Guide to the Selection and Use of Hydraulic Cements

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Guide to the Selection and Use of Hydraulic Cements

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Cement is the most active component of concrete and usually has the greatest unit cost; therefore, its selection and proper use is imperative to attaining the desired balance of properties and cost for a particular concrete mixture. Selection should include consideration of the cement properties in relation to the required performance of the concrete. This guide covers the influence of cement on the properties of concrete, summarizing the composition and availability of commercial hydraulic cements and the factors affecting their performance in concrete. It includes a discussion of cement types, a brief review of cement chemistry, the influences of chemical admixtures and supplementary cementitious materials, and the effects of the environment on cement performance, and reviews the sustainability aspects for the use and manufacture of portland cement. Cement storage, delivery, sampling, and testing of hydraulic cements for conformance to specifications are addressed. Users will learn to recognize when a readily available, general-purpose cement will perform satisfactorily or when conditions require selection of a cement that meets additional requirements.

Keywords: admixture; blended cement; calcium-aluminate cement; cement storage; cement types; chemical analysis; hydraulic cement; pozzolan; physical properties; portland cement; slag cement; supplemental cementitious materials; sustainability.

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CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

This guide assists specifiers and designers in choosing appropriate cement for specified concrete applications. Although hydraulic cements are only one ingredient of a concrete mixture, they are the active ingredient and, therefore, play a key role in the long-term viability of the structure, floor, or pavement. Cement choice depends on many variables, such as the service conditions for which the concrete is designed, properties of other materials used in the mixture, or the performance characteristics of the concrete required during or shortly after placement.

Cement paste is the binder in concrete or mortar that holds the fine aggregate, coarse aggregate, or other constituents together in a hardened mass. The term "hydraulic" in this guide refers to the basic mechanism by which the hardening of the cement takes place—a chemical reaction between the cement and water. The term also differentiates hydraulic cement from binder systems that are based on other hardening mechanisms, as hydraulic cements can harden underwater.

Concrete properties depend on the quantities and qualities of its constituents. Because cement is the most active component of concrete and usually has the greatest unit cost, its selection and proper use are fundamental in obtaining the most economical balance of properties desired for a particular concrete mixture. Most cements will provide adequate levels of strength and durability for general use. Some provide higher levels of certain properties than are needed in specific applications.

1.2—Scope

This guide summarizes information about the composition, availability, and factors affecting the performance of commercial hydraulic cements. It also provides information regarding:

a) Cement selection, whether a cement is readily available, and if conditions require a general-purpose cement or a special cement

b) How the chemical and physical characteristics of a cement can affect certain properties of concrete

c) How interaction of cements with various additives, admixtures, and mixture designs can affect concrete

This guide only deals with hydraulic cements manufactured under North American standards (ASTM International, American Association of State Highway and Transportation

Officials [AASHTO], and Canadian Standards Association [CSA]). For information on other hydraulic cement standards, the user is directed to local specifications and building codes.

CHAPTER 2—NOTATION AND DEFINITIONS

2.1—Notation

Cement phases referred to throughout this guide follow the cement chemists' notations as follows:

A = Al_2O_3
C = CaO
$\overline{C}$ = CO_2
F = Fe_2O_3
H = H_2O
M = MgO
S = SiO_2
$\overline{S}$ = SO_3
tricalcium silicate: $3CaO \cdot SiO_2 = C_3S$
dicalcium silicate: $2CaO \cdot SiO_2 = C_2S$
tricalcium aluminate: $3CaO \cdot Al_2O_3 = C_3A$
tetracalcium aluminoferrite: $4CaO \cdot Al_2O_3 \cdot Fe_2O_3 = C_4AF$

Tricalcium silicate, Ca_3SiO_5, in conventional notation becomes $3CaO \cdot SiO_2$ in oxide notation, or C_3S in cement chemists' notation. Simple oxides, such as CaO or SiO_2, are often written in full.

2.2—Definitions

ACI provides a comprehensive list of definitions through an online resource, "ACI Concrete Terminology," https://www.concrete.org/store/productdetail.aspx?ItemID=CT16.

Equivalent alkali in hydraulic cement is the total of sodium and potassium oxides as calculated from the chemical analysis, and using the formula: $Na_2Oeq = \%Na_2O + 0.658\%K_2O$ (ASTM C219).

CHAPTER 3—CEMENT TYPES, AVAILABILITY, AND SELECTION

Selection of cement is an important consideration when proportioning mixtures for specific project requirements and intended use. It is important that the specification for hydraulic cements be appropriate for the project and the hydraulic cements available in the area. Factors such as exposure conditions and desired properties can often require specific cement types based on the chemistry or physical properties. Special cements may be available that are designed for applications where performance requirements cannot be achieved with ordinary portland cement.

3.1—Portland and blended hydraulic cements

A majority of the cement used for concrete construction in the United States is either portland cement, manufactured to meet the requirements of ASTM C150/C150M, blended hydraulic cement manufactured to meet the requirements of ASTM C595/C595M, or performance-based hydraulic cement manufactured to meet the requirements of ASTM C1157/C1157M. Tables 3.1a and 3.1b include basic characteristics of these cements as listed in ASTM. Other portland cement specifications can be found in AASHTO M 85 or, for Canada, in CSA-A3001. Blended cements are also specified under the AASHTO M 240 requirements. For more on hydraulic cement specifications and selection, refer to 3.4.

Table 3.1a—Characteristics of portland cements*

Type*	Description	Optional characteristics†
I	General use	1, 4
II	General use; moderate sulfate resistance	1, 4
II (MH)	General use; moderate heat of hydration	1, 4
III	High-early-strength	1, 2, 3
IV	Low heat of hydration	4
V	High sulfate resistance	4, 5

*For cements specified in ASTM C150/C150M.

†Optional characteristics:

1. Air entraining (A)
2. Moderate sulfate resistance: C_3A maximum, 8 percent
3. High-sulfate resistance: C_3A maximum, 5 percent
4. Low alkali: maximum of 0.60 percent alkalies, expressed as Na_2O equivalent
5. Alternative limit of sulfate resistance is based on expansion tests of mortar bars

Portland cements are manufactured by a process that begins by combining a source of lime such as limestone, a source of silica and alumina such as clay, and a source of iron oxide such as iron ore. The properly proportioned mixture of the raw materials is finely ground and then heated to approximately 2700°F (1480°C) for the reactions that form cement phases to take place. The product of a cement kiln is portland cement clinker. After cooling, the clinker is ground with calcium sulfate (gypsum); processing additions; and, in many cases, limestone to form a portland cement. Processing additions are organic or inorganic materials used in the manufacture of cements that are added at the finish mill. Their use is governed by ASTM C465. Processing addition rates for portland cements are specified in ASTM C150/C150M. The specific gravity of portland cement will vary slightly depending on the amounts of limestone, gypsum, and inorganic processing addition added to the clinker (for further reference on inorganic process addition refer to Taylor [2008]). Most of these additions are less dense than clinker and tend to reduce the specific gravity of the portland cement. When proportioning concrete mixtures, unless an actual measurement of the specific gravity of the cement has been made, 3.15 has been used for portland cements (Kosmatka and Wilson 2011). As the amount of processing additions increase, the specific gravity value has been found to decrease.

Blended hydraulic cements are usually made by intergrinding portland cement clinker with calcium sulfate (gypsum); processing additions; and a quantity of a suitable material such as slag cement, fly ash, limestone, silica fume, or raw or calcined natural pozzolans. They may also be made by blending the finely ground ingredients, or by a combination of blending and intergrinding. The specific gravity of a blended cement will vary with the type and amount of material(s) that is interground or interblended.