

**ACI Education Bulletin E3-13**

**Cementitious Materials for Concrete**

Developed by ACI Committee E-701



**American Concrete Institute®**



**American Concrete Institute®**  
*Advancing concrete knowledge*

First Printing  
August 2013

## **Cementitious Materials for Concrete**

Copyright by the American Concrete Institute, Farmington Hills, MI. All rights reserved. This material may not be reproduced or copied, in whole or part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of ACI.

The technical committees responsible for ACI committee reports and standards strive to avoid ambiguities, omissions, and errors in these documents. In spite of these efforts, the users of ACI documents occasionally find information or requirements that may be subject to more than one interpretation or may be incomplete or incorrect. Users who have suggestions for the improvement of ACI documents are requested to contact ACI via the errata website at [www.concrete.org/committees/errata.asp](http://www.concrete.org/committees/errata.asp). Proper use of this document includes periodically checking for errata for the most up-to-date revisions.

ACI committee documents are intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. Individuals who use this publication in any way assume all risk and accept total responsibility for the application and use of this information.

All information in this publication is provided “as is” without warranty of any kind, either express or implied, including but not limited to, the implied warranties of merchantability, fitness for a particular purpose or non-infringement.

ACI and its members disclaim liability for damages of any kind, including any special, indirect, incidental, or consequential damages, including without limitation, lost revenues or lost profits, which may result from the use of this publication.

It is the responsibility of the user of this document to establish health and safety practices appropriate to the specific circumstances involved with its use. ACI does not make any representations with regard to health and safety issues and the use of this document. The user must determine the applicability of all regulatory limitations before applying the document and must comply with all applicable laws and regulations, including but not limited to, United States Occupational Safety and Health Administration (OSHA) health and safety standards.

Participation by governmental representatives in the work of the American Concrete Institute and in the development of Institute standards does not constitute governmental endorsement of ACI or the standards that it develops.

Order information: ACI documents are available in print, by download, on CD-ROM, through electronic subscription, or reprint and may be obtained by contacting ACI.

Most ACI standards and committee reports are gathered together in the annually revised ACI Manual of Concrete Practice (MCP).

**American Concrete Institute**  
**38800 Country Club Drive**  
**Farmington Hills, MI 48331**  
**U.S.A.**  
**Phone: 248-848-3700**  
**Fax: 248-848-3701**

[www.concrete.org](http://www.concrete.org)

## CEMENTITIOUS MATERIALS FOR CONCRETE

Prepared under the direction and supervision of ACI Committee E-701,  
Materials for Concrete Construction

Thomas M. Greene, Chair  
Corina-Maria Aldea  
Richard P. Bohan\*  
David A. Burg

Darrell F. Elliot  
Darmawan Ludirdja  
Mark R. Lukkarila  
Clifford N. MacDonald

Charles K. Nmai  
David M. Suchorski  
Lawrence L. Sutter  
Joseph E. Thomas

Kari L. Yuers  
Robert C. Zellers  
\*Chair of document subcommittee.

*This document discusses commonly used cementitious materials for concrete and describes the basic use of these materials. It is targeted at those in the concrete industry not involved in determining the specific mixture proportions of concrete or in measuring the properties of the concrete. Students, craftsmen, inspectors, and contractors may find this a valuable introduction to a complex topic. The document is not intended to be a state-of-the-art report, user's guide, or a technical discussion of past and present research findings. More detailed information is available in ACI 225R-99, "Guide to the Selection and Use of Hydraulic Cements," ACI 232.2R-03, "Use of Fly Ash in Concrete," ACI 233R-03, "Slag Cement in Concrete and Mortar," and ACI 234R-06, "Guide for the Use of Silica Fume in Concrete."*

### CONTENTS

#### CHAPTER 1—INTRODUCTION, p. E3-2

- 1.1—History of portland cement, p. E3-2
- 1.2—Sustainability, p. E3-2

#### CHAPTER 2—MANUFACTURE OF PORTLAND CEMENT, p. E3-4

- 2.1—Raw material preparation, p. E3-4
- 2.2—Pyroprocessing, p. E3-6
- 2.3—Final processing, p. E3-6
- 2.4—Quality control, p. E3-6

ACI Committee Reports, Guides, and Commentaries are intended for guidance in planning, designing, executing, and inspecting construction. This document is intended for the use of individuals who are competent to evaluate the significance and limitations of its content and recommendations and who will accept responsibility for the application of the material it contains. The American Concrete Institute disclaims any and all responsibility for the stated principles. The Institute shall not be liable for any loss or damage arising therefrom.

Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer.

#### CHAPTER 3—PROPERTIES AND CHARACTERISTICS OF CEMENTS, p. E3-6

- 3.1—Compound composition, p. E3-6
- 3.2—Types of portland cement, p. E3-6
- 3.3—Hydration of portland cements, p. E3-7
- 3.4—Cement fineness, p. E3-8
- 3.5—Setting behavior, p. E3-9
- 3.6—Heat of hydration, p. E3-9
- 3.7—Strength development, p. E3-9
- 3.8—Sulfate resistance, p. E3-9

#### CHAPTER 4—PORTLAND CEMENTS AND THEIR SPECIFICATIONS, p. E3-10

- 4.1—Cement types, p. E3-10

#### CHAPTER 5—STANDARD TESTS FOR PORTLAND CEMENTS, p. E3-15

- 5.1—Chemical tests, p. E3-16
- 5.2—Physical tests, p. E3-16

#### CHAPTER 6—FLY ASH AND NATURAL POZZOLANS, p. E3-18

- 6.1—Classification of pozzolans, p. E3-18
- 6.2—Fly ash as cementitious material, p. E3-19
- 6.3—Effect of fly ash on fresh concrete, p. E3-19
- 6.4—Effect of fly ash on hardened concrete, p. E3-20
- 6.5—Concrete mixture considerations with fly ash, p. E3-21

#### CHAPTER 7—SLAG CEMENT, p. E3-22

- 7.1—Classification of blast-furnace slag, p. E3-22

Copyright © 2013, American Concrete Institute.

ACI Education Bulletin E3-13 supersedes E3-01 and was published August 2013.

All rights reserved including rights of reproduction and use in any form or by any means, including the making of copies by any photo process, or by electronic or mechanical device, printed, written, or oral, or recording for sound or visual reproduction or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the copyright proprietors.

7.2—Slag cement as supplementary cementitious material, p. E3-23

7.3—Effects of slag cement on fresh and hardened properties of concrete, p. E3-23

## CHAPTER 8—SILICA FUME, p. E3-23

8.1—Silica fume production, p. E3-23

8.2—Silica fume as cementitious material, p. E3-24

8.3—Effects of silica fume on properties of fresh and hardened concrete, p. E3-24

## CHAPTER 9—ADDITIONAL FACTORS IN SELECTION AND USE OF PORTLAND CEMENT, p. E3-24

9.1—Uniformity, p. E3-24

9.2—Handling and storage of cement, p. E3-25

9.3—Availability, p. E3-25

## CHAPTER 10—REFERENCES, p. E3-25

### CHAPTER 1—INTRODUCTION

Concrete is made from a properly proportioned mixture of hydraulic cement, water, fine and coarse aggregates and, often, chemical admixtures and supplementary cementitious materials (SCMs). The most common hydraulic cement used in construction today is portland cement. Although other types exist, portland cement is the most widely manufactured and the focus of this document. Exceptions are noted otherwise. The successful use of concrete in construction depends on the correct selection of the appropriate materials necessary and the proper proportioning of those materials. This requires knowledge of the material properties and the tests used to measure those properties.

The selection and characterization of hydraulic cement and SCMs are the subjects of this bulletin, while aggregates, admixtures, and concrete characteristics are discussed in companion volumes. There are several varieties of hydraulic portland cement, as recognized by [ASTM International](#), which vary in their properties. Hydraulic cement is defined as cement that sets and hardens by chemical reaction with water and is capable of doing so underwater. The following chapters review the composition and properties of the various portland cements and SCMs, discuss the tests used to evaluate a cement, and consider how cement properties influence the performance of the concrete.

#### 1.1—History of portland cement

The name “portland” originates from a trade name used by Joseph Aspdin in 1824 to describe the new cement he patented that year in England. He claimed that the artificial stone (concrete) made with his cement was similar in appearance to portland stone, a high-quality limestone used in construction during that time period. Although the term “portland cement” dates from Aspdin’s patent in 1824, hydraulic cement as a material can be traced back to ancient times, where several famous landmarks of the Roman era owe their survival to the cementitious qualities of the forerunner to portland cement.

The portland cement industry quickly spread in England. By 1890, there was a flourishing export business to the United States. The fledgling U.S. industry founded by David Saylor at Coplay, PA, in 1871, soon captured the domestic market. U.S. production rose from 54,000 metric tons (60,000 tons) per year in 1890 to 1.5 million metric tons (1.7 million tons) in 1900, and by 1915 had increased to 14.1 million metric tons (15.5 million tons). Early cement production was measured on the basis of a barrel. One barrel of cement was equivalent to 374 lb (170 kg) of cement. One-quarter barrel of cement was then equivalent to 94 lb (43 kg), which quickly became the accepted basis for the quantity of cement in a bag or sack. Today, more than 121 million metric tons (133 million tons) of portland cement are used each year in the United States. The worldwide consumption of cement is more than 2160 million metric tons (2376 million tons). In the past, cement production was measured in tons (2000 lb) and now it is measured in metric tons (1000 kg). A metric ton, or megagram (Mg), is equal to 1 million grams and is approximately 10% more than a U.S. ton.

#### 1.2—Sustainability

The sustainable attributes of concrete are strongly tied to the service life and performance of the cementitious binder system used. Conventional systems based on portland cement have an unparalleled record of performance under a wide range of conditions. However, as is the case with manufacturing processes used in the production of other building materials, production of portland cement requires a significant amount of energy and inherently produces greenhouse gases. Given this fact, engineers have developed approaches to improving the sustainability of concrete by an increased use of cementitious materials that rely less on portland cement and more on alternative materials (for example, coal fly ash, silica fume, slag cement, and natural pozzolans). Through the use of alternative materials, the ability to accomplish significant reductions in the embodied energy and greenhouse gas emissions associated with portland cement production has served to significantly improve the overall sustainability of concrete. In the future, the use of alternatives to portland cement will only increase. However, any changes in the binder system used in concrete must be accomplished without sacrificing the service life and performance attributes that have made concrete the most widely used construction material on the planet.

When examining the sustainability of concrete, and specifically the role of the hydraulic cement binder system in achieving sustainability goals, it is important to consider those areas where portland cement contributes. Portland cement provides a low-cost, effective binder system, whether used alone or in combination with alternative materials. As a result, society has reaped the benefits, enabling the construction of bridges, roads, dams, and buildings that simply cannot be constructed with other materials. Importantly, the most critical infrastructure systems of our society are built with concrete that uses a portland-cement-based binder system. The societal benefits of concrete, and indirectly the societal benefits of portland cement, cannot be overstated.