



Standard Practice for Design of Stabilization of Soil and Soil-Like Materials with Self-Cementing Fly Ash¹

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1. Scope

1.1 This guide covers procedures for the design of stabilization of soil and soil-like materials using self-cementing coal fly ash for roadway applications, treatment of expansive subgrade or organic subgrade, and limiting settlement of fills below buildings. The coal fly ash covered in this method includes self-cementing fly ashes described in Specification [D5239](#).

1.2 The testing and engineering practices for self-cementing coal fly ash are similar to generally accepted practices for soil stabilization with fly ash and other pozzolans that require lime.

1.3 The test methods in this guide are applicable to the characterization of mechanical properties of *in situ* mixed self-cementing fly ash stabilized materials. There are other related fly ash stabilization standards. Practice [D5239](#) can be used to characterize the general types of fly ash for use in soil stabilization. Specification [C593](#) can be used to evaluate the performance of fly ash and other pozzolans that require lime soil stabilization. Guide [E2277](#) can be used to characterize properties of fly ash and bottom ash in structural fills and related design and construction considerations.

1.4 The standard units are the SI units, unless other units are specified.

1.5 *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 limitations prior to use.*

1.6 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of*

a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.

2. Referenced Documents

2.1 ASTM Standards:²

- [C593](#) Specification for Fly Ash and Other Pozzolans for Use With Lime for Soil Stabilization
- [C597](#) Test Method for Pulse Velocity Through Concrete
- [D75](#) Practice for Sampling Aggregates
- [D420](#) Guide to Site Characterization for Engineering Design and Construction Purposes (Withdrawn 2011)³
- [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/ft³ (600 kN-m/m³))
- [D1557](#) Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort (56,000 ft-lbf/ft³ (2,700 kN-m/m³))
- [D1883](#) Test Method for CBR (California Bearing Ratio) of Laboratory-Compacted Soils
- [D4609](#) Guide for Evaluating Effectiveness of Admixtures for Soil Stabilization
- [D5102](#) Test Methods for Unconfined Compressive Strength of Compacted Soil-Lime Mixtures
- [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
- [D5918](#) Test Methods for Frost Heave and Thaw Weakening Susceptibility of Soils
- [E2201](#) Terminology for Coal Combustion Products (Withdrawn 2011)³

¹ This practice is under the jurisdiction of ASTM Committee [D18](#) on Soil and Rock and is the direct responsibility of Subcommittee [D18.14](#) on Geotechnics of Sustainable Construction.

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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.

E2277 Guide for Design and Construction of Coal Ash Structural Fills (Withdrawn 2012)³

2.2 *AASHTO (American Association of State Highway and Transportation Officials) Standard*.⁴

AASHTO T 307 Standard Method of Test for Determining the Resilient Modulus of Soils and Aggregate Materials

2.3 *TRB (Transportation Research Board) Standard*.⁵

NCHRP 1-28A Harmonized Test Method for Laboratory Determination of Resilient Modulus for Flexible Pavement Design

2.4 *ACAA (American Coal Ash Association) Soil Stabilization Manual*.⁶

Soil Stabilization and Pavement Recycling with Self-Cementing Coal Fly Ash

3. Terminology

3.1 Definitions:

3.1.1 For definitions related to Coal Combustion Productions, see Terminology **E2201**. For definitions related to geotechnical properties, see Terminology **D653**.

4. Significance and Use

4.1 Self-cementing coal fly ashes are suitable materials for the stabilization of soils, recycled pavement materials and road surface gravel. Fly ash stabilization can result in improved properties, including increased stiffness, strength and freeze-thaw durability; reduced hydraulic conductivity, plasticity, and swelling; and increased control of soil compressibility and moisture. Fly ash stabilized materials (FASM) may be used in roadway construction, such as working platforms during construction, stabilized subgrade, subbase, and base layers. Fly ash stabilization can also be used in limiting settlement of fills below buildings.

4.2 This guide is intended for use with self-cementing fly ash that can be used separately or along with other stabilizing admixtures to improve soil properties.

4.3 The guide describes the unique design considerations that may apply to stabilization of soils and soil-like materials with self-cementing coal fly ash. The requirements for stabilization of specific materials may vary due to local conditions or the intended use of the stabilized material, or both.

4.3.1 This guide is not intended to limit the flexibility of design in stabilization. The degree of success attained in stabilization with coal fly ash is highly dependent on the particular combination of soil, fly ash, and other additives and the construction procedure used. The selection of appropriate materials, applicable tests, acceptance criteria, and specification is the responsibility of the design engineer.

4.4 The test methods in this guide are intended for the determination of mechanical properties of FASM. The charac-

terization of mechanical property improvement with self-cementing fly ash will assist in the evaluation of the fly ash stabilized materials.

4.5 The use of self-cementing fly ash in geotechnical engineering application may be regulated by state and local codes. The codes should be consulted.

5. Stabilization Applications

5.1 *General*—High calcium oxide content and self-cementing properties of subbituminous coal fly ash (self-cementing fly ash) can be used effectively in stabilization, such as drying wet soils to facilitate compaction and increase subgrade support, improving stiffness and strength and reducing compressibility of both cohesive soils and granular materials. However, the effectiveness depends on specific material to be stabilized and specific fly ash and has to be determined on a case-specific basis.

5.2 *Stabilization of Fine-Grained Soils*—In the fly ash stabilization of fine-grained soils, flocculation, agglomeration, and cementitious reactions may occur. Self-cementing coal fly ash has been demonstrated to be an effective stabilization agent for a range of fine-grained soils in increasing subgrade support capacity for pavements, in reducing swelling potential of expansive soils, in increasing shear strength of organic soils and fine-grained soils, and in reducing the compressibility of fills under foundations. The fly ash stabilized section also provides a more stable platform (working platform) during pavement construction over very soft subgrades. Such stabilized subgrade working platforms can be treated as a subbase section in the pavement thickness design.

5.3 *Stabilization of Coarse-Grained Materials*—In coarse-grained materials, such as aggregate base, gravels, recycled pavement materials, recycled road surface gravel, cementation through pozzolanic reactions and hydration within the self-cementing coal fly ash can cause strength gain and enhance durability. The reaction rate depends on the self-cementing coal fly ash used.

5.4 *Pavement Recycling: Full Depth Reclamation*—Recycling or reclaiming existing flexible pavements with self-cementing fly ash as a stabilizing agent has been demonstrated to be an efficient and economical method of pavement rehabilitation for roadways. The process is accomplished by pulverizing the entire pavement section to the subgrade and stabilizing the pulverized mixture by adding self-cementing coal fly ash and water (as needed). The recycled section provides an enhanced base for a new hot mix asphalt (HMA) wearing surface. Self-cementing fly ash stabilized recycled sections have structural capacities (enhanced modulus and reduced plastic deformations), which are considerably better than a crushed-stone aggregate base and can be equivalent to an asphaltic concrete base section.

5.5 *Gravel Road Recycling: In Situ Reclamation*—Recycling or reclaiming existing road surface gravel (RSG) with self-cementing fly ash stabilization is an economical method for converting gravel roads to paved roads. The process is accomplished by placing the appropriate amount of self-cementing fly ash over the entire road surface and then

⁴ Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 249, Washington, DC 20001, <http://www.transportation.org>.

⁵ National Cooperative Highway Research Program, Transportation Research Board, Washington, DC.

⁶ American Coal Ash Association Educational Foundation, 15200 E. Girard Ave., Suite 3050, Aurora, Colorado 80014-3955.

blending it into the RSG down to the required depth to form a base for the HMA layer. The self-cementing fly ash stabilized-RSG has similar or better properties as a high-quality crushed aggregate base course in the stabilized section. The recycled and stabilized RSG section provides an enhanced base for a new HMA wearing surface.

6. Laboratory Mix-Design

6.1 *General*—A laboratory mix design is developed to establish the optimum fly ash content, optimum moisture content, maximum dry density, and maximum strength gain for design and construction testing purposes. Since most stabilization applications with self-cementing fly ash rely on the fly ash as stabilizing agent, the test and design procedures should address the rapid rate at which the fly ash hydrates upon exposure to water. Ash hydration can significantly alter the compaction characteristics of materials treated with self-cementing fly ash.

6.2 *Hydration Rate*—Self-cementing ash hydrates at a much more rapid rate than Portland cement, a 2-h delay in compaction may decrease the maximum density and reduce strength. A 1- to 2-h compaction delay should be achievable *in situ* and should be stated in the project specifications. The specified maximum compaction delay time in the project specification is measured from the time the self-cementing fly ash is incorporated into the materials being stabilized and has been exposed to water. Laboratory tests conducted to establish construction and design parameters should be based on the properties of the stabilized materials compacted at the specified maximum allowable delay time.

6.3 *Moisture Content for Stabilization*—For a given compactive energy, an optimum moisture content exists at which maximum strength is achieved. This optimum moisture content for maximum strength is generally 1 to 8 % below optimum moisture content for maximum density, depending on mineralogy of the self-cementing fly ash and the type of material being stabilized. Construction specifications that specify moisture ranges based solely upon compaction characteristics can produce stabilized materials having strengths 50 % or less of the maximum potential strength, greatly reducing the benefits achieved through the stabilization operation. The allowable range in moisture content must be specified and monitored during construction to ensure that the moisture content of the stabilized section is near the optimum maximum strength.

6.4 *Mix Design Procedure*—The procedure herein follows ACAA manual, Soil Stabilization and Pavement Recycling with Self-Cementing Coal Fly Ash, for determining moisture-density and moisture-strength relationships of the fly ash stabilized materials. Standard size compaction molds with a diameter of 100 mm (4 in.) or 150 mm (6 in.) depending on maximum particle size of the material to be stabilized can be used with standard Proctor or modified Proctor compactive energy. Use of split molds (metal or polyvinyl chloride reinforced with clamps) is desirable for the ease of specimen removal after compaction. After blending of the soil, fly ash, and water, specimens are compacted using the specified compaction delay. A minimum of five test specimens, compacted

over a wide range of moisture contents, should be prepared for each test series to define both moisture-strength and moisture-density relationships. After extruding the specimens and sealing with plastic wrap, they should be cured for a minimum of 7 days in a curing room with near 100 % relative humidity at room temperature (23 ± 20 °C (73 ± 40 °F)) prior to compression testing. The standard compaction specimens prepared in 102 mm molds have a height-to-diameter ratio of 1.15; therefore, unconfined compressive strengths determined using Test Methods **D5102** provide a relative measure of strength and allow determination of optimum moisture content for maximum strength. For specimens that need to be compacted using a 150-mm (6-in.) diameter mold because of coarse particles, CBR tests in accordance with Test Method **D1883** can be performed on compacted specimens after curing to determine the optimum moisture content for maximum CBR as a measure of relative strength. For a rigorous measure of unconfined compressive strength, specimens compacted to the maximum relative density at the optimum moisture content for strength gain and having a height-to-diameter ratio of 2 have to be prepared, cured, and tested.

6.4.1 An alternative mix design procedure for the moisture-density and moisture-strength relationships of the self-cementing fly ash stabilized fine-grained soils uses combined compaction-unconfined compression tests using Harvard Miniature compaction and unconfined compression (Guide **D4609**) using 35-mm (1.38 in.) diameter compaction molds for fine-grained soil stabilization. A similar combined compaction-CBR approach using 150-mm (6-in.) diameter compaction molds can be used for coarse-grained material stabilization.⁷ These methods can determine optimum moisture content for maximum density and optimum moisture content for strength gain with less work and materials.

7. Testing Procedure for Mechanical Properties of Self-Cementing Fly Ash Stabilized Materials

7.1 *General*—Tests are required to determine the mechanical properties and improvements of self-cementing fly ash stabilization for design purposes.

7.2 *California Bearing Ratio (CBR)*—Determine CBR in accordance with the procedure outlined in Test Method **D1883** after 7 days of curing. Specimens can be tested after soaking or unsoaked depending on the application. Test at a strain rate of 1.3 mm/min (0.05 in./min).

7.3 *Resilient Modulus*—Determine resilient modulus in accordance with the procedure outlined in AASHTO T 307 after 14 days of curing. Use loading sequence for cohesive soils.

7.3.1 *Resilient Modulus (Alternative Test Method)*—Determine resilient modulus in accordance with the procedure outlined in NCHRP 1-28A protocol for FASM after 14 days of curing. Different loading sequences should be used for fine-grained FASM and coarse-grained FASM.

⁷ Senol, A., Edil, T. B., and Bin-Shafique, M. S. "Laboratory Evaluation of Stabilization of Soft Subgrades by Class C Fly Ash," Proceedings of the 15th Southeastern Asian Geotechnical Engineering Conference, Bangkok, Thailand, S. Sambhandharaksa, D. T., Bergado, T. Boonyatee, eds., 2004, Vol 1, pp. 593,596.

7.3.2 *Calculation of Resilient Modulus*—Calculate resilient modulus in accordance with the procedure outlined in NCHRP 1-28A protocol.

7.4 *Unconfined Compressive Strength*—Determine unconfined compressive strength in accordance with the procedure outlined in Test Methods **D5102**. Test at a strain rate of 0.21 %/min. The unconfined compressive strength tests can be performed on the resilient modulus specimens after the resilient modulus test. Resilient modulus test does not fail specimens because the applied stresses are typically lower than the strength of the FASM.

7.5 *Freeze-Thaw Test*—Determine freezing-point depression test in accordance with the procedure outlined in Test Methods **D5918**. To verify that freezing and thawing is occurring in the specimens, use a specimen to determine the freezing and thawing durations needed. Prepare the specimen and test as intended (7.5.1 or 7.5.2). Place a thermocouple at the center of the specimen and record the temperature every 10 min. Once the time for freezing and thawing is determined, use these durations on other test specimens. For freeze-thaw tests, FASM can be tested after soaking or unsoaked. Research has indicated that soaked and unsoaked samples have similar properties in freeze-thaw tests. Testing of unsoaked samples is recommended. For testing soaked samples, soak 5 h prior to the freeze-thaw cycles. Conduct 0, 1, 3, 5, 10, and 20 cycles of freeze-thaw. Initially cool the specimens to 5 °C so that all

specimens begin the freezing phase at uniform temperature. Freeze FASM specimen to the freezing point as determined by Test Methods **D5918** (-5 to -20 °C (23 to -4 °F)). Thaw specimen to 5 °C (41 °F). When there is more than one cycle of freeze-thaw, repeat the freezing and thawing procedure. When specimen reaches room temperature (23 ± 2 °C (73 ± 4 °F)), the strength or stiffness tests, or both, can be conducted on the specimens. Alternatively, a non-destructive test such as pulse velocity (Test Method **C597**) can be conducted on a single specimen after each freeze-thaw cycle to determine degradation due to freeze-thaw exposure.

7.5.1 *One-Dimensional Freeze-Thaw Cycling Test*—Open the ends of specimens and place 100 mm (3.9 in.) of insulation around the circumference of the specimen. Place the specimens horizontally to allow heat flow through the ends. Before wrapping the specimens with the insulation, completely wrap the specimens with plastic to prevent water content changes.

7.5.2 *Three-Dimensional Freeze-Thaw Cycling Test*—No insulation is used for the specimens frozen and thawed in 3-D. All other conditions are the same as one-dimensional freeze-thaw cycling test.

8. Keywords

8.1 durability; fly ash stabilized materials; mechanical properties; mixed design; self-cementing fly ash; stabilization; stiffness; strength

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