CEMENT STANDARDS

EVOLUTION AND TRENDS

P. K. Mehta, *editor*

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Dedication

This publication is dedicated to the chairmen of ASTM Committee C-1 on Cement:

G. F. Swain (1903–1916)

R. S. Greenman (1916–1926)

P. H. Bates (1926–1945)

F. H. Jackson (1945–1950)

R. R. Litchiser (1950–1963)

W. J. Halstead (1963–1968)

B. Mather (1968–1974)

H. H. Newlon (1974–)

By the members of Subcommittee C01.93 on Papers and Symposia

E. Farkas
G.J. Frohnsdorff
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J. Mander
P.K. Mehta, Chairman

Foreword

The symposium on Cement Standards – Evolution and Trends was held in St. Louis, Mo., on 7 Dec. 1977. Committee C-1 on Cement of the American Society for Testing and Materials sponsored the event. P. K. Mehta, University of California, Berkeley, presided as chairman of the symposium and served as editor of this publication.

Related ASTM Publications

1978 Annual Book of ASTM Standards, Part 13, Cement, Lime, Ceilings and Walls (Including Manual of Cement Testing), $20.00, 01-013078-07

Fineness of Cement, STP 473 (1970), $7.75, 04-473000-07

Living with Marginal Aggregates, STP 597 (1976), $5.50, 04-597000-07

A Note of Appreciation to Reviewers

This publication is made possible by the authors and, also, the unheralded efforts of the reviewers. This body of technical experts whose dedication, sacrifice of time and effort, and collective wisdom in reviewing the papers must be acknowledged. The quality level of ASTM publications is a direct function of their respected opinions. On behalf of ASTM we acknowledge with appreciation their contribution.

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Introduction

In order to commemorate the 75th anniversary of Committee C-1 on Cement of the American Society for Testing and Materials, a symposium on Cement Standards–Evolution and Trends was held in St. Louis, Mo., during the ASTM Committee Week in Dec. 1977. This publication contains the texts of the papers which were presented at that symposium.

A 75th anniversary is a significant milestone in the life of any organization. Such an occasion provides a good opportunity for self-examination. It is with this intent that the Subcommittee on Papers and Symposia (C01.93) of Committee C-1 decided upon "Cement Standards–Evolution and Trends" as the theme of the symposium.

Since strength, volume change, and chemical durability are important characteristics of concrete which are influenced by the properties of cement, test methods and specifications pertaining to these properties have been emphasized in the symposium presentations. In their papers, the authors have not only described the past accomplishments of ASTM Committee C-1 on Cement, but have also attempted to identify the areas of responsibility that need prompt attention from the Committee C-1 with regard to the development of cement specifications and test methods.

At the conclusion of this volume a Summary appears. The editor recommends that the Summary be read first, as it contains a concise statement of the principal results of each paper, as well as an overall view of the content of the symposium.

P. K. Mehta
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symposium chairman and editor.

W. S. Weaver[1]

Committee C-1 on Cement—Seventy-Five Years of Achievement

REFERENCE: Weaver, W.S., "Committee C-1 on Cement–Seventy-Five Years of Achievement," *Cement Standards–Evolution and Trends, ASTM STP 663,* P.K. Mehta, Ed., American Society for Testing and Materials, 1978, pp. 3–15.

ABSTRACT: Committee C-1 on Cement for the American Society for Testing and Materials convened its first meeting in Philadelphia on Oct. 31, 1902. Seventy-five years have passed; there have been many changes to the original specification for cement adopted in 1904, and additional standards have been written. Many individuals have been involved; there have been special committees, subcommittees, and task forces. The number and complexity of requirements have increased.

Progress during the 75 years is traced in respect to specific requirements and in terms of general topics–strength, soundness, setting behavior, air-entrainment, alkali reactivity, optimum sulfur trioxide and sulfate resistance. Comments are made on the factors and forces which have contributed to the success, pertinence, and growth of specifications under the jurisdiction of Committee C-1 on Cement.

KEY WORDS: cement, specifications, history, tests, air-entrainment, alkali-aggregate reaction, consistency, false set, fineness, insoluble residue, mechanical mixing, mortar, paste, regulations, setting times, soundness, sulfur trioxide content, surface area, sulfate resistance, water/cement ratio

The Committee on Cement of the American Society for Testing and Materials convened its first meeting in Philadelphia, Pa., on 31 Oct. 1902. It was one of the first of ASTM's technical committees, and over the ensuing 75 years it has been closely identified with the growth and development of the Society. This is, of course, a natural consequence, because the objectives and motivating forces of the committee have been very similar to those of the Society.

ASTM Committee C, as it was originally called, was born of necessity. The rapid industrial expansion in the United States at the turn of the century pro-

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duced a plethora of agencies drawing up cement specifications, and, consequently, there was a real need for standardization.

The first ASTM Standard Specifications for Cement (1904) were first tabled. Details are recorded in the ASTM *Proceedings*, Vol. IV; the discussions are reported verbatim. The first motion was that "these specifications be referred back to the committee for further consideration and amendment." Fortunately, that motion was defeated; the second motion, that they "be sent out to letter ballot for adoption by the Society," was carried.

The original ASTM Standard Specifications for Cement (1904) consisted of general conditions and specific requirements relating to both natural cement and portland cement. These terms were applied to the finely pulverized products resulting from "the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas" (in the case of natural cement) and "from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3 percent has been made subsequent to calcination" (in the case of portland cement).

The requirements of the 1904 specifications consisted of specific gravity; fineness (residues on both 100- and 200-mesh sieves); tensile strength (both neat and 1:3 mortar); time of setting (Vicat needle, both initial set and hard set); consistency of volume (neat pats, both normal and accelerated cures); and two chemical requirements–the sulfate and magnesia contents.

As an addendum to the first ASTM Standard Specifications for Cement (1904) there were "Recommended Methods of Testing," which had been developed over a period of several years by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers. These, along with the standard specifications, were given final approval on 14 Nov. 1904.

In 1907, R. W. Leslie, Vice-President of ASTM, expressed the opinion that "this specification stands as one of the extremely successful specifications of the Society . . . after 2½ years of 40,000 copies . . . all over the world." At the same time, Leslie pointed to a basic reason for the success of the standard–cooperative study and efforts by individuals representing different interests. He described the cement standard as conservative in character and slow to change but open to change.

The first changes were effected in 1908 and 1909. These were relatively minor in nature but included for portland cement the introduction of a 4 percent limit on ignition loss.

It was during this period, notably, and continuing subsequently over the years, that many research reports dealing with cement and concrete were presented at technical sessions of ASTM. These studies were conducted by industry, by federal and state government agencies, by universities, and by consulting engineers. In those days, research was extensive in nature but laborious and unsophisticated by today's standards. This sharing of research results had an obvious impact on the early members of Committee C.

In 1910 an organizational change occurred. Committee C became Committee C-1 on Cement, and other technical committees bearing C designations appeared, such as Committee C-2 on Reinforced Concrete, and Committee C-4 on Clay and Cement Sewer Pipes. (Committee C-7 on Lime first appeared in the *Proceedings* of 1913 and Committee C-9 on Concrete and Concrete Aggregates in the *Proceedings* of 1915.)

An action taken by Committee C-1 in March 1912 is interesting, in that it reflected a situation which existed then, which has surfaced many times in the intervening years, and which is current even today. I refer to the establishment of a liaison committee to "reconcile differences between specifications issued by Committee C-1 on Cement and the U.S. government's Committee on Cement. Government agencies have always been represented on Committee C-1, and their views on specification matters have carried considerable weight. However, the differences between the ASTM published specifications and those of the U.S. government has continued to be a matter of stimulation to Committee C-1.

A persistent concern of the early members of Committee C-1 related to the soundness of cement. The original specification required that neat pats be made and be subsequently subjected to *two* different exposure conditions: one normal and the other accelerated. A brief review of how Committee C-1 has handled this matter will illustrate a basic pattern by which progress has been achieved by the Committee. In 1908 a paper entitled "The Influence of Fine Grinding on the Physical Properties of Portland Cement" had been presented by R. K. Meade; in 1911 there had been a report on "The Expansion and Contraction of Cement Mortars" by A. H. White; and, in 1913, a paper on "The Autoclave Test for Cement" was given by A. J. Force. In 1914 Committee C-1 set up a subcommittee to investigate the accelerated test of constancy of volume of cements. The following year, as a result of an extensive cooperative study, the subcommittee reported "that the autoclave test does not show appreciable merit as a test for soundness," and its consideration as a specification test was dropped. The reason for discarding the autoclave test at that time was a lack of knowledge relating the independent expansions of free lime, periclase, and tricalcium aluminate. It was not until 1928 when A. H. White reported a lengthy study of volume change of neat portland cement mortars, carried out at the University of Michigan, that the way was opened for reconsideration. The autoclave test was eventually published by Committee C-1 as a tentative in 1940 and adopted as a standard in 1943. The original maximum permissible limit of volume change was 0.50 percent; this was relaxed to 1.0 percent during World War II and established at the current value of 0.80 percent in 1961. The original pat tests were carried in the ASTM Methods of Sampling and Testing Portland Cement (C 77-30) from 1930 to 1944 and as the ASTM Test for Soundness of Hydraulic Cement over Boiling Water (C 189-44) from 1944 until 1956, at which time it was honorably withdrawn.

Although there had been rules of committee procedure established in 1903, a more formal set of regulations governing Committee C-1 was adopted in 1914.

It is interesting to note that five members constituted a quorum and that four meetings per year (including the Annual Meeting of the Society in June) were required. Committee membership started with 28 persons in 1902, rose to 77 in 1927, increased to 106 in 1952, and currently numbers 253. Some 200 main committee meetings have been held during the 75-year period. The four-a-year rate, however, was not practical. The modal year contained three meetings. Since 1956 Committee C-1 has held two meetings in each year.

One other aspect of the 1914 regulations was the establishment of working subcommittees. Previously, there had been ad hoc or special subcommittees. In addition to the Subcommittee on Accelerated Tests of Constancy of Volume of Cements, reference was made in the 1914 *Proceedings* to a Subcommittee on Methods for Determining Consistency and a Subcommittee on Standard Screen Scale and, in the 1916 *Proceedings*, to Subcommittees on Fineness, Time of Set, and Strength.

The problems of how to assess the strength potential of portland cement and how to relate strength of paste or of mortar to strength of concrete were ones which occupied a great deal of thought and research effort in the early days of Committee C-1. It must be recalled that the basic principles of the water/cement ratio (*W/C*) were not then well understood and not clearly enunciated until stated in a publication by D. A. Abrams of the Lewis Institute, Chicago, in 1918. Likewise, the effects of aggregate gradation and compaction were obscure.

The tension tests in the original ASTM Standard Specifications for Cement (1904) were on neat and on 1:3 mortar specimens. The requirement for paste specimens was dropped in 1917, but the minimum limits for the mortar specimens were raised in successive revisions (Table 1).

TABLE 1–*ASTM specifications for portland cement: minimum limits for the tensile strength of mortar specimens.*

Cement Specification	Mortar Tensile Strength, psi[a] 3 days	7 days	28 days
1904	---	150	200
C 1-09	---	200	275
C 9-17	---	200	300
C 9-26	---	225	325
C 9-30	---	275	350
C 150-41	150	275	350

[a] 1 psi = 0.006 895 MPa.

These latter requirements continued in force until 1969, at which time they were deleted from the ASTM Specification for Portland Cement (C 150-69). The

test method, however, continues in the *Annual Book of ASTM Standards* as the ASTM Test for Tensile Strength of Hydraulic Cement Mortars (C 190-72).

The history of strength tests has another side to it. Early accounts reveal dissatisfaction with tension testing and the desire for a compression test. In 1916 a tentative ASTM Specification and Method of Test for Compressive Strength of Portland Cement Mortar (C 9-16 T) was approved by letter ballot. The specified mortar had proportions of 1:3 using 20/30 standard sand and was cast into 2- by 4-in. cylindrical molds. The water requirement was not specified. This tentative method received a great deal of attention. Thus, in 1927, Subcommittee VII on Strength tabled a report entitled "Tests of Fluid Cement-Water Mixtures," which involved a total of some 62 000 tests but had results described as "disappointing." A year later, in 1928, however, a paper by E. M. Birkett of Lehigh Portland Cement Company described "A Plastic Compression Test for Cement." The proportions were 1:2.75; sand was graded with a fineness modulus of 2.23; the *W/C* ratio had a fixed value; and the specimens were 2-in. cubes. The Subcommittee on Strength immediately set up a new cooperative study program, but it was not until 1934 that the ASTM Test for Compressive Strength of Portland Cement Mortar (C 109-34 T) was adopted by Committee C-1 and not until 1941 that requirements were accepted into the portland cement specifications (ASTM Method C 150-41). Over the ensuing years, these compressive strength requirements were frequently reviewed and revised (Table 2).

TABLE 2–*ASTM specifications for portland cement; minimum limits for compressive strength of mortar specimens.*

Type I Cement Specification	Compressive Strength of Mortar, psi[a]		
	3 days	7 days	28 days
C 150-41	1000	2000	3000
-47	900	1800	3000
-55	1200	2100	3500
-74	1800	2800	3500
-76	1800	2800	4000

[a] 1 psi - 0.006 895 MPa.

As a result of the compressive strength test being adopted in 1941, there were in the specifications (ASTM Method C 150-41) two alternative strength tests. It was incumbent on the purchaser to specify the one required; if he did not so specify, the requirements of the tensile strength test(ASTM Method C 190-72) governed. In 1960 this condition was reversed, giving the compression test precedence, and in 1969 the tensile strength limits were dropped entirely from the list of physical test requirements.

Since the properties of hydraulic cement in paste, mortar, or concrete are

greatly influenced by the *W/C* ratio, it has been imperative to specify the proportion of gaging water to be used in each test. For the determination of setting times, autoclave soundness, and tensile strength, it has been found eminently satisfactory to base the water requirement on normal consistency–a test which was developed by L. J. Vicat in France over 160 years ago, adopted in the initial ASTM Standard Specifications for Cement of 1904, and only slightly modified in spite of much research during intervening years (ASTM Test for Normal Consistency of Hydraulic Cement (C 187)).

For compressive strength the first standard test method (ASTM Method C 109-34 T) called for a *W/C* ratio of 0.53. In 1943, to accommodate the increased number of portland cement types and to conform to federal requirements, the water demand was established for each test cement on the basis of plasticity by means of a prescribed flow table. At that time, manual mixing was routine, but in 1954 mechanical mixing (ASTM Test for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency (C 305-53 T)) was introduced, and in 1956 it was made mandatory. However, in spite of flow table refinements and the improvements derived from mechanical mixing, the precision of this procedure for establishing water requirements was not adequate, and, in 1970, after much study and debate, Committee C-1 adopted a fixed *W/C* requirements of 0.485 for all portland cements tested in plastic mortar (ASTM Test for Compressive Strength of Hydraulic Cement Mortars (using 2-in. or 50-mm Cube Specimens) (C 109-70 T)).

From the review of the strength specifications–in which, first, the tensile strength test was the only requirement; then, a compressive strength test was developed; next, that test was introduced as a lesser option; then, that test was promoted to a preferred position; and, finally, the compressive strength test was established as the only acceptance test for strength–a principle is illustrated, a principle held by Committee C-1 over the years and expressed by Chairman R. S. Greenman in 1925, as follows:

> The Committee believes its function to be not only investigative but judicial; that is, its duty is to conduct investigations and to review current practice and to express improvements in this practice through its recommended specifications and methods of test for cement.

Although in 1904 there had been an addendum of Recommended Methods of Test, and although the American Society of Civil Engineers' Committee on Uniform Tests for Cement continued its efforts, it became increasingly apparent from cooperative studies involving many laboratories that accuracy and precision of testing were sadly lacking. In 1925 Committee C-1 adopted a *Manual on Cement Testing*, which was "intended as a supplement to ASTM Method C 9-21, and for distribution with those specifications." The purposes were to point out the causes of some variations and to interpret the specified methods of test in the hope that a more uniform practice would develop among testing laboratories. Since that time, regularly and with constant revision, compilations of