BLENDED CEMENTS

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BLENDED CEMENTS

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Foreword

The symposium on Blended Cements was held in Denver, Colorado, on 27 June 1984. ASTM Committee C-1 on Cement sponsored the symposium. Geoffrey Frohnsdorff, National Bureau of Standards, served as symposium chairman and editor of this publication.

Related ASTM Publications

Masonry: Materials, Properties, and Performance, STP 778 (1982), 04-778000-07

Cement Standards–Evolution and Trends, STP 663 (1979), 04-663000-07

A Note of Appreciation to Reviewers

The quality of the papers that appear in this publication reflects not only the obvious efforts of the authors but also the unheralded, though essential, work of the reviewers. On behalf of ASTM we acknowledge with appreciation their dedication to high professional standards and their sacrifice of time and effort.

ASTM Committee on Publications

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Contents

Introduction

Blended cements are usually, but not always, blends of portland cements with other finely ground materials. The most common ingredients for blending with portland cements are pozzolans and latent hydraulic materials, such as, ground granulated blast-furnace slags, but other materials, such as ground limestone, may be also used. Blended cements without portland cement are sometimes made, an example being slag cements made from ground, granulated blast-furnace slag and slaked lime or gypsum.

Blended cements have been manufactured in many countries but, at least in the United States, the volumes manufactured have been small compared to the volumes of portland cements. A renewed interest in blended cements came about in the United States following the oil embargo in 1973. This was because portland cement manufacture is energy-intensive and blended cements generally require less energy per unit volume to manufacture. The ASTM specifications for blended cements which existed in 1973 were not as well-developed as the portland cement specifications. This probably was the result of less interest and greater complexity in defining the product. The blended cement standards appeared to be too restrictive in terms of the ingredients permitted and in the range of acceptable proportions. However, in the absence of adequate data on factors affecting the performance of blended cements, the specifications have been difficult to change.

This volume presents the papers which were presented at the ASTM Symposium on Blended Cements sponsored by Committees C-1 on Cement. The Symposium was organized to provide more information on blended cements of all kinds, so as to aid the standards development process. We hope and believe it will achieve its purpose.

Geoffrey Frohnsdorff
National Bureau of Standards, Washington, DC 20234; symposium chairman and editor.

Portland Blast-Furnace Slag Cements

Jean Daube [1] *and Robert Bakker* [2]

Portland Blast-Furnace Slag Cement: A Review

REFERENCE: Daube, J. and Bakker, R., **"Portland Blast-Furnace Slag Cement: A Review,"** *Blended Cement, ASTM STP 897,* G. Frohnsdorff, Ed., American Society for Testing and Materials, Philadelphia, 1986, pp. 5–14.

ABSTRACT: It is a two-part report; in the first section the properties required for the components of blast-furnace slag cements, cement standards, and applications are described; in the second section, a review of the performance of blast-furnace slag cements compared to portland cement is described with special reference to sulfate and seawater resistance, reduced alkali-silica expansion, and low-heat properties.

KEY WORDS: specifications, use, portland slag cements, properties, slags, performance, cements, standards, sulfate resisting cements, seawater corrosion, alkali silica expansion, low-heat cements

Blast-furnace slag cements (BFSC) have been used for decades in Europe and in many cases they are used to replace normal portland cements (OPC). In the BENELUX market (Belgium, Netherlands, and Luxembourg), which annually amounts to a total of 9 million metric ton of cements, approximatively 50% are BFC.

Quality of BFC Components

Quality of Iron Blast-Furnace Slag

Two main characteristics determine the hydraulic properties of granulated iron blast-furnace slag (BFS), that is, its chemical composition and its vitreous state.

Based on the results of a previous study [*1*], an empirical formula defines an hydraulic index I_h which characterizes the quality of the slag

$$I_h = \frac{\mathrm{CaO} + 1.4\ \mathrm{MgO} + 0.56\ \mathrm{Al_2O_3}}{\mathrm{SiO_2}}$$

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[2]Fellow-worker, Vereniging Nederlandse Industrie, Hertogenbosch, The Netherlands.

TABLE 1—*Hydraulic values of BFS from chemical composition.*

Hydraulic Index I_h	Expected Quality of Slag
<1.65	unacceptable
1.65 to 1.85	normal
1.85 to 2.10	superior

This formula was obtained by correlating the hydraulic index of 56 laboratory slags with the mechanical strengths of cement mortars made from those slags and which were tested after 3 and 7 days in accordance with the European ISO method on 4 by 4 by 16-cm mortar bars. The validity of this formula was confirmed recently by tests on industrial slags [*2*].

The fact that the coefficients affecting magnesia and alumina are identical, respectively, to the mole ratios calcium oxide/magnesium oxide (CaO/MgO) and calcium oxide/aluminum oxide (CaO/Al_2O_3), denotes a molecular substitution of CaO in the vitreous slag; silicon-ion is to be considered as a network former, and calcium, magnesium, and aluminum ions as network modifiers [*2*].

Statistical data for industrial slags from BENELUX reveal I_h-values ranging from 1.55 to 2.10. Table 1 gives a rough classification of the hydraulic quality of slags within this range.

In order to have hydraulic properties, the slag must have been quenched and fixed in its vitreous state which may be checked by means of X-ray diffraction analysis. Systematic X-ray analysis is generally not required but may be important for the products obtained from new quenching methods such as, for example, expanded pelletizing. A complete vitrification is not required, and a low percentage of crystallization (3 to 5%) may improve the reactivity [*2*].

It is known that magnesia does not appear in granulated slags in its crystallized form, periclase, but enters as a modifier in the silicon network of the glass. Consequently, high magnesia contents in the slags will not induce expansion in concrete.

A direct measurement of the compressive strength on industrial cements replaces the slag activity test described in the ASTM Specification for Ground Iron Blast-Furnace Slag for Use in Concrete and Mortars (C 989-82).

Quality of Portland Cement Clinker and Calcium Sulfate

Intergrinding of portland clinker, BFS, and calcium sulfate ($CaSO_4$) allows the three components to adapt to each other. The reactivity of slag is enhanced by alkalinity; experience has confirmed that clinker with a lime saturation factor (LSF) in excess of 0.95 and a relatively high alkali-oxides and -sulfates content will favor the early strength development of the BFSC. Consequently, clinker from dry-process kilns is a better activator for BFS because it tends to have higher alkali content.

TABLE 2—*Maximum SO_3 limits in cement standards in the United States, United Kingdom, and BENELUX countries.*

Slag in Cement, %	Maximum SO_3 Allowed In				
	USA	UK	Belgium	Netherlands	Luxembourg
27 to 70	3.0	3.0	3.75	4.0	4.5
⩾ 70	4.0	3.0	3.75	4.0	4.5
⩾ 85	4.0	3.0	5.00	...	4.5

The nature of $CaSO_4$ plays an important role in the regulation of the setting of BFSC. Special attention must be paid when using a $CaSO_4$ waste product such as phospho-gypsum or anhydrite. This waste sulfate may contain traces of retarding constituents, the effects of which will be proportional to the slag percentage in the cement. The choice between gypsum and anhydrite as a regulator is of utmost importance so as to avoid rheological difficulties during handling of concrete. It has been proven that BFSC with anhydrite will sometimes result in quick set, especially in the presence of admixtures, while slag cement interground with gypsum only may result in false set. So it is often advisable to produce BFSC using a mixture of both gypsum and anhydrite. The ratio $CaSO_4 \cdot 2H_2O/CaSO_4$ will be adjusted by the cement manufacturer as a function of the clinker content and the clinker composition.

An important and disputable problem stems from the maximum admissible sulfur trioxide (SO_3) content in BFSC. $CaSO_4$ favorably influences the strength development of BFSC, and it would be detrimental to limit unnecessarily its content because of exaggerated fear of the product's not meeting the requirements of volume stability.

Table 2 gives a comparison between the SO_3 requirements in ASTM, British, and the corresponding standards in the BENELUX countries.

Due to the accelerating properties of SO_3, an increase in its limits as set forth in the United States and British Standards would allow to improve the quality of BFSC, especially in the case of cements with a high percentage of slag.

Performance of Blast-Furnace Slag Cement

Table 3 compares the ASTM, British, and BENELUX denominations of BFSC. In addition to this nomenclature, in the BENELUX distinction is made between three classes of compressive strengths, as shown in Table 4. These classes are applicable for OPC as well as for BFSC. Nevertheless because of technical or economical reasons not all types of cement are produced in every strength class. For example, there is no class 33.3 MPa (4830 psi) BFSC on the market.

The strength requirements for ASTM Types I and III on one hand, and for Types 40 (B) and 50 (C) on the other hand are rather similar. On the contrary, the

TABLE 3—*Nomenclature of blended hydraulic cement following slag content.*

Clinker, %	ASTM	British	Belgium	Netherlands	Luxembourg	Slag, %
100						0
90	Slag-modified portland cement, Type I (SM)					10
80		portland blast-furnace cement, Type PBLF	slag portland cement, Type PL	slag portland cement, Type psc		20
70			Iron portland cement, Type PF		Iron portland cement, Type PF	30
60						40
50	Portland blast-furnace slag cement, Type I S					50
40			blast-furnace cement, 35/60 Type HK 60/85 Type HL	blast-furnace cement, Type hc	blast-furnace cement, Type HF	60
30		low heat portland blast-furnace cement, Type LH PBLF				70
20						80
10	Slag cement, Type S					90
0			Permetallurgic cement, Type LK		Permetallurgic cement, Type PM	100