Debray, which was recommended by the French Commission, Bauschinger's caliper apparatus, and Le Chatelier's tongs.*

The Chimney Expansion Test, in which a small quantity of neat cement is solidly pressed into a straight lamp chimney with the idea that an unsound cement will break the glass, is worthless, as all first-class cements expand to a greater or less degree.

*Described in Spalding's Hydraulic Cement, 1903, p. 166.

CHAPTER VIII

SPECIAL TESTS OF CEMENT AND MORTAR

The most important tests for comparing the qualities of different cements and for determining their practical value have been described in the preceding chapter. Certain other tests are often made to investigate special qualities of a cement or mortar, or for scientific research.

Such special tests may be enumerated as follows:

Color.
Weight.
Microscopical.
Compressive.
Transverse.
Adhesive.
Shearing.
Abrasive.
Porosity.
Permeability.
Yield of mortar.
Rise in temperature.

COLOR

The color of a cement bears but slight relation to its quality, but a variation of color in the same brand is sometimes an indication of inferiority. Natural cements made in different localities may often be distinguished from each other and from Portland cements by their color.

Portland Cement. The chemical composition of Portland cements made by different processes is so uniform that the color of different brands varies less than that of Natural cements.

The color of Portland cement is described as a cold blue gray. In England the term "foxy" is applied to a Portland cement of a brownish color. According to Mr. David B. Butler* this denotes "insufficient calcination or the use of unsuitable clay or possibly excess of clay." He further states that if a Portland cement contains a large quantity of underburned particles, on account of their lower specific gravity they tend to rise to the surface on troweling, thus forming a yellowish brown film which is noticeable in the section of the briquette after fracture.

*Butler's Portland Cement, 1899, p. 255.

The dark color of the coarser particles of a Portland cement left as residue on a screen is due simply to the fact that cement clinker is black, and pieces which are not finely ground retain the color of the clinker.

Natural Cement. The color of Natural cement varies with the character of the rock and consequently with the locality in which it is produced. It ranges from the light écru of the Utica (Ill.) cement to the dark grayish brown of the Rosendale (N. Y.). Samples received by the authors from various manufactories show the James River cement to be a light yellowish brown, the Akron (N. Y.) cement, écru, the Milwaukee (Wis.) cement, drab, and the Louisville (Ky.) cement, a brownish gray. Certain other brands are similar in color to Portland.

Puzzolan Cement. Puzzolan cement made from slag is of a light lilac shade, much lighter than Portland. After being kept under water it assumes, when freshly fractured, a bluish green tint. This green tint, which according to Candlot* is due to sulphide of calcium present in the cement, is especially noticeable in a sample kept in sea water, and fades on exposure to dry air.

WEIGHT OF CEMENT

Weight is no indication of quality. Formerly, nearly all specifications required that a cement should reach a certain standard of weight per struck bushel or per cubic foot, on the principle that, other things being equal, a thoroughly burned cement is heavier than one which is underburned. But when, on the other hand, the degree of fineness was found to affect the weight much more than any difference in calcination, the worthlessness of this requirement became apparent, and the test for specific gravity was substituted.

The following table by Eliot C. Clarke† illustrates the difference in weight between cements of the same manufacture which contain different percentages of coarse particles.

Weights of Cements Containing Varying Percentages of Coarse Particles. (*See p* 114.)

BY ELIOT C. CLARKE.

Percentage of cement retained on No. 120 sieve	Weight per cu. ft.
0	75 lb.
10	79 "
20	82 "
30	86 "
40	90 "

*Candlot's Ciments et Chaux Hydrauliques, 1898, p. 159.

†Transactions American Society of Civil Engineers, Vol. XIV, p. 144.

Mr. Henry Faija's experiments* arranged in the following table prove that the weight of a cement decreases with age. His explanation for this is that the lower specific gravity of the moisture and carbonic acid absorbed from the air tends to increase the bulk of the cement without correspondingly increasing its weight.

Decrease of Weight of Cement with Age. (*See p.* 115.)

BY H. FAIJA.

	Weight per cu. ft. lb.	Percentage of loss in weight per cent.
When received	88	..
After one month	85½	2.7
" three months	79½	9.9
" six "	78	11.4
" nine "	75½	14.2
" one year	74	15.9

Method of Weighing Cement. The apparatus finally recommended by the French Commission, after a series of tests by Mr. P. Alexandre,† was a circular funnel with screen, as shown in Fig. 40. The cement placed upon the screen is stirred with a wooden spatula 4 cm. (1⅝ in.) wide, and 25 cm. (10 in.) long, and falls through the screen into the cylindrical measure of one liter capacity (0.61 cu. ft.).

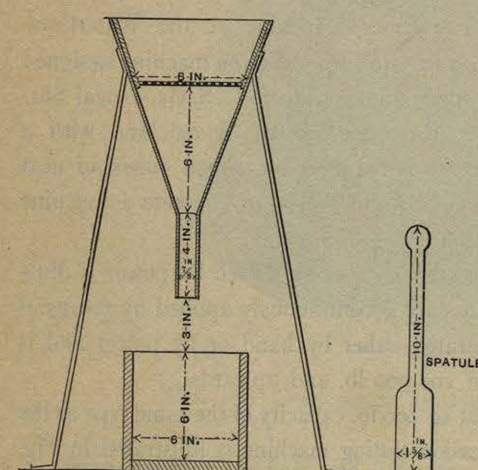

FIG. 40. Funnel Used in Weighing Cement. (*See p.* 115.)

MICROSCOPICAL EXAMINATION OF PORTLAND CEMENT CLINKER

The structure of Portland Cement clinker can be clearly discerned with the aid of the microscope and polarized light by preparing thin sections of it in the same way as those of rocks made by petrographers.

Le Chatelier, a French engineer, and Törnebohn,

*Butler's Portland Cement, 1899, p. 240.

†Commission des Méthodes d'Essai des Matériaux de Construction, 1895, Vol. IV, p. 21.

a Swedish petrographer, some years ago identified two essential mineral entities, and three others of less importance, as constituents of Portland cement clinker. Törnebohn denominated the two essential constituents alite and celite.

Mr. Clifford Richardson has within the last few years taken the subject up very elaborately in this country, and his results go to show that optical methods of examining clinker will eventually prove of great interest, not only in determining the character of clinker, but also in pointing out means of improving the methods of production.

COMPRESSIVE TESTS OF CEMENT

Compression testing machines are coming into general use in America. For merely determining the quality of a cement, tensile tests are more convenient because they can be made more quickly and require less powerful machines, but for comparing different sand aggregates and for its adaptability to testing concrete by compression or by transverse, *i.e.*, beam, tests, the compression machine possesses great advantage. The French Commission recommend compression tests in addition to tension, and many engineers in the United States advise them in well equipped laboratories.*

Types of Compression Testing Machines. Machines especially adapted for compressive tests are built with capacities ranging from 30 000 to 400 000 lb., or even larger. The Emery Machine at the Watertown Arsenal, U. S. Army, is of 800 000 lb. capacity while the machine designed in 1908 for the structural materials laboratory of the U. S. Geological Survey at St. Louis has a capacity of 10 000 000 lb. A machine with a capacity of not less than 40 000 lb. is required for 2-inch cubes of neat cement or mortar, while for 6-inch cubes of mortar or concrete a machine should run to at least 150 000 lb.

A testing machine for general laboratory work driven by power is illustrated in Fig. 41, in which the pressure is continuously applied by means of a screw pump. It may be operated either by hand or by power and is built for maximum capacities of 200 000 lb. and upwards.

An American machine of about 40 000 lb. capacity of the same type as the German Amsler-Laffon compression testing machine is illustrated in Fig. 42, page 118. The hydraulic power is applied by turning the hand wheel and the load is read directly from the pressure gage.

* Proceedings American Society of Civil Engineers, April, 1900, p. 125.

Form of Compression Specimens. Extended tests were made for the French Commission by Mr. P. Siméon,* in which he employed specimens of various shapes and sizes, and compared the results with those obtained

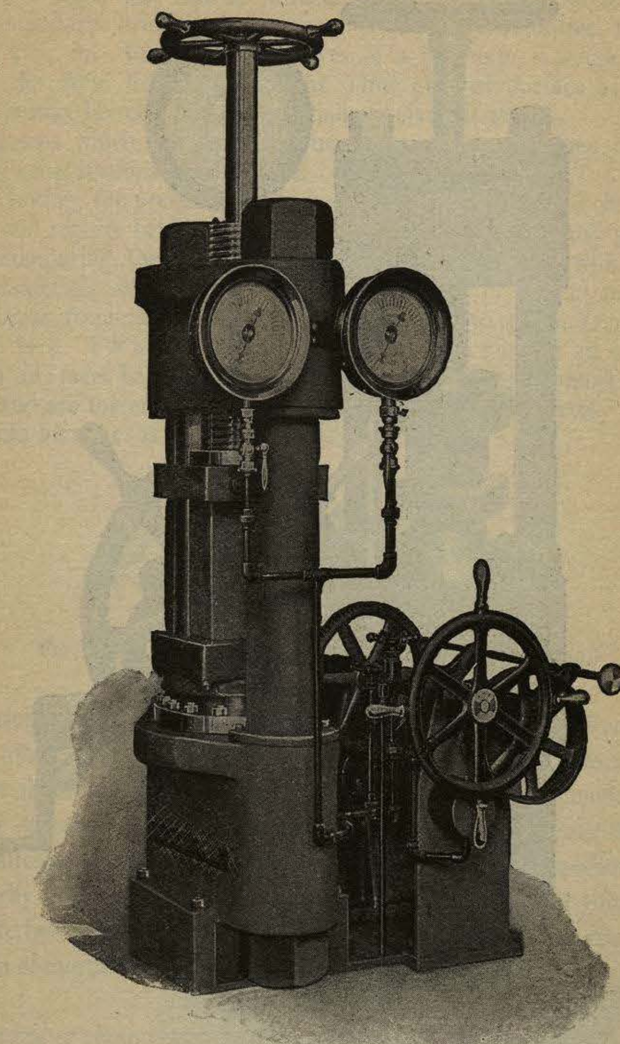

FIG. 41.—Compression Testing Machine. (*See page* 116.)

from crushing the halves of briquettes which had been broken in tension. Quoting from a discussion of Mr. Thompson† upon the Report of the Cement Committee of the American Society of Civil Engineers:

*Commission des Méthodes d'Essai des Matériaux de Construction, Vol. IV, 1895, p. 187.

†Sanford E. Thompson in Proceedings American Society of Civil Engineers, August, 1903, p. 646.

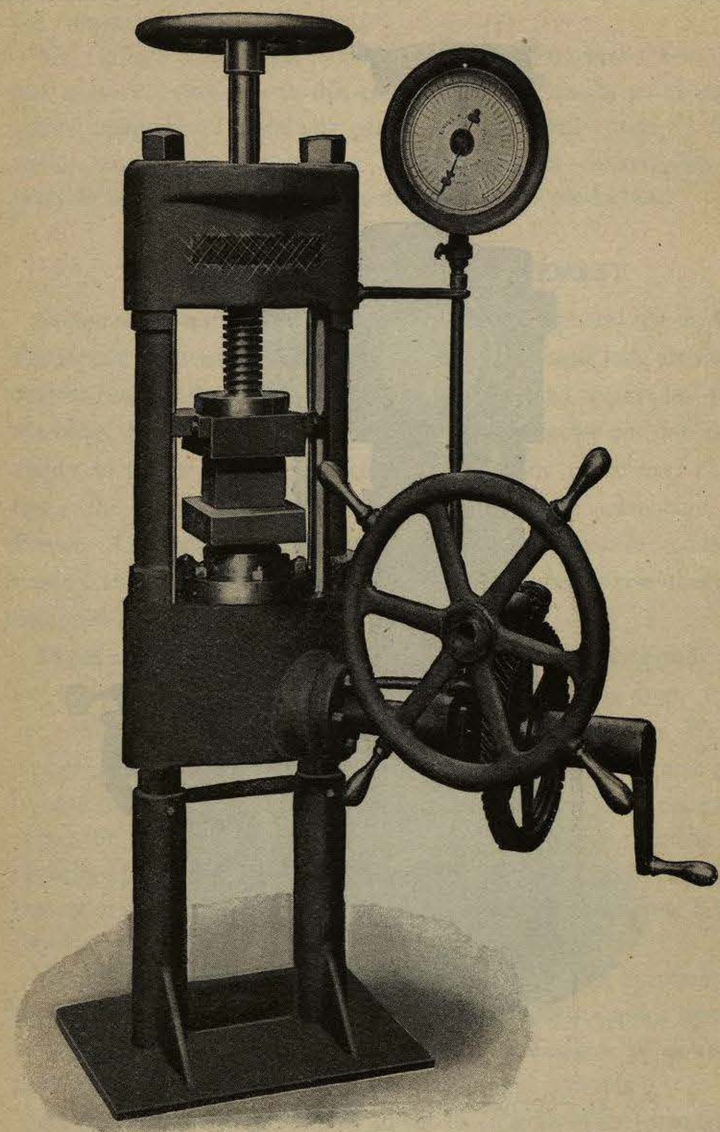

FIG. 42.—Hydraulic Compression Testing Machine. (*See page* 116)

The Commission reached the conclusion that the briquettes which had been broken in halves by tension should be used for the compressive tests. The two halves of each briquette are crushed separately and the sum of the two results divided by the total area of the briquette, thus obtaining the compressive strength per unit of surface. The surface area of the United States standard briquette recommended by our Committee is almost exactly 4 sq. in. Instead of the halves of a briquette, a single cylinder having the same thickness and the same area of surface as a whole briquette may be used with substantially equivalent results.

Specimens which are rough or uneven may be smoothed by gentle rubbing on a stationary grindstone.

In breaking, the pressure should increase uniformly, and at such speed that it will require between one and two minutes to crush each specimen.

For comparing the strength of cement paste or mortar, with that of other materials which cannot readily be molded in cement molds, the Commission recommends cubes having an area of 50 sq. cm. (7.75 sq. in.) on each face. For a United States standard, cubes 2 in. on an edge, that is, with all faces having an area of 4 sq. in., conform to most common usage, and are therefore best for this class of comparative tests.

A mold for cubes is shown in Fig. 43.

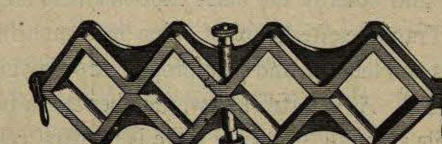

FIG. 43.—Gang Mold for Compression Cubes. (*See p.* 119.)

Relation of Compressive to Tensile Strength. Mr. R. Feret* concludes, after an extended series of tests, that there is no constant relation between resistances to compression and tension. He also concludes that the rate of increase in strength varies with the different cements, so that "two different mortars having the same resistance to compression do not necessarily break under the same tension." He claims that compression tests give better results than tension and furnish "the real measure" of the cohesion of mortars. These opinions are generally corroborated by cement experts.

The ratio of compression to tension also varies with the character of the sand or other aggregate. With a larger proportion of cement the compressive strength increases faster than the tensile strength, thus giving a higher ratio. This law continues to hold with concrete of different proportions, that containing the largest proportion of cement showing the highest compressive strength in comparison to its tensile strength.

* Bulletin de la Société d'Encouragement pour l'Industrie Nationale, 1897, Series 5, Vol. II.

A comparison of the compressive and tensile strength of 1:3 mortars based upon tests at the U. S. Government Structural Materials Laboratory at St. Louis, in 1908, gives a formula

$$\frac{\text{Compressive strength}}{\text{Tensile strength}} = 6.6 + 2.3 \log. A,$$

where

A = age of the cement mortar in months.

By this formula it will be seen that the ratio varies from 6.8 on a one-month test up to 10.3 on a 12-months test. The formula is in the same form, but the ratios are somewhat greater than those obtained by Prof. J. B. Johnson * from Prof. Tetmajer's tests at Zurich.

TRANSVERSE TESTS OF CEMENT

Transverse, or flexion, tests of beams or prisms while very convenient for concrete are now seldom used for testing the quality of cement, although Gillmore and other of the older experimenters largely employed this form of test. Transverse tests are of value in comparing the relation between fiber stress and tension, and with proper care may give as uniform results as tension tests. As is stated below, the fiber stress bears a definite relation to the tensile strength, but since there is no fixed relation between tension and compression, there can be no fixed relation between transverse strength and compressive strength. Compression testing machines (see Figs. 41 and 42, pages 117 and 118) may be adapted for transverse tests by a suitable arrangement of supports and knife edges.

Size of Specimen. Mr. Durand-Claye† made for the French Commission an extended series of tests by flexion or bending. As a result of his report, the Commission adopted for this form of test square prisms 12 cm. (4.72 in.) long by 2 cm. (0.79 in.) on a side.

In breaking, a prism is placed on its side — that is, on a face which has been in contact with the mold — upon two knife-edges, 10 cm. (3.94 in.) apart, and the load is applied at the center through a slightly rounded knife-edge. The load should be applied continuously at the rate of 1 kgr. (2.2 lb.) per second. The same number of specimens should be broken as in tensile tests, and the results averaged.

*Johnson's Materials of Construction, 1903, p. 419.

†Commission des Méthodes d'Essai des Matériaux de Construction, 1895, Vol. IV, p. 211.

English measure will naturally change the dimensions of the specimen to 1 by 1 by 6 in., to be broken upon knife-edges 5 in. apart.*

A prism 2 by 2 by 8 in. was employed by General Gillmore in experiments described in his famous "Treatise on Limes, Hydraulic Cements and Mortars," and has been adopted by other American engineers, but with apparatus of sufficient delicacy there is no reason why the specimens need be larger in section than tensile specimens, and the dimensions of 1 by 1 by 6 inches suggested above are recommended for comparative tests of neat cements and mortars. A form of mold is shown in Fig. 44.

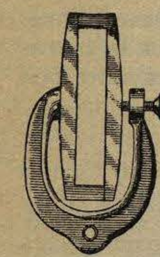

FIG. 44. — Mold for Prism. (*See p.* 121.)

Relation of Tensile to Fiber Stress. In the experiments mentioned above Mr. Durand-Claye compared all of his tests for flexion with tensile tests of briquettes made and tested at the same time. As a result, he obtained as the ratio between the ultimate fiber stress in flexion and the tensile strength, 1.92 at 7 days and 1.86 at 28 days; or in round numbers, 1.9 for both. That is, tensile fiber stress is 1.9 times the simple tensile stress of the same material. In this connection he calls attention to the fact that a briquette tested in tension gives a result less than the real resistance, while a prism tested in flexion gives a greater result. He judges that the real resistance may be approximated by taking the mean of the two results.

Mr. Durand-Claye also found the mean error by the two methods of testing to be very similar, with tensile briquettes the variation being about 2.02 % as compared with 2.52% variation in the flexion tests. In tests with mortar there was less variation with prisms than with briquettes.

Prof. Edgar B. Kay states that in recent experiments he has obtained more uniform results with tranverse than with tensile tests.

Comparative tests of Mr. R. Feret in tension, flexion, and compression are shown in the table on page 136.

ADHESION TESTS OF CEMENT

Mr. E. Candlot† made a large number of tests of adhesion for the French Commission, and designed a mold adopted as the French Standard. With reference to such tests he says that since the adhesion of mortar to a stone depends upon the state of the surface and the nature of the cement,

*Sanford E. Thompson in Proceedings American Society Civil Engineers, August, 1903, p. 646.

†Commission des Méthodes d'Essai des Matériaux de Construction, 1895, Vol. IV, p. 281.