.3 *Treatment of Exposed Acid-Forming Materials*—Any exposed acid-forming materials existing after mining should be covered. It may be beneficial to apply materials such as alkaline CCPs to limit or halt the release of acid from these areas. The hydrological evaluation will facilitate an understanding of releases from these in situ acid forming materials. Alkaline CCPs can be used to create a buffering zone or low permeability barrier, or both, for acid releases. CCPs may also be appropriate for creating a low permeability barrier upgradient of the acid-forming material to limit infiltration and movement of water through that area and to limit access to oxygen after the mining and reclamation is completed.

8.4 *Identifying Appropriate CCPs*—Various CCPs may have appropriate characteristics to meet the requirements for soil reconstruction of amendment. The pH and buffer capacity of candidate CCPs are key in applications where neutralization of acid being formed is the goal. Cementitious CCPs may be best suited to create low-permeabilty barriers to reduce infiltration of water and direct water to other locations away from acid-forming materials. Other CCPs, especially sulfite-rich FGD materials, may also be appropriate where the goal includes limiting infiltration of oxygen. Care must be exercised however as sulfite rich materials are toxic to plants and should not be utilized in surface environments. The CCPs under consideration should be tested for pH, buffer capacity, total elemental concentrations, strength and hydraulic conductivity with appropriate tests as noted in Section 6. If CCPs are combined with soils or other materials, the final mixture should be evaluated for appropriateness for the intended applications.

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