absolute tests are of little value, but comparative tests, if made under identical conditions, are of real interest to the builder.

Thus, to cite several examples, the tests of adhesion prove that a mortar regaged after having set possesses a strength of adhesion much smaller than the same mortar gaged and put in place before its set, the resistance to tension and compression of these two mortars remaining, however, almost the same; that mortars gaged dry have a more feeble adhesion than mortars gaged slightly liquid; that mortars gaged with an excess of water have in tension a resistance less than their adhesive strength, etc.

Method of Making Adhesion Tests. In the same report Mr. Candlot describes the forms of specimens suggested by Dr. Michaelis and others, and then presents a form which he considers to best meet the requirements. On account of the difference in section of the French standard briquette, the mold he describes is not suitable for making specimens to fit the clips

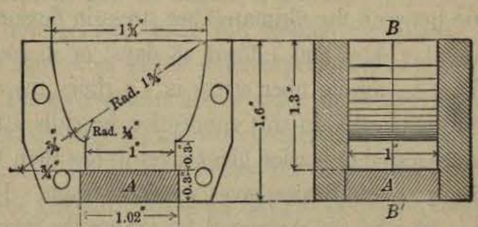

Fig. 45.—Mold for Adhesion Block. (*See p.* 122.)

on American testing machines. To adapt his mold to American standards, the authors have designed the mold shown in Fig. 45. The method of making tests is described by Mr. Thompson* as follows:

Adhesion is considered by Mr. Candlot in two ways: First, with reference to the relative adhesive qualities of different cements; and, second, with reference to the adhesion of the same cement mortar to other materials of different natures. The same general method is advocated in both cases.

Briquettes are formed, as described below, of a shape which can be broken in an ordinary tensile testing machine. The European tensile briquette is of small section, 5 sq. cm. (0.775 sq. in.), and of an inconvenient shape for molding in halves. The area of the breaking section is therefore doubled by the Commission, while the curves where the clips take hold remain the same, so that the distance between the two points of each clip is unchanged. The shape of the United States standard briquette is such that fewer changes have to be made in its outline, and the regular section of 1 sq. in. need not be altered.

*Proceedings American Society of Civil Engineers, August, 1903, p. 647.

The Commission found that adhesion briquettes could not be molded satisfactorily in the manner used for tension briquettes. They advised finally a mold in which a half briquette could be made, and then when this had set, the same mold could be used for completing the other half. In Fig. 45 is shown the style of mold selected, but with the dimensions changed to adapt the briquette to the United States standard form of clip. It consists of a bottomless box, which divides vertically in the center on the line *BB*, so that the half briquette can be removed readily. The bottom is formed of a movable bronze plate, shown at *A*.

For the first class of tests, to determine the relative adhesion of different cements, a normal adhesion block is formed of a mortar composed, by weight, of 1 part of highest quality Portland cement, which has passed a No. 75 sieve, and 2 parts of fine sand, gaged 9% of water. As soon as it is rammed into the mold, the mold is removed, and after remaining in moist air for 24 hours the half briquette is placed in water until it is required. It must set for at least 28 days. When required for use, the block is dried and the surface polished with emery paper. The block is then placed on a table with the large end down, the half mold, with the disc *A* removed, set on top of it and filled with plastic mortar consisting of the cement which it is desired to test mixed with sand in the required proportions, thus completing the briquette. This briquette is treated and tested as an ordinary tension specimen.

For the second class of tests, if the material can be molded, it is formed as a half briquette, and the specimen completed with the mortar to be tested. If solid, a plate of the material, several millimeters thick, having one smooth face, is prepared, and placed at the bottom of the mold, on top of the bronze plate, and the first half of the specimen is formed by filling the mold with neat cement. After setting, the half of the briquette is completed with the mortar which it is desired to test.

Adhesive Strength of Mortar. The following table from tests of Mr. Candlot, presented to the French Commission,* shows the results of adhesive tests upon Portland cement mortars cemented to the normal adhesion block by the method described in the preceding paragraphs. It is noticeable that, in the same column, the values, each of which represents a single specimen, are fairly regular, but that there is a very great variation in the adhesive strength of mortars made from different cements, and no uniform relation between the strength of mortars of different proportions.

Adhesion of Mortar to Various Materials. The results of tests made by Professor Tetmajer in Germany, quoted by Mr. E. Candlot, are briefly as follows: 1:2 Portland cement mortars cemented to sandstone gave an adhesive strength after 28 days of from 5.5 to 8.8 kg. per sq. cm. (78 to 125 lb. per sq. in.). To rough glass the adhesion was about 3.5 kg. per sq. cm

*Commission des Méthodes d'Essai des Matériaux de Construction, 1895, Vol. IV, p. 285.

(50 lb. per sq. in.). Tests made at Boulogne-sur-Mer using blocks of marble showed, after 28 days, variations of 3.1 to 8.3 kg. per sq. cm. (44 to 118 lb. per sq. in.). Regaged mortar showed about half the strength in adhesion of fresh mortar.

*Adhesive Strength of Portland Cement Mortars in Pounds per Square Inch.**

BY E. CANDLOT.

Cement.	A				B		C		D	
Proportions of mortar.	1:3	1:3	1:2	1:2	1:3	1:2	1:3	1:2	1:3	1:2
Per cent. of water.	12	13.8	9.5	15	12	13	15	17	12	13
	lb	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.
7 day tests.	107	135	142	149	36	36	36	43	60	65
	195	131	145	152	36	43	38	50	60	65
	131	156	135	128	28	36	38	36	57	71
	156	152	135		28	50		36	67	82
					36				57	107
Average. ...	147	143	139	143	33	41	37	41	60	78
28 day tests.	164	192	188	178	92	142	78	95	152	95
	178	206	294	152	81	114	74	78	128	88
	178	220	124	192	85	114	71	117	114	74
	199	220	185	156	60	85	81	100	107	
					67	102		88		
Average. ...	180	209	198	169	77	111	76	96	125	86

Mr. E. S. Wheeler† has made several series of tests, inserting thin discs of different materials in the center of briquettes. Although the irregularity in the results cast considerable doubt upon his method of testing, the experiments tended to show that the adhesive strength to sawn limestone of Portland cement mortar in proportions 1:0 to 1:2 is about one-third the cohesive strength of the mortar alone. Mr. Wheeler concluded that grooving the surface of the stone has no appreciable effect on the adhesive strength. For the maximum adhesive strength more water is required than for the maximum cohesive strength even if the surface of the stone be saturated. The substitution of a small portion of lime for a part of the cement apparently increases the adhesive strength.

*Molded upon normal adhesion blocks, see pp. 122 and 123.

†Report Chief of Engineers, U. S. A., 1895, p. 3019 and 1896, pp. 2799 and 2834.

Mr. R. Feret* states that adhesion to stone increases as the stone becomes more porous. He found, as did Mr. Wheeler, that irregularities of surface of the stone do not seem to affect the adhesive strength. With iron, however, roughening the surface increases the adhesion of the mortar. A dirty surface or insufficient moistening of the surface lowers the adhesion

The method adopted by various experimenters of crossing two bricks and cementing them together, then determining the loads required to separate them, is obviously inaccurate because of the difficulty of distributing the pull uniformly over the entire surface.

The adhesion of mortar to iron or steel is of such practical importance in the use of iron or steel for reinforcement, and the setting of bolts in mortar and concrete, that the subject is discussed in connection with reinforced concrete in Chapter XXI.

SHEARING TESTS OF CEMENT AND MORTAR

Mr. R. Feret made a series of shearing tests upon different mortars which are quoted in column (20) of the table on page 136. He employed for the shearing test the halves of small prisms which had been broken to determine the transverse strength, placing the specimens and loading them as is shown in Fig. 46.

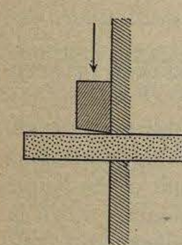

FIG. 46.—Shearing Test. (*See p. 125.*)

ABRASION

Abrasion or wearing tests have been made by pressing the specimen against a grindstone, an emery wheel, or a cast-iron disc, the last requiring sand in definite proportions to be poured upon it to increase the friction.

Tests by Mr. Eliot C. Clarke† tend to indicate that for Portland cement mortar the best proportions to resist abrasive forces are 1:2 and for Natural cement mortar 1:1, the resistance of Portland cement mortar mixed with two parts of sand being nearly double that of both the richer 1:1 mixture and the leaner 1:2½ mixture.

POROSITY TESTS

The determination of the porosity of a specimen is often necessary in scientific research and for comparing the relative absorptive properties of

*Communication au Congrès de Budapest, 1901.

†Transactions American Society of Civil Engineers, Vol. XIV, p. 167.

building materials. Porosity is a passive quality referring to the actual voids, *i.e.*, air and uncombined water in a substance as distinguished from permeability or percolation, the quality of a substance which permits the flow of a liquid or gas through it.

Method of Testing Porosity. Messrs. P. Alexandre, P. Debray, and H. Le Chatelier* recommended a method for making the test for porosity which, with the units converted into English measure, is summarized by Mr. Thompson† in his "Discussion on the Report of the Committee of the American Society of Civil Engineers on Uniform Tests of Cement." This method is suitable for testing the porosity of concrete as well as of mortar.

The porosity of a mortar is expressed as the ratio or percentage of voids to the total volume. In measuring the voids all water in the mortar is included except that of crystallization.

If

V = total apparent volume of mortar;
v = volume of solid portion of mortar;
v' = volume of voids in mortar;

then

$$\text{Porosity} = \frac{v'}{V} = \frac{V-v}{V}.$$

The size of specimen recommended is that having a volume of between 0.3 and 0.5 liter (18 to 30 cu. in.).

The solid volume, v, is found by the application of the principle of Archimedes, that the difference between the weight of a body in air and its weight when suspended in a liquid is equal to the weight of the liquid displaced. From the weight of the displaced liquid, its volume, which is manifestly the volume, v, of the mortar, can be readily calculated.

In English measure, if

P = weight of specimen after drying;
p = weight suspended in water after saturation;
W = weight of 1 cu. ft. of water;
v = volume of solid portion of mortar;

then

$$v \text{ (in cubic feet)} = \frac{P-p}{W}.$$

In order that the specimen may be thoroughly impregnated with water and all air driven from the pores when determining p, its weight in water, the specimen is first exposed for ½ hour in rarefied air at a pressure not greater than 25 mm. of mercury. Water is made to cover it, and then the atmospheric pressure is restored. It must now remain in the water 24 hours before being weighed. If apparatus for rarefying the air is not at hand, and if the specimen will stand exposure to heat, an alternate method may be used. The specimen, after 48 hours in water, is placed in cold water, raised to boiling, and boiled for 2 hours, then allowed to cool for 24 hours. The weight, P, used in this determination, is taken after exposing it to a heat of between 40° and 60° Cent. (104° and 140° Fahr.), until there is no loss in weight, care being taken to prevent any access of carbonic acid gas from the heating apparatus.

*Commission des Méthodes d'Essai des Matériaux de Construction, 1895, Vol. IV, p. 247.

†Proceedings American Society of Civil Engineers, Aug. 1903, p. 648.

The apparent volume, V, of the specimen, can be found by direct measurement, or by calculation from its loss of weight in water, using again the principle of Archimedes. To prevent saturation in the later proceeding, it can be covered with a thin coating of grease spread with the fingers. The weight in water must be taken before that in air.

The standard test of porosity is made with 1:3 mortars of normal plastic consistency, 28 days old. Other proportions and ages suggested are 1:2, and 1:5, at 7 days, 28 days, 6 months and 1 year.

The Porosity of Different Mortars. Porosity includes the voids or pores occupied by both air and water, the relative volumes of the two classes of voids varying with the freshness of the mortar.

In different fresh mortars there is much less variation in the volume of air voids than is generally supposed. If we leave out of consideration mortars that are mixed to such a dry consistency that voids are apparent to the eye, we notice from column 10 of the table on page 136 that in mortars proportioned richer than 1:5 the air voids rarely exceed 12%, and for most mixtures are in the neighborhood of 4% to 8%, that is, 4% to 8% by volume of air is entrained when gaging. Although experiments of Messrs. Candlot* and Alexandre show similar results, the authors, by mixing the materials with gloves, as recommended by the American Society of Civil Engineers, and using more water than required for standard consistency, — about, in fact, the consistency used by stone masons, — have obtained mortars in proportions of cement to either standard sand or bank sand of 1:0, 1:1 and 1:2 with no appreciable entrained air, and leaner mixtures with 1% to 2% air. A few experiments carefully made tend to show that in larger batches thoroughly mixed to soft consistency these low percentages may be obtained. Such mortars require no ramming, in fact the volume cannot be reduced after it is carefully introduced into the measure, except that if a very wet mixture is used it will expel a portion of its surplus water when setting so that the volume set is less than the volume green. One would naturally expect a greater variation with different materials and different proportions of water, but as a matter of fact, in a fresh mor-

*Candlot gives a range of from 2 or 3% for mortars of coarse sand, up to 10% with fine sand.

tar slightly softer than standard consistency, the spaces between the particles of sand and cement are not occupied by air but by water.

As the mortar dries after setting, the variation between different mortars is more appreciable, since the additional amount of water which is required with mortars of fine sand partially evaporates and leaves air voids. It is evident from experiments by Mr. Alexandre that the percentage of air voids due to evaporation of water ranges from 7% with a very coarse sand to 18% with a very fine sand. Assuming a small allowance for entrained air in the fresh mortar, due to imperfect mixing, we may estimate a range of from 7% to 25% total air voids in mortar after setting and drying. An average mortar of Portland cement and fairly coarse bank sand, in proportions 1 : 2 by weight or 1 : 2½ by volume, from experiments of the authors, may be expected to contain about 10% of air voids after setting and hardening, and to have a total porosity of about 25%. The porosity of well proportioned concrete is much lower (see p. 339). The porosity is but slightly affected by the percentage of water used in gaging, because an excess of water rises to the surface. (See p. 338.)

PERMEABILITY OR PERCOLATION TESTS

The permeability of mortar and concrete is discussed and the laws which govern it formulated in Chapter XIX, page 338. Permeability is distinguished from porosity on page 126.

Method of Testing Permeability. When preparing its final report, the French Commission* first experimented with cylindrical blocks having in the center a truncated well into which a vertical tube was introduced for a short distance to convey the water under pressure. They finally recommended instead of this form a cube of cement or mortar with a pipe cemented to its upper surface. Quoting again from Mr. Thompson's Discussion† on Uniform Tests of Cement:

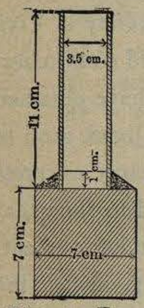

Fig. 47.—French Test for Permeability. (*See p.* 128.)

The permeability of neat cement and mortars is expressed by the number of liters of water passed in one hour through a cubical block, 50 sq. cm. (7.75 sq. in.) on a face, the size used for compressive tests. The block is placed on its side, that is, with a face which has been against the mold uppermost; this surface is carefully cleaned and a glass tube 3.5 cm. (1.38 in.) in diameter, and 11 cm. (4.33 in.) high is sealed vertically to it by means of neat cement, as shown in Fig. 47. For varying the pressure, a rubber pipe is attached to this tube, and its upper end connected with a reservoir. The height of pressure, according to the permeability of the mortar, may be 10 cm. (4 in.), 1 m. (3 ft. 3 in.) or 10 m. (33 ft.).

Before taking the test, the block is immersed in water for 48 hours, and remains in water during the test. The periods recommended are: 24 hours, 7 days, 28 days, 3 months, etc. The standard test is made at 28 days. Tests are made on three blocks, and an average taken of the two which most nearly agree.

Logically, we should suggest for the block to be used for testing permeability in this country, the size mentioned for compression, that is, a 2-inch cube. Further investigation is considered necessary, however, before adopting either the size or shape as a standard.

Since the publication of the above discussion, the authors have performed a series of tests on the relative permeability of concretes, as described on page 348, obtaining satisfactory relative results by cementing a short length of pipe to the surface of a solid block of concrete in a manner similar to that adopted by the French Commission.

*Commission des Méthodes d'Essai des Matériaux de Construction, 1894, Vol. I, p. 313.

†Proceedings American Society of Civil Engineers, August, 1903, p. 649.

YIELD TESTS OF PASTE AND MORTAR

The French Commission* recommend the testing of cement paste and mortar to determine the volume occupied. The yield or *rendement* is the volume of mortar obtained by gaging to any given consistency a unit of weight of cement or of a mixture of cement and sand in the selected proportions. One kilogram of cement, or of the required mixture of cement and sand, gaged to the given consistency, is introduced into a graduated cylindrical glass test tube about 6 cm. (2.37 in.) in diameter, with care to avoid imprisonment of air, and its volume is noted.

Another method, which they consider more accurate, is to allow the paste or mortar to harden and then determine the difference in weight in air and in water.

Mr. R. Feret in his report to the French Commission† on the production and density of mortars considers that sands should be submitted to a thorough test. He advises determining their granulometric composition, as described on page 142, the proportion of gravel (that is, of particles remaining on a sieve with holes of 50 mm. (0.19 in.) diameter, the mineralogical nature, and the form of the grains. Disregarding the yield test he would study the absolute volumes of the cement, the sand, the water,

*Commission des Méthodes d'Essai des Matériaux de Construction, 1894, Vol. I, p. 307.

†Commission des Méthodes d'Essai des Matériaux de Construction, 1895, Vol. IV, p. 243.

and the voids in a unit volume of fresh mortar, and would estimate the cost per cubic meter of mortar made with different sands, and its strength under various conditions, as is discussed at length in the following chapter.

TEST OF RISE IN TEMPERATURE WHILE SETTING

The determination of the rise in temperature which takes place in a cement while setting has often been suggested as an indication of its quality, but the increase in temperature is due to so many causes that it is of slight value as a test of the cement.

Mr. Le Commandant Ribaucour* found that the temperature commenced to rise at the commencement of the setting, and the rise was generally higher with quick-setting cements.

Mr. J. E. Howard at the Watertown Arsenal† discovered that the

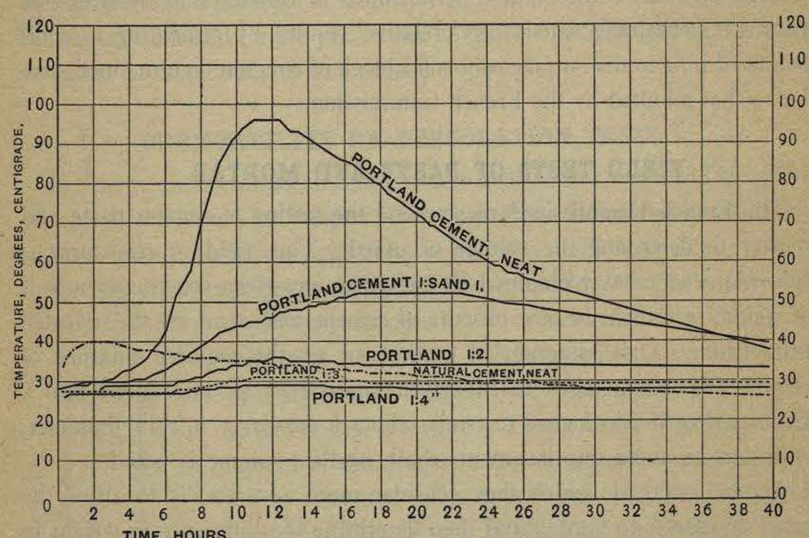

Fig. 48.—Rise in Temperature in 12-inch Cubes of Cement and Mortar. (Tests of Metals, U. S. A., 1901.) (*See p.* 130.)

temperature was largely dependent upon the size of the specimen, small cubes showing very slight increase. He therefore made a series of tests upon 12-inch cubes to determine the temperature acquired by different brands of cement and mortars during setting, and plotted his volumes in a series of curves. The curves for a first-class brand of American Portland cement with and without sand, and for a typical Natural (Rosendale) cement, are shown in Fig. 48.

*Commission des Méthodes d'Essai des Matériaux de Construction, 1895, Vol. IV, p. 133.

†Tests of Metals, U S A., 1901, p. 493.

Mr. Howard found that while first-class American brands of neat Portland cement often reached a maximum temperature of 100° Cent. (212° Fahr.); the maximum temperature of the various brands of American Natural cement was generally from 35° to 40° Cent. (95° to 104° Fahr.), and was reached at a shorter time than the Portland cements. The rise in temperature of the German brands of Portland cements was in general less than that of the American Portlands.

The rise in temperature in Portland cement concrete is less than in neat Portland cement, but in the interior of a large mass like a dam may reach nearly 100° Fahrenheit.

TESTS OF SAND FOR MORTAR

Tests of sand for mortar and concrete are as important as tests of cement. Methods of making tests are given on page 159.