Practitioner's Guide for Alternative Cements

Reported by ACI Innovation Task Group 10

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As performance demands of concrete increase, and given recent initiatives to address the sustainability of construction, owners, architects, and engineers are actively seeking alternatives to portland cement for concrete. An alternative cement is intended to be a replacement for portland cement in some applications. In some cases, alternative cements may also be used in combination with portland or blended hydraulic cements. This document covers currently available and emerging alternative cements and is intended to provide information to help guide practitioners seeking to implement alternative cements.

Keywords: alkali-activated fly ash cement; alkali-activated glass cement; alkali-activated slag cement; alkali activation; alternative cements; calcium aluminate cement; calcium sulfoaluminate cement; carbonated calcium silicate cement; durability; functional addition; geopolymer; magnesium oxychloride cement; magnesium phosphate cement; reactive belite cement; specifications; supersulfated cement; sustainability; test method.

CONTENTS

CHAPTER 1—INTRODUCTION AND SCOPE

1.1—Introduction

This guide is intended as an introduction for engineers, architects, contractors, and owners who are interested in using an alternative cement on a project, but lack experience with these materials. This guide assumes the reader has experience with conventional concrete materials and construction, and is seeking knowledge on how these new cement technologies compare to portland cement when used in concrete.

The alternative cement properties summarized in this document are those reported for properly designed and placed alternative cement concretes. As with all types of concrete, material quality, mixture design, curing method-

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ology, and placement technique are all crucial to obtaining the desired properties; the examples presented are not universally applicable but are illustrative of what to expect from specific alternative cements.

1.2—Background

Portland cement concrete (PCC) is unrivaled when it comes to versatility and durability and, as such, is the most widely used man-made material on Earth. Countless civil engineering and architectural structures use concrete in their construction, including roads, bridges, public water and sanitary systems, and buildings. Almost 200 years of experience has resulted in a solid, practical understanding of how PCC works, and with the correct mixture design and materials, practitioners can manipulate concrete to easily meet the needs of society.

As engineers, architects, and contractors continue to push the bounds of what is possible in design and construction, materials must evolve as well, which is where alternative cements come in. To serve as an alternative to portland cement, a binder technology needs to offer demonstrable improvements when considering factors such as environmental impact, life-cycle cost (LCC), and performance. The use of an alternative cement is motivated by one or more of three main drivers:

1. Reduced cost—both initial cost and LCC
2. Reduced environmental impact
3. The need for specific properties unattainable with PCC

Improving the sustainability of construction is clearly one force driving the emergence of alternative cement concrete technologies. Increasingly, construction alternatives are being considered in terms of their LCC, in addition to or in place of initial cost. When it comes to LCC determination, the industry has considerable experience with PCC and can estimate the individual costs that contribute to the LCC. For some alternative cements, the industry still needs to develop that experience and establish life-cycle costs. A life-cycle cost is strongly intertwined with the material's functional performance and is inextricably linked to its durability. Given their recent development, long-term durability data are not available for all alternative cements.

As is the case with all manufacturing processes, portland cement production has environmental impacts that represent a cost to society. Chief among these are: 1) the energy-intensive nature of producing portland cement; and 2) the inherent release of greenhouse gas (GHG) emissions in the production process. A key advantage of alternative cement production is a significant reduction in environmental impact as compared to portland cement. The specific nature of the reduction varies between different alternative cement technologies. Burris et al. (2015) states manufacture of the alternative cements described in this document results in anywhere from 44 to 84 percent of the CO_2 associated with the production of an equal mass of portland cement.

Apart from sustainability considerations, in some applications an alternative cement concrete may offer enhanced functional performance when compared to PCC, and in those cases, the market value of the alternative cement concrete may exceed that of PCC. In most cases, however, initial costs should be similar for an alternative cement to be considered for use. More importantly, for alternative cements to replace PCC in less-specialized applications, functional equivalence with PCC is required. Functional equivalence is required due to the empirical nature of the concrete design and construction environment. Demonstrated performance, both in the laboratory and in practice, is required to ensure that life-safety considerations are met when using alternative cement concrete in place of PCC. Demonstrating this performance to specifiers has been a challenge for alternative cement producers largely due to the lack of a clear testing protocol or, in some cases, the lack of applicable tests.

Another aspect of functional performance is constructability. To achieve the desired hardened properties, the concrete must be properly placed and cured in the field. This aspect limits the application of some alternative cements that require specific non-atmospheric curing regimes such as a CO_2-rich curing environment, or elevated temperatures. For other alternative cements, rapid setting and rapid strength gain, as compared to PCC, are principal value-added aspects of their performance. Constructability also depends on the availability of knowledgeable people to both place and adjust the mixture designs to achieve the desired performance. Therefore, it is necessary to have a workforce that is trained and able to proportion, test, mix, place, and cure these new materials.

1.3—Scope

This guide covers both currently available and emerging alternative cements, and is intended to aid people interested in using alternative cements in a project. A brief summary of each of the alternative cement technologies is provided, as well as selected case studies and a guideline for use that addresses mixture design as well as construction and design properties. References made to portland cement and portland cement production are for comparison purposes only. An in-depth discussion of portland cement is not within the scope of this guide.

1.4—Organization of this guide

This guide is organized into five chapters; a synopsis of each is presented below.

Chapter 1—**Introduction and Scope:** Describes the need for alternative cements and identifies the scope and objectives of this guide.

Chapter 2—**Notation and Definitions:** Defines terminology unique to alternative cements or not currently defined in *ACI Concrete Terminology*.

Chapter 3—**Alternative Cement Properties and Applications:** Summarizes the alternative cement technologies currently considered commercially available, as well as those in development.

Chapter 4—**Selected Case Studies:** Provides selected case studies to help illustrate how some of these materials have been used successfully.

Chapter 5—**Guidelines for Use:** Provides guidelines for issues to consider when deciding to use an alternative